effect of plant spacing and runner removal on twelve strawberry cultivars. Adv. in Strawberry Prod. 1:1–5.
10. Leblanc, M., Y. Desjardins, R. Bedard, and A. Gosselin. 1987. The effect of blossom removal on production characteristics of day-neutral strawberry plants grown in a northern climate. Adv. in Strawberry Prod. 6:23–26.
11. Maggs, D.H. 1963. The reduction in growth of apple trees brought about by fruiting. J. Hort. Sci. 38:119–128.
12. SAS Institute, Inc., 1985. Statistics. Version 5. SAS Institute, Inc., Cary, N.C.
13. Schaffer, B., J.A. Barden, and J.M. Williams. 1986. Whole plant photosynthesis and dry-matter partitioning in fruiting and deblossomed day-neutral strawberry plants. J. Amer. Soc. Hort. Sci. 111:430–433.

J. Amer. Soc. Hort. Sci. 113(2):189–193. 1988.

Response of Blueberry Species to Excessive Manganese

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Additional index words. aluminum, roots, *Vaccinium* spp.

Abstract. **The response of blueberries (*Vaccinium* spp.) to added Mn was studied in soil, solution, and sand cultures. Weekly additions of up to 0.8 mg Mn to Berryland sand soil (4.3 kg/pot) for 7 months produced the most growth in highbush blueberries, and additions of 6.4 mg Mn/week resulted in growth reductions but no visual toxicity symptoms. Solution culture- (800 ml/bottle) grown 'Blueray' highbush blueberries tolerated Mn additions up to 96 $\mu g \cdot ml^{-1}$ without significant growth reductions. Under similar conditions, a lowbush clone grew best at high added Mn and had higher foliar Mn concentrations than did 'Blueray', the rabbiteye cultivar 'Tifblue', or a selection of *Vaccinium elliotti* Chapman. Lowering solution Ca, Mg, and NO_3 levels sharply increased foliar or stem Mn concentrations of all species. Growth of three genetically diverse hybrid blueberry progenies were not signficiantly affected by relatively high levels of applied Mn or Al when grown in sand culture. Increasing Al had a greater effect on increasing root Mn concentrations than did an increase in Mn levels. There were no visual Mn toxicity symptoms expressed in any of the three media from excessive Mn levels.**

Members of the Ericaceae family, which includes blueberries, are regarded as Mn accumulators, with the possible exception of *Vaccinium uliginosum* L. (2, 12). There are numerous reports of foliar Mn values in excess of 2000 to 4000 $\mu g \cdot g^{-1}$, particularly for *V. angustifolium* Ait. (4, 9, 15, 16) and for *V. vitis-idaea* L. (11). These high foliar levels have not been associated with either visual toxicity symptoms or depressed growth. However, some reports have hypothesized the occurrence of toxicity (1, 6). Data are needed on foliar Mn toxicity symptoms and associated tissue Mn levels to ascertain the importance of soil Mn on blueberry adaptation to either acidified, atypical (high soil Mn) soils or soil that is too wet. The latter condition is known to increase soil Mn availability (3). Recently, Rosen and Luby (14) have shown, from work on *V. angustifolium,* that the tendency for high Mn accumulation in blueberries can be inherited from accumulator parents.

Due to the acidophilic nature of blueberries, Al has received little attention, since it is generally assumed that these plants tolerate relatively high Al levels. However, most blueberry soils have few if any secondary minerals; thus, they are low in Al. Growth of blueberries on atypical soils, particularly those soils high in clays, raises the issue of whether or not soil Al is detrimental to growth. Aluminum is transported readily to the tops of blueberries, unlike Mn, which is distributed about equally between roots and tops (9). Nitrogen source has been shown to influence the toxicity of Al, with NO_3-N intensifying Al toxicity (13).

This study was initiated to describe the response to high Mn levels for a number of blueberry species grown in sand, solution, or soil cultures and to examine the influence of other nutritional regimes on the response to high Mn.

Materials and Methods

Expt. 1. A greenhouse soil culture experiment was designed using Berryland (Typic haplaquad) sand soil collected from a commercial blueberry field in the Pine Barrens of New Jersey. The soil had an initial aqueous (1:1) pH of 4.1, with 1.8% wet oxidizable organic matter. Plastic pots containing 4.3 kg of soil were amended weekly with 100 ml of a $MnSO_4$ solution containing 0, 2, 4, 8, 16, 32, or 64 $\mu g \cdot ml^{-1}$ of Mn. The test plant was an essentially pure highbush (*Vaccinium corybosum* L.) blueberry progeny, G-694, which is known to be quite vigorous (A. Draper, personal communication). Rooted softwood cuttings were planted, one per pot, in three replications and allowed to grow for 6 weeks prior to treatment initiation.

All plants received a biweekly addition (100 ml/pot) of a complete (minus Mn) fertilizer solution containing: 1.9 mM Ca $(NO_3)_2 \cdot 4H_2O$, 0.83 mM Mg $(NO_3)_2 \cdot 6H_2O$, 0.25 mM KCl, 0.19 mM K_2HPO_4, 0.72 mM K_2SO_4, 1.6 mM $(NH_4)_2 SO_4$, 0.89 mM NaFeEDTA, 24 μM H_3BO_3, 1.5 μM $ZnSO_4 \cdot 7H_2O$, 0.4 μM $CuSO_4 \cdot 5H_2O$, and 0.3 μM $NaMoO_4 \cdot 2H_2O$. All pots were flushed weekly with tap water to remove excess salts.

After 7 months of Mn treatments, total shoot length and leaf dry weights were determined and tissue samples taken. Leaf samples consisted of all fully expanded leaves.

Expt. 2. A solution culture experiment was designed to test the effects of Mn levels on four blueberry species: *V. corym-*

Received for publication 30 June 1987. The cost of publishing this paper was defrayed in part by the payment of page charges. Under postal regulations, this paper therefore must be hereby marked *advertisement* solely to indicate this fact.

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bosum cv. Blueray; *V. ashei* Reade cv. Tifblue; *V. angustifolium* Aiton, selection ME-4161; and *V. elliottii*, selection US 280. Rooted softwood cuttings of each species were placed in wide-mouth, plastic, amber 1-liter bottles, one plant per bottle with three replications, under continuous aeration. The plants were grown in 0.1-strength nutrient solution (same original composition as in Expt. 1 without Mn) for 2 weeks followed by treatment with full-strength nutrient solution plus 0, 4, or 64 $\mu g \cdot ml^{-1}$ Mn (from $MsSO_4$). Solutions were changed weekly, and the starting solution pH ranged from 5.4 to 5.7. After 6 weeks of growth, all plants were cut back to two growing stems and total shoot length recorded. The harvested stems and leaves (harvest 1) were separated and prepared for analysis. Immediately after harvest 1 the high Mn level, 64 $\mu g \cdot ml^{-1}$, was changed to 96 $\mu g \cdot ml^{-1}$ Mn. After an additional 4 weeks of growth, new samples were obtained (harvest 2). The third and last growth period followed under the same Mn levels as the second period but solution Ca was reduced from 76 to 19 $\mu g \cdot ml^{-1}$ and Mg from 20 to 5 $\mu g \cdot ml^{-1}$ by reducing the Ca- and Mg-NO_3 levels. The solution NO_3 level was reduced from 76 to 19 $\mu g \cdot ml^{-1}$ as a consequence of reducing Ca and Mg levels. This last growth period lasted 4 weeks, at which time total new shoot length plus leaf, stem, and root tissue samples were obtained (harvest 3).

Expt. 3. Three blueberry progenies were used in this experiment: MU 652 × G179, an essentially pure *V. corymbosum* selection (progeny No. 1); MS76 x NC1522 of approximately three-fourths *V. corymbosum* and one-fourth *V. darrowi* Camp. parentage (progeny No. 2), and G 352 x US 245, whose parents were mostly *V. corymbosum* with some *V. darrowi* and *V. angustifolium* (progeny No. 3). All plants were rooted in a greenhouse mist bench from hardwood cuttings taken in Jan. 1985. In Oct. 1985 they were removed for 3.5 months of cold treatment. After another month in the mist bench, roots were gently washed clean and then transplanted into pots of sand. Each plant was fertilized immediately with 100 ml of half-strength nutrient solution (pH 5.6). This application was repeated the following week and repeated with full-strength nutrient solution on the 3rd and 4th weeks. In the 5th week, 27 plants of each progeny were arranged in a completely randomized block design with three replications and allowed to grown until the 9th week, when all plants were pruned to two growing shoots. The shoot tips were marked with threads to differentiate between old and new growth. Tri-weekly treatments (100 ml/dose) with nine solutions of varying Mn and Al concentrations were begun in the 11th week. The plants also received biweekly applications of modified nutrient solution (pH 5.7) and a weekly flushing with distilled water. This treatment continued through the 17th week, at which time the Mn and Al treatment concentrations were doubled. All plants were harvested on the 22nd week, with only the new growth portions of the stems removed.

The full-strength nutrient solution contained 1.91 mM Ca $(NO_3)_2$, 0.83 mM $Mg(NO_3)_2$, 0.68 mM $(NH_4)_2SO_4$, 0.25 mM KCl, 0.19 mM K_2HPO_4, 0.68 mM $MgSO_4$, 1.5 μM $ZnSO_4$, 0.4 μM $CuSO_4$, 0.72 mM K_2SO_4, 0.089 mM, and 0.089 mM, NaFe EDTA. The original nine treatment solutions contained the following concentrations of Mn and Al: no added $MnSO_4$ or $Al_2(SO_4)_3$, $MnSO_4$ and 0.095 mM $Al_2(SO_4)_3$ (5 ppm Al), $MnSO_4$ and 0.380 mM $Al_2(SO_4)_3$ (20 ppm Al), 0.090 $MnSO_4$ (5 ppm Mn) and no $Al_2(SO_4)_3$, 0.36 mM $MnSO_4$ (20 ppm Mn) and no $Al_2(SO_4)$, 0.090 mM $MnSO_4$ and 0.095 mM $Al_2(SO_4)$ (5 ppm Al + Mr)$_3$, 0.090 mM $MnSO_4$ and 0.380 mM $Al_2(SO_4)_3$, (5 ppm Mn + 20 ppm Al), 0.360 mM $MnSO_4$ and 0.095 mM $Al_2(SO_4)_3$ (20 ppm Mn + 5 ppm Al), and 0.360 mM $MnSO_4$ and 0.380 mM Al $(SO_4)_3$ (20 ppm Mn + Al). All chemicals used were analytical grade. These treatment levels were doubled for the last 5 weeks of the growth period.

The experiment was conducted in a greenhouse with a day length of 12 hr and temperatures ranging from 18° to 24°C.

Common procedures. Harvesting data included visual inspection of the plants, total shoot length measurements, and leaf, stem, and root tissue sampling. The visual inspection focused on signs of Mn toxicity (e.g., brown necrotic foliar spots). Shoot length was measured as new stem growth, above the marker thread, and old stem length, below the marker. Leaf samples also were taken with respect to new and old growth. All of the leaves above the markers, except the three uppermost, were taken as new leaves, and all of the leaves below the markers were taken as old leaves. Stems from which the leaves were removed were kept as new and old stem samples. All of the leaves and stems were washed in 0.1% Na lauryl sulfate, rinsed with distilled water twice, and dried in a 70°C forced-air oven. The root balls were rinsed thoroughly in water and oven-dried. The leaf, stem, and root samples then were ashed at 500°, digested in 6 N HCl, and analyzed where appropriate for Mg, Ca, Al, Fe, and Mn with an Instrumentation Laboratory Model 257 Atomic Absorption Spectrophotometer.

Table 1. Total stem length and leaf Mn and Fe concentrations of the highbush (G-694) plants grown in Berryland soil for 7 months under a range of Mn levels (Expt. 1).

Mn treatment ($\mu g \cdot ml^{-1}$)	Total shoot length (mm)	Leaf concn ($\mu g \cdot g^{-1}$)	
		Mn	Fe
0	714	29	39
2	574	80	44
4	573	86	37
8	863	185	44
16	493	195	44
32	575	441	45
64	473	976	44
LSD[z]	295	256	NS

[z]Least significant difference within columns at the 5% level, NS = not significant.

Results

Expt. 1. Growth, as indicated by total stem length after 7 months, was not significantly different between the control (minus Mn) and 64 Mn treatments (Table 1). The most growth was produced at the 8 Mn level, and only the 16 and 64 Mn treatments produced significantly lower growth compared to the 8 Mn tretment. However, there were no visual indications of Mn deficiency (at the control level) or Mn toxicity (levels above 8 Mn) on any of the plants. Growth responses were similar for both leaf and stem dry weights. Plant growth at the 64 Mn level was not significantly different than the control (0 Mn level). However, a tendency towards reduced growth (compared to the control) was evident at the 16, 32, or 64 Mn levels.

Foliar Mn concentrations increased with increasing applied Mn, whereas leaf Fe was not significantly different among treatments (Table 1).

Expt. 2. The initial 6 weeks exposure to the Mn treatment (harvest 1) resulted in no significant total shoot length differences for 'Blueray' and US 280 (Table 2). However, ME-4164 exhibited increased stem length with increased Mn levels, and stem length was greatest for 'Tifblue' at the 4 $\mu g \cdot ml^{-1}$ Mn level and significantly decreased at either 0 or 64 $\mu g \cdot ml^{-1}$ Mn.

Table 2. Total stem length of four blueberry species grown for three harvest periods under a range of solution culture Mn levels (Expt. 2).

Harvest	Mn[z] Level ($\mu g \cdot ml^{-1}$)	Stem length (mm) Species Blueray	ME-4161	Tifblue	US 280
Harvest 1 (6 weeks)	0	50	36	77	49
	4	42	55	129	53
	64	58	68	90	42
	LSD[y]	NS	18	21	NS
Harvest 2 (4 weeks)	0	72	61	88	10
	4	74	80	83	72
	96	70	86	96	59
	LSD	NS	11	7	19
Harvest 3 (4 weeks)	0	34	22	27	NA[x]
	4	31	16	46	NA
	96	35	26	31	NA
	LSD	NS	NS	12	

[z]Manganese level was increased from 64 to 96 $\mu g \cdot ml^{-1}$ at harvest 2 or 3. Additionally, at harvest 3, solution Ca and Mg were lowered.
[y]Least significant difference within columns/harvests, NS = not significant at the 5% level.
[x]NA = data not available.

Table 3. Average leaf dry weight of four blueberry species grown for three harvest periods under a range of solution culture Mn levels (Expt. 2).

Harvest	Mn[z] Level ($\mu g \cdot ml^{-1}$)	Leaf dry wt (g) Species Blueray	ME-4161	Tifblue	US 280
Harvest 1 (6 weeks)	0	3.7	1.4	3.1	1.0
	4	3.1	2.7	6.0	1.0
	64	4.0	2.2	4.5	0.6
	LSD[y]	NS	0.6	1.4	NS
Harvest 2 (4 weeks)	0	3.1	1.3	2.9	0.1
	4	3.0	2.5	4.2	0.9
	96	3.1	1.8	3.0	0.9
	LSD	NS	0.6	0.4	0.3
Harvest 3 (4 weeks)	0	1.0	1.2	0.9	NA[x]
	4	0.9	0.8	1.5	NA
	96	1.1	0.7	1.4	NA
	LSD	NS	NS	0.3	

[z]Manganese level was increased from 64 to 96 $\mu g \cdot ml^{-1}$ at harvest 2 or 3. Additionally, at harvest 3, solution Ca, Mg, and NO_3 were lowered.
[y]Least significant difference within columns/harvests, NS = not significant at the 5% level.
[x]NA = data not available.

When the highest Mn level was increased to 96 $\mu g \cdot ml^{-1}$ for a 4-week regrowth period (harvest 2), there was still no significant difference among levels for 'Blueray' (Table 2). In both ME-4161 and 'Tifblue', however, stem growth increased at the highest Mn level. US 280 produced significantly more stem growth at either the 4 or 96 $\mu g \cdot ml^{-1}$ Mn level than at the minus Mn level.

Reducing Ca, Mg, and NO_3 levels during the last 4-week regrowth period (harvest 3) in general reduced stem growth at all Mn levels compared to the second period, independent of plant species. There were no significant differences among Mn levels on stem growth for 'Blueray' or ME-4161, but 'Tifblue' stem growth was significantly higher at the 4 $\mu g \cdot ml^{-1}$ Mn level. A fungal infection occurred in most of the US 280 solution cultures (independent of Mn treatment) at the end of the first regrowth period (harvest 2); therefore, data for harvest 3 are missing.

Leaf dry weight data displayed trends similar to stem growth for each of the three harvests (Table 3).

Foliar and stem Mn concentrations of the four blueberry species varied in response to Mn treatment (Table 4). 'Blueray' foliar Mn ranged from 19 to 1265 and stem Mn from 24 to 4261 $\mu g \cdot g^{-1}$ dry weight over the three harvests, which corresponded to no significant differences in stem growth (see Table 2). ME-4161 tended to contain the highest foliar Mn concentrations compared to the other species and perhaps has a higher critical deficiency level, since stem length was significantly reduced at the minus Mn level for both harvests 1 and 2, although foliar Mn was the highest. US 280 was intermediate in foliar Mn between 'Blueray' and ME-4161, although stem Mn concentrations were usually the highest of all species, independent of applied Mn level. 'Tifblue' displayed the lowest foliar Mn levels among all cultivars.

Lowering the levels of solution Ca and Mg (harvest 3) tended to increase sharply the foliar and stem Mn concentrations at the 4 and 96 $\mu g \cdot ml^{-1}$ levels.

Throughout the experiment, visual symptoms of Mn deficiency and/or Mn toxicity symptoms were not evident on any of the plants, independent of species or Mn treatment.

Table 4. Foliar and stem Mn concentrations of four blueberry species grown for three harvest periods under a range of solution culture Mn levels (Expt. 2).

Harvest	Mn level[z]	Cultivar Blueray	ME-4161	Tifblue	US 280
		Foliar Mn ($\mu g \cdot ml^{-1}$)			
1	0	19	26	14	13
	4	275	1300	82	408
	64	859	2180	166	1254
	LSD[y]	91	202	37	183
2	0	24	44	18	35
	4	589	1237	163	533
	96	969	2073	347	1419
	LSD	144	290	45	111
3	0	19	28	22	NA[x]
	4	350	1254	316	NA
	96	1265	4272	784	NA
	LSD	78	171	55	
		Stem Mn ($\mu g \cdot g^{-1}$)			
1	0	24	23	103	15
	4	1140	1300	589	1502
	64	859	1448	1539	3077
	LSD	164	202	117	318
2	0	73	55	98	63
	4	1693	1147	708	1092
	96	2797	1593	1850	4397
	LSD	180	154	89	214
3	0	41	29	57	NA
	4	2041	5490	751	NA
	96	4261	4053	3198	NA
	LSD	195	251	132	

[z]Mn level was increased from 64 to 96 $\mu g \cdot ml^{-1}$ at harvest 2 or 3. Additionally, at harvest 3, solution Ca and Mg were lowered.
[y]Least significant difference within columns/harvests, NS = not significant at the 5% level.
[x]NA = data not available.

Expt. 3. As in the previous two experiments, no visual symptoms of Mn deficiency or excess were apparent from the Mn × Al treatments, independent of blueberry progeny. The growth parameters measured, root dry weight, and total stem length, were both not significantly affected by Mn, Al, or progeny (Table 5).

There existed Mn × Al and progeny × Al interactions for root Mn levels (Table 6). Root Mn increased with increased solution Al at each Mn level. However, with increasing Mn within an Al increment, root Mn did not increase consistently. This response was particularly true at the high Mn (40 $\mu g \cdot ml^{-1}$) for the 10 and 40 $\mu g \cdot ml^{-1}$ Al treatment, where root Mn decreased compared to the 10 $\mu g \cdot ml^{-1}$ Mn treatment. Likewise, root Mn increased with increasing Al level for each of the three progenies. Within an Al treatments, progeny 2 (*V. corymbosum* + *V. darrowi*) had significantly reduced root Mn levels at the minus Al and 10 $\mu g \cdot ml^{-1}$ Al treatments, whereas progeny 1 (*V. corymbosum*) was significantly reduced in root Mn at the 40 $\mu g \cdot ml^{-1}$ Al treatment level (Table 6).

Manganese was significantly increased in new and old leaves and stems by increasing applied Mn. Only new leaf and old stem Mn levels were significantly different among progenies (Table 7). The magnitude of the differences between new and old tissue Mn was more pronounced for leaves than stems, particularly at the highest applied Mn level. Progeny 2 (*V. corymbosum* + *V. darrowi*), on the average, contained lower foliar Mn concentrations than the other 2 progenies. Progeny 3 contained the highest concentrations of leaf and stem Mn.

Table 5. Average root dry weight and total stem length from the Mn × Al treatments from the three blueberry progenies (Expt. 3).

Al treatment ($\mu g \cdot ml^{-1}$)	Mn treatment ($\mu g \cdot ml^{-1}$)		
	Minus	10	40
	Root dry wt (g/plant)		
Minus Al	1.57[z]	1.62	1.69
10	1.22	1.77	1.51
40	1.60	1.69	1.45
	Stem length (mm/plant)		
Minus Al	91	109	100
10	97	111	111
40	95	91	86

[z]There were no significant differences due to Mn or Al treatments.

Table 6. Significant interactions between Al levels and either Mn level or progeny on root Mn concentrations (Expt. 3).

	Root Mn ($\mu g \cdot g^{-1}$)		
	Al level ($\mu g \cdot ml^{-1}$)		
Main effect	Minus Al	10	40
Mn level			
Minus Mn	86	400	754
10	122	501	719
40	125	455	523
LSD[z]	18	31	42
Progeny			
1	126	475	565
2	102	378	629
3	106	504	802
LSD	11	23	54

[z]Least significant differences between means within columns at the 5% level.

Table 7. Significant main effect of Mn level and progeny on new and old leaf or stem Mn concentrations (Expt. 3).

	Mn concn (μg Mn/g dry wt)							
	Main effect							
	Mn level				Progeny			
Tissue	0	10	40	LSD[z]	1	2	3	LSD
New leaf	57	318	665	169	387	238	415	90
Old leaf	109	299	427	89	260	231	347	NS
New stem	93	487	693	101	445	362	466	NS
Old stem	169	486	633	98	361	395	532	97

[z]Least significant difference within row at the 5% level, NS = not significant.

Table 8. Significant main effects of Al level and progeny on new and old leaf and stem plus root Al concentrations (Expt. 3).

	Al concn ($\mu g \cdot g^{-1}$ dry wt)				
	Root	New leaf	Old leaf	New stem	Old stem
Al level					
0	501	66	103	21	26
10	1114	88	142	39	34
40	1779	92	190	43	56
LSD[z]	101	11	21	10	8
Progeny					
1	---	---	---	39	33
2	---	---	---	25	33
3	---	---	---	38	50
LSD	---	---	---	10	14

[z]Least significant difference, P = 5%.

Aluminum concentrations of all tissue increased with increasing solution Al (Table 8). The general order of Al concentration among tissues was root > old leaves > new leaves > new stem = old stem. The only other significant main effects were by progeny on new or old stem Al concentrations (Table 8).

Root and new leaf Ca concentrations were significantly decreased with increased solution Al, from 0.44% to 0.29% Ca in roots and 0.39% to 0.33% Ca in new leaves. Manganese level had no effect on tissue Ca levels. Progeny 3 had significantly higher new or old leaf Ca or old stem Ca than the other two progenies, about 0.50% compared to about 0.35% for the other two progenies. Treatment did not influence tissue Mg (data not shown).

Discussion

Plant response. Visual symptomology of Mn toxicity was not evident from the soil, solution, or sand culture experiments. Although a minus Mn treatment was incorporated, Mn deficiency symptoms were likewise not expressed. However, no attempt was made to have completely Mn-free solutions (e.g., purification of chemicals). The foliar Mn levels at the minus Mn treatment level indicate that critical deficiency levels may be relatively low, in the range of 20 to 30 $\mu g \cdot g^{-1}$ dry weight. This level is in contrast to reports of Trevett et al. (17) on *V. angustifolium* and the standard values for *V. corymbosum* proposed by Hancock and Hanson (5), where critical values are reported to be 270 and 168 μg Mn/g, respectively.

The highbush selection G-694 (Expt. 1), when grown in Mn-amended Berryland soil, grew best at the 8 $\mu g \cdot ml^{-1}$ Mn addition, and significant decreases in growth were only noted at the

16 and 64 $\mu g \cdot ml^{-1}$ Mn levels (Table 1). These levels corresponded to a range of foliar Mn from 29 to 441 $\mu g \cdot g^{-1}$ in nondepressed plants. The lack of Mn effect on tissue Fe has been noted for other crops (7).

The nonsignificant response of the highbush cultivar Blueray to solution culture additions of Mn (Expt. 2) concurred with the initial Berryland soil experiment. Although no growth differences were noted among treatments (Table 2), tissue Mn ranged from 19 to 1265 $\mu g \cdot g^{-1}$ (Table 4). The increased foliar Mn concentration corresponded to reduced solution Ca and Mg. However, species differences were apparent. The lowbush clone ME-4161 tended to exhibit improved growth at the highest Mn solution level, whereas 'Tifblue' and US-280 preferred the intermediate Mn level. The contrast among species was more pronounced in foliar Mn concentration (Table 4). ME-4161 tolerated very high tissue Mn levels, which is in accord with data from Lockhart and Longille (10) and Hall et al. (4), but 'Tifblue' accummulated relatively low levels of foliar Mn, with US-280 intermediate.

Stem Mn concentrations tended to be higher for all species than foliar Mn (Table 4, Expt. 2). This tendency was particularly pronounced for 'Tifblue'.

Response to Mn and Al. Response of the three blueberry progenies to added Mn with or without the addition of Al (Expt. 3) was nonsignificant when either root dry weight or total stem length was measured (Table 5). These same progenies had been used previously in a field pot study examining growth on different soil types (9). Tissue Mn levels followed similar trends among progeny in this study, as did the magnitude of foliar Al. The addition of Al increased root tissue Mn more than did an increase in Mn at a constant Al level.

The root was the predominant accumulator of Al (Table 8), which is contrary to tests done in the greenhouse with a number of blueberry progenies grown on different soils that ranged in secondary mineral and clay contents (8).

The blueberry plants used in the current tests, particularly highbush, tended to tolerate high levels of added Mn. The 'Tifblue' rabbiteye blueberry was the only blueberry to display a trend in reduced growth at high levels of applied Mn (Table 2) and comparatively low foliar Mn levels. However, as with the other test material, no visual toxicity symptoms were noted. Thus, it is apparent that identification of Mn toxicity in the field would be difficult at best, particularly when the plants are grown in nontypical blueberry soils where soil Mn levels may be high. These experiments using both a range of experimental media and blueberry germplasm indicate that blueberry can tolerate a rather wide range of foliar Mn levels. The N source for all experiments was nitrate, which could be the form available to plants grown on pH media higher than the normal 3.5 to 5.0 pH of blueberry soils. The use of an all nitrate source was found satisfactory in all three media.

Literature Cited

1. Bailey, J.S. and J.N. Everson. 1937. Further observations on a chlorosis of the cultivated blueberry. Proc. Amer. Soc. Hort. Sci. 35:495–496.
2. Gerloff, G.C., D.D. Moore, and J.T. Curtis. 1964. Mineral content of native plants of Wisconsin. Wisconsin Agr. Expt. Sta. Res. Rpt. 14.
3. Grasmanis, V.O. and G.W. Leeper. 1966. Toxic manganese in near-neutral soils. Plant & Soil 25:41–48.
4. Hall, I.V., L.E. Aalders, and W.G. Barker. 1964. A preliminary investigation of factors limiting lowbush blueberry production on Cape Breton Island. Can. J. Plant Sci. 44:491–492.
5. Hancock, J. and E. Hanson. 1986. Highbush blueberry nutrition. Mich. State Univ., East Lansing. Coop. Ext. Ser. Bul. E-2011.
6. Haynes, R.J. and R.S. Swift. 1986. The effects of pH and of form and rate of applied iron on micronutrient availability and nutrient uptake by highbush blueberry plants grown in peat or soil. J. Hort. Sci. 61:287–294.
7. Horst, W.J. 1983. Factors responsible for genotypic manganese tolerance in cowpea (*Vigna unguiculata*), p. 117–222. In: M.R. Saric and B.C. Loughman (eds.). Genetic aspects of plant nutrition. Nijhoff, Boston.
8. Korcak, R.F. 1986. Adaptability of blueberry species to various soil types: II. Leaf and soil analysis. J. Amer. Soc. Hort. Sci. 111:822–828.
9. Korcak, R.F., G.J. Galletta, and A. Draper. 1982. Response of blueberry seedlings to a range of soil types. J. Amer. Soc. Hort. Sci. 107:1153–1160.
10. Lockhart, C.L. and W.M. Longille. 1962. The Nutrient content of the lowbush blueberry. Can. Plant Dis. Surv. 42(3):124–128.
11. Miller, P.M. and W.C. Hechel. 1985. Manganese tolerance in *Vaccinium vitis-idaea*. Bul. Ecol. Soc. Amer. 66:232. (Abstr.)
12. Popp, M. 1983. Geotypic differences in the mineral metabolism of plants adapted to extreme habits. Plant & Soil 72:261–273.
13. Rorison, I.H. 1975. Nitrogen source and metal toxicity. J. Sci. Food Agr. 26:1426.
14. Rosen, C.J. and J.J. Luby. 1986. Variation in foliar elemental composition in *Vaccinium* crosses, p. 45–51. In: H.W. Gabelman and B.C. Loughman (eds.). Genetic aspects of plant mineral nutrition. Martinus Nijhoff, Boston.
15. 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.
16. Townsend, L.R. and I.V. Hall. 1970. Trends in nutrient levels of lowbush blueberry leaves during four consecutive years of sampling. Naturalist Can. 87:461–466.
17. Trevett, M.F., P.N. Carpenter, and R.E. Durgin. 1968. A discussion of the effects of mineral nutrient interactions on foliar diagnosis in lowbush blueberries. Maine Agr. Expt. Sta. Bul. 665.