Fruit Varieties Journal 53(2):73-90 1999

Blueberry Hybrids with Complex Genetic Backgrounds Evaluated on Mineral Soils: Stature, Growth Rate, Yield Potential and Adaptability to Mineral Soil Conditions as Influenced by Parental Species

J. C. SCHEERENS,[1] W. A. ERB,[2] B. L. GOULART[3] AND J. F. HANCOCK[4]

Abstract

A population of 54 blueberry (*Vaccinium* subsection *Cyanococcus*) cultivars or interspecific hybrid selections derived from combinations of nine *Vaccinium* species were evaluated in replicated trial for their mineral soil adaptation response. Individuals within the population varied significantly for the following objectively-measured traits: plant form (height and volume), growth pattern and rate (canopy volume increase over time) and fruit yield/volume. Subjective evaluations also uncovered a high level of variability among genotypes for vegetative vigor (the ability to produce new shoots in proportion to existing plant mass), fruit/foliage ratio (the ability to balance fruit production and vegetative/floral growth/induction) and freedom from foliar nutrient deficiency symptoms. Indices based on subjective evaluations and compared to objective measurements indicated the following genotypes to exhibit a moderate degree of mineral soil adaptation: 'Jersey,' 'Sunrise,' US 612, 645, 665, 673, 676, 693, 702, 714, 723, 730, 845 and 848. When genotypes were grouped according to their genetic constitutions, significant heritage effects were found for plant height, fruit yield/volume, 1995 and 1996 vegetative vigor scores and 1995 fruit/foliage ratios. However substantial within group variability for all traits was evident, suggesting that mineral soil adaptation can be derived from a number of species combinations. Although some deleterious patterns in growth and yield potential can be anticipated when interspecific hybridization is used within a blueberry breeding program, unique individuals do appear which have captured beneficial traits (such as mineral soil adaptation) from feral species.

Introduction

Cultivated blueberry (*Vaccinium* subsection *Cyanococcus*) breeding programs have used interspecific hybridization as an important means of cultivar development since F. V. Coville's first controlled cross pollination [i.e., 'Brooks' (*V. corymbosum* L.) X 'Russell' (*V. angustifolium* Ait.)] in 1911 (14, 28). Interspecific hybridization in breeding programs may be used to elucidate or confirm the predominant role of introgression and polyploidization in the evolution and diversification of the genus (1, 5, 23, 32) or to broaden the narrow genetic base of current blueberry cultivars (1, 7, 18, 19). However, according to Darrow and Camp (5), the primary motivation for using interspecific hybridization in breeding programs is because "...it is the only means whereby the numerous divergent characters of the various species may be combined to produce the desired forms for further breeding and for the selection of new horticultural types." Both primary and secondary feral gene pools of cultivated blueberry species contain a wealth of genetic diversity for the following characteristics: plant habit and architecture; vigor, precocity; productivity, variability in flowering and fruiting habit,

Salaries and research support provided b state and federal funds appropriated to the Ohio Agriculture Research and Development Center, The Ohio State University. Manuscript No. 98-24.

[1]Associate Professor, Dept. Horticulture and Crop Science, Ohio State Univ., Ohio Agric. Res. & Dev. Center, Wooster OH 44691.

[2]Assistant Professor, John C. Pair Horticultural Research Center, Kansas State University, Wichita KS 67233.

[3]Associate Professor, Dept. Horticulture, Pennsylvania State University, University Park PA 16802.

[4]Professor, Dept. Horticulture, Michigan State University, East Lansing MI 48824.

disease resistance/tolerance, insect resistance/tolerance, tolerance to environmental stresses, broad climatic and edaphic adaptation, variability in chilling requirement, fruit quality and nutritional factors, and mechanical harvestability (1, 14, 23, 28, 32, Table 1).

To date, various breeding programs have successfully hybridized highbush blueberry (*V. corymbosum*) with other species to broaden the climatic adaptation of cultivars, and thus, expand the range of commercial production. Breeders in MI, ME, MN and the USDA have developed winter hardy half-high cultivars by combining wild selections such as 'Michigan Lowbush #1' (putatively a *V. angustifolium* - tetraploid *V. myrtilloides* Michx. hybrid) and N. 'Sedgewick Lowbush' (*V. angustifolium*) with various highbush cultivars (13, 22). In addition, the range of highbush blueberry was expanded southward by hybridizing cultivars of *V. corymbosum* with elite genotypes of the rabbiteye blueberry, *V. ashei* Reade and with selections of *V. darrowi* Camp, a wild species with relatively low chilling requirements (6, 24). To capture additional genes for low chilling requirement as well as a broad range of traits of commercial interest, Draper and colleagues (6) created an extensive interspecific hybrid germplasm pool from over a dozen native *Vaccinium* species. From this pool, several low-chill highbush cultivars composed of a complex blend of genes from both northern and southern biotypes have been released within the last decade (6, 24).

Although breeders have successfully transferred genes for climatic adaptation from wild relatives to cultivated blueberries, the development of cultivars specifically suited to a broader range of soil types remains a challenge. Highbush blueberries are naturally adapted to sandy soils of low pH and high organic matter content that is chemically and physically reactive. Unfortunately, existing production sites with ideal soil conditions are limited, and cultural inputs necessary to modify more traditional agricultural sites are costly. Therefore, future expansion of the blueberry industry will likely depend upon the development of cultivars which grow well on mineral soils (14). Rapid growth rate (canopy volume increase over time), vegetative vigor and the ability to mature commercial fruit loads when grown on mineral soils are considered to be primary indicators of a genotype's mineral soil adaptation response (2, 3, 8). In turn, these responses are conditioned by genotype's physiological ability to acquire moisture and nutrients from soils that contain high levels of calcium and low levels of organic matter and to optimize photosynthetic capacity (gas exchange) under these conditions (10, 11, 12, 20, 21). Draper's interspecific germplasm pool contains genetic material for these traits and it has been used by several researchers to investigate aspects of mineral soil adaptation within *Vaccinium* species and their hybrids, including growth (2, 8, 20), nutrient uptake (21), and drought and heat tolerance (9, 10, 11, 26, 27).

Through these studies and others, a core of elite selections potentially adapted for mineral soil production were identified and propagated. However, because most of these selections also contain genes from southern-adapted species and because the selection process occurred at mid-Atlantic or southern facilities, it remained to be determined whether or not mineral soil adaptation and cold tolerance, along with horticultural performance and fruit quality could be found within the same genotype. A primary goal of this project, therefore, was to evaluate the elite selections for mineral soil adaptation, cold tolerance, horticultural performance and fruit quality in replicated trial and under North Central USA growing conditions. Variability regarding physiological responses (e.g., gas exchange rates and water potentials), as well as horticultural and fruit quality traits among individuals and within heritage groups will be addressed in companion papers (12, 30, 31) whereas aspects of cold tolerance were addressed and cold tolerant selections within the population were identified in previous reports (16, 17). The objectives of the study reported herein were as follows: to explore diversity in plant form and primary mineral soil adaptation response (i.e., growth rate, general vigor, yield potential, and nutrient deficiency symptom severity) among Draper's elite hybrids; to uncover trends in performance with respect to heritage; and to identify those individuals based on performance, that demonstrated improved mineral soil adaptation.

Materials and Methods

Genetic materials: Of the 39 complex interspecific selections in this study, 30 were formed from crosses involving five parents: 1) G 362 (*V. corymbosum*), tetraploid; 2) US 75 (*V. darrowi* X *V. corymbosum*), tetraploid; 3) US 226 [(*V. myrtilloides* X *V. atrococcum* Gray, Heller) doubled], tetraploid; 4) NJUS 11 (*V. ashei* X *V. atrococcum*), hexaploid; and 5) NJUS 64 (*V. myrsinites* Lamarck X *V. angustifolium*), tetraploid. Seven additional complex genotypes had *V. elliottii* Chapman as a parent or grandparent and two had *V. darrowi* as a grandparent. The 15 standards examined included three *V. corymbosum* cultivars, 11 cultivars resulting from the hybridization of *V. corymbosum* with *V. angustifolium*, *V. ashei*, *V. constablaei* Gray, *V. darrowi* and/or *V. myrtilloides*, and one *V. constablaei* X *V. ashei* hybrid cultivar. The genetic constitution of all selections and cultivars in the study are listed in Table 2. To obtain plant material for the trial, all selections and two cultivars were propagated by the authors, whereas the remaining cultivars were donated by a commercial nursery.

Experimental design and culture: The planting was established in 1993 at the Ohio Agricultural Research and Development Center on Wooster Silt Loam soil (fine-loamy, mixed, mesic Typic Fragiudalf) with the following characteristics: pH = 6.4, organic matter = 1.6%, CEC = 5.75 and base saturation = 3.1% K: 26.5% Mg: 70.2% Ca. Because the target pH as specified in the protocol was 5.5, the site was amended in the fall of 1992 with 990 lbs/acre granular sulfur. Triple super phosphate (300 lbs/acre) and KCI (300 lbs/acre) were also applied at that time. A drip irrigation system was installed prior to planting.

The field was planted in an RCB design with 4 replications. Two year old rooted cuttings were planted at 1.2 X 3.0 m spacings without amendment or mulch. All plants were sprayed until run-off with a 100 ppm Fe-chelate solution (Dragon Corp., Roanoke, VA) on 8 and 17 June, 1993 to ameliorate the chlorotic condition exhibited by a majority of the selection propagules. Thereafter, cultural management of the plot followed the recommendations of Goulart et al. (15), except for those regarding amendment or mulch. Plants were netted as fruit ripened in order to limit bird predation.

Stature, growth and growth rate and fruit yield/volume measurements: Overall growth and stature of each plant were monitored by determining plant height and estimating plant canopy volume (height X width at widest point X width perpendicular to widest point) on the following dates: 26 May 1993, 22 Sept. 1993, 17 May 1994, 5 Sept. 1994, 9 Sept. 1995, 19 Sept. 1996. Volume increases or decreases were calculated by subtraction. Ripe fruit were harvested from the trial from 7 July to 28 Aug 1995; during the peak fruiting season, individual plants were harvested on approximately a three-day picking cycle. For each plant, yield was recorded cumulatively over harvests. A fruit yield/plant canopy volume ratio was then determined at the end of the 1995 growing season.

Vegetative vigor, fruit/foliage ratio, yield balance and nutrient deficiency symptom ratings: Each plant was rated by at least two evaluators for vegetative vigor and fruit/foliage balance on 13 June, 1995 and 1 Aug., 1996 using 1-10 scales in 0.5 unit increments. Nutrient deficiency symptoms were also rated using the same technique, but these values were obtained only once, on the Aug. 1996 date. Vegetative vigor ratings estimated the volume (number and length) of new shoots in relation to the volume of hardwood present (I = almost no new growth evident; 10 = highly vegetative). Fruit/foliage ratios were based on whether or not the foliage on the plant was adequate to simultaneously support the current fruit load and sufficient new growth and floral initiation for sustained fruiting in subsequent seasons (1 = extremely sparse or overcropped; 5 = optimum foliage to fruit ratio; 10 = extremely vegetative or undercropped). Fruit/foliage ratings were then transformed to yield balance scores in order to compensate for the bipolar nature of the fruit/foliage ratio scale. Yield balance scores were derived as follows: for fruit/foliage ratings of 5.0 - 10.0, the yield balance rating = [(10 – fruit/foliage ratio) X 2]; for fruit/foliage ratings of 1- 4.9, the yield balance rating = (fruit/foliage rating X 2). Thus a yield balance rating of 1 implied that the selection was extremely undercropped or overcropped, whereas a rating of 10 indicated that vegetative growth and fruiting were well-balanced. Nutrient deficiency symptom ratings were based on a visual assessment of their severity (1 = all foliage was apparently nutrient deficient; 10 = all foliage was free of necrosis or discoloration).

Mineral soil adaptation indices: A mineral soil adaptation index (0-10) for each genotype was calculated as follows: mineral soil adaptation score = $\sum$ mean ratings for vegetative vigor (1995 and 1996), yield balance (1995 and 1996) and nutrient deficiency symptoms (1996) $\div$ 5. This index was used in conjunction with growth and fruiting data to evaluate genotypic response to the mineral soil environment.

Data analysis: For all continuous parameters, variability among genotypes and differences among genotypic means were determined by analysis of variance using SAS PROC GLM (29). Genotypic means (i.e., means of the four field replicates of each genotype) were separated by the Duncan's Multiple Range option to assess individual performance (data not shown). To characterize parental effectiveness and the role native species in hybrid performance, genotypes within the study were clustered in heritage groups based on their pedigrees or genetic constitutions (Table 2). Thereafter, for each parameter, the means of member genotypes were considered to be replicates within the group. To ascertain statistical differences among groups, group means were separated by the non-parametric Kruskal-Wallis procedure (4). Relationships among variables were determined by the calculation of Pearson (r_p) or Spearman (r_s) correlation coefficients (SAS PROC CORR), the latter being employed when comparisons involved discrete (rating scale) data.

Results and Discussion

Diversity for growth and fruiting habits among blueberry species is well documented (1, 5, 7, 14, 25, 28, 32). Therefore, as might be expected from their complex genetic constitutions, characteristics such as growth habit, plant form (height and volume), growth rate, vegetative vigor and reproductive capacity varied substantially among the cultivars and interspecific selections evaluated (Table 3). For continuous variables [i.e., final height, final volume, canopy volume increase and fruit yield/volume ratio], F-values were very highly significant for both genotype and replicate; genotypic means within the lowest 10% cluster were significantly different ($P = 0.05$) from those in the highest 10% cluster.

Growth habit and plant form: Growth habit is under genetic control, (5, 14), with the lowbush characteristic (short, spreading, rhizomatous or colony-forming) partially dominant over the highbush phenotype (tall, upright, crown-forming). However, even though colony forming species were used extensively in the development of Draper's interspecific gene pool (Table 1), all elite hybrids in this study were predominantly crown-forming.

Genotypic means for final height and final volume were evenly distributed throughout their ranges (Table 3), resulting in individuals which resembled half-high or highbush blueberries as described

Table 1. Description and characteristics of the *Vaccinium* species progenitors of cultivars and interspecific hybrids studied herein.[1]

				Traits of commercial value[2]					
Species	**Ploidy**	**Stature**	**Description**	**D/HT**	**CH**	**FR**	**IR**	**LCR**	**MSA**
V. angustifolium	4X	5-20 cm	Rhizomatous, colony-forming; high chilling requirement, flowers mid-May to mid-June; fruit borne on uprights; fruit blue, usually small; crop harvested from wild stands, domestication underway.		X	X			X
V. ashei[3]	6X	2-6 m	Perennial, crown-forming; fibrous and deep-rooted; low chilling requirement, flowering period variable and dependent on genotype and location; fruit blue to black and variable in size; domesticated and feral types.	X		X	X	X	X
V. atrococcum[3]	2X	2-3 m	Perennial, crown-forming; fruit dull black, usually small; not domesticated.			X			X
V constablaei[3]	6X	1 - 5 m	Perennial, crown-forming; late-flowering and early fruiting; fruit very light frosty blue; closely related to *V. ashei.*		X				
V. corymbosum[3]	4X	1-3 m	Perennial, crown-forming; fine rooted; high chilling requirement, flowers mid-May to mid-June; fruit blue to black, usually large; domesticated and feral types.		X	X			X
V. darrowi	2X	15-40 cm	Rhizomatous, colony-forming; bears blue fruit of excellent flavor and quality; not domesticated but selected feral material used extensively for breeding.	X				X	X
V. elliottii[3]	2X	-4 m	Perennial, crown-forming; bears dark, poorly-flavored fruit; not domesticated.			X	X		X
V. myrsinites	4X	25-100 cm	Rhizomatous, colony-forming; bears small, shiny, black fruit with fair to poor flavor; not domesticated.	X				X	
V. myrtilloides	2X	20-40 cm	Rhizomatous, colony-forming; bears frosty-blue fruit with good to excellent flavor; limited commercial harvest from native stands; not domesticated			X			X
V. tenellum	2X	10-75 cm	Rhizomatous, colony-forming; fruit black with fair to poor flavor; not domesticated	X					X

[1]References: 1, 14, 23, 28, 32.
[2]D/HT, CH, FR, IR, LCA and MSA = drought and heat tolerant, cold hardiness, fungal resistance, insect resistance, low chilling requirement and mineral soil adaptation, respectively.
[3]Taxa are considered to be one species, *V. corymbosum* by Vander Kloet (31).

Table 2. The constitution and heritage of *Vaccinium* interspecific hybrid groups.

			Genetic Constitution (%)[1]									
Gp	Heritage	Genotypes in group	Ang[2]	Ash	Atr	Con	Cor	Dar	Ell	Myr	Mys	Ten
1	G 362, US 75	US 607, 665, 667 & 671	-	-	-	-	75	25	-	-	-	-
2	G 362, US 226	US 621 & 625	-	-	25	-	50	-	-	25	-	-
3	G 362, NJUS 11[3]	US 673, 675, 676 & 679	-	30	30	-	40	-	-	-	-	-
4	G 362, NJUS 64	US 612, 702, 703 & 717	25	-	-	-	50	-	-	-	25	-
5	US 75, US 226	US 643, 644, 645, 647, 652, 654, 657, 658 & 659	-	-	25	-	25	25	-	25	-	-
6	US 75, NJUS 11[3]	US 720, 723, 729 & 730	-	30	30	-	20	20	-	-	-	-
7	US 226, NJUS 11[3]	US 696 & 714	-	30	50	-	-	-	-	20	-	-
8	US 226 selfed	US 693	-	-	50	-	-	-	-	50	-	-
9	Ell hybrids	US 772	-	-	-	-	63	13	25	-	-	-
		US 845	-	8	-	8	25	35	25	-	-	-
		US 734, 846, 847 & 848	3	3	-	-	38	28	25	-	-	3
		US 851	-	3	-	-	41	3	50	-	-	3
10	Cor cultivars	Bluecrop, Jersey & Spartan.	-	-	-	-	100	-	-	-	-	-
11	Cor-Ang cultivars	Bluetta, Northblue, Northcountry, Northland, Patriot & St. Cloud	25	-	-	-	75	-	-	-	-	-
		Polaris & Sunrise	12	-	-	-	88	-	-	-	-	-
12	Cor-Dar	G 344 & US 508	-	-	-	-	75	25	-	-	-	-
	cultivars/	Blueridge & Cape Fear	-	-	-	-	63	25	-	13	-	-
	hybrids	Sierra	-	13	-	13	50	25	-	-	-	-
13	Ash-Con cultivar	Little Giant	-	50	-	50	-	-	-	-	-	-
Total population		54 Genotypes	6	6	11	1	50	13	4	7	2	tr.

[1]Genetic constitution expressed to the nearest whole percentage.

[2]Species designations as follows: Ang = *V. angustifolium;* Ash = *V. ashei;* Atr = *V. atrococcum;* Con = *V. constablaei;* Cor = *V. corymbosum;* Dar = *V. darrowi;* Ell = *V. elliottii;* Myr = *V. myrtilloides;* Mys = *V. myrsinites;* Ten = *V. tenellum.*

[3]Progeny of the hexaploid NJUS 11 are putative pentaploids.

by Galletta and Ballington (14) and Eck (7), or which were intermediate between these two types. Although final canopy volume was highly correlated with final canopy height (r_p = +0.806), differences among plants for degree of spread were also observed (Fig. 1). It is not likely that variability in the size of propagules used to establish the study influenced variability in final plant form among cultivars and selections as planting stocks were of similar age and correlations between initial height and final height (r_p = +0.21) and between initial volume and final volume (r_p = +0.01) were not significant.

In general, differences in final height and final volume among cultivars and selections reflected differences in their heritage; final height was significantly related to heritage groups, whereas some heritage-related trends were evident for final volume (Table 4). The species parents of NJUS 64 (*V. angustifolium* and *V. myrsinites*) were the shortest among blueberry species described by Vander Kloet (32), and as progeny of NJUS 64 crosses, individuals in Group 4 were uniformly short, compact plants. With the exception of 'Sunrise,' Group 11 plants (12-25% *V. angustifolium*) were also relatively compact (Fig. 1). Selections within Groups 2, 5, 6 and 8 tended to be tall (≈70-90 cm), but variable in form. Aside from these relationships, individual or group means for final height or volume did not appear to be inextricably associated with a specific progenitor (e.g., G 362) or with percentages of high and low bush ancestry, reflecting a quantitative inheritance pattern for plant form, a differential response to mineral soil conditions or both.

Growth rate and vegetative vigor: In general, the most rapid growth rates occurred during the 1993 and 1994 growing seasons punctuated by a significant loss of volume (population mean = –44.7% ± 27.7%) during the severe winter which separated them (16, 17). Although plant growth was still evident during the 1996 season, canopy volume increases associated with most cultivars and selections were much reduced from those exhibited in previous seasons. Differences in growth rate among genotypes was statistically significant during the 1993, 1994 and 1995 seasons, but not during 1996 (yearly data not shown).

Growth patterns also varied substantially among genotypes within this study (Fig. 2 a-c). Mean volume increases in 1994 were most noteworthy for clones that were severely winter-damaged such as US 643 (Group 5), US 723 (Group 6) and 729 (Group 6) (Fig. 2 a). Understandably, the growth rates of northern *V. corymbosum* cultivars such as 'Jersey' and cultivars and selections with large percentages of *V. corymbosum* germplasm combined with genes from cold-adapted *V. angustifolium* such as US 612 (Group 4) and 'Sunrise' (Group 11) or genes from northern *V. myrtilloides*, such as US 625 (Group 2) and US 645 (Group 5) were less effected by the severe January 1994 temperatures (below –25°F) than their counterparts containing greater percentages of southern germplasm. However, notable exceptions to this trend (e.g., 'Sierra') were also evident (17), and variability for winter damage, even among siblings (e.g., the full siblings, US 643 and US 645) was substantial (Fig. 2 a-b).

Vaccinium corymbosum cultivars such as 'Jersey' and 'Bluecrop' tended to grow rapidly during the first season, and more moderately in subsequent years (Fig. 2 c). Both 'Sunrise' and 'Polaris' (i.e., 88% *V. corymbosum*, 12% *V. angustifolium*) behaved similarly during the first year of growth, but in subsequent seasons, grew as typical highbush and half-high cultivars, respectively. The growth pattern of US 845 and other *V. elliottii* hybrids were intermediate between these two types. Some genotypes (e.g., 'Blueridge' and 'Little Giant') grew very little throughout the entire study even though others of similar genetic constitution grew well. Whether their lack of vigor was due to their specific genotype, poor adaptation to mineral soils, and/or to a pre-existing stressed condition at the time of planting is unknown. Understandably, final canopy volume and canopy volume in-

Table 3. Variation among *Vaccinium* cultivars and interspecific hybrid genotypes for growth, vigor and fruiting characteristics.

Characteristic	Range among genotype means[1]	Genotypic performance extremes[2]	
		Lowest 10%	Highest 10%
		Plant form, growth and fruiting parameters	
Final height (cm)[3,4]	38.0 - 98.3	B'ridge, N'blue, N'country, US 702, 717	B'crop, US 621, 645, 665, 676
Final volume (m^3)[3,4]	0.10 - 0.95	B'ridge, L' Giant, N'blue, US 657, 717	US 643, 645, 665, 676, 772
Volume increase (m^3)[4,5]	–0.08 - 0.77	B'ridge, L' Giant, US 508, 675, 696	Sunrise, US 643, 645, 676, 772
Fruit yield/volume kg/m^3)[4,6]	0.36 - 6.27	US 643, 673, 675, 729, 847	B'etta, N'blue, Spartan, US 702, 717
		Vegetative vigor, fruit/foliage, yield balance and deficiency symptom ratings	
Vegetative vigor[7] (1995)	1.5 - 9.6	B'ridge, L' Giant, N'blue, Spartan, US 675,	US 643, 645, 714, 772, 848
Vegetative vigor (1996)	1.5 - 10.0	B'ridge, Patriot, Sierra, US 508, 607, 659	US 643, 693, 723, 729, 730, 772, 845, 847
Fruit/foliage ratio[8] U995)	2.9 - 9.5	B'ridge, N'blue, N' land, Spartan, St. Cloud	US 643, 720, 729, 734, 847,
Fruit/foliage ratio[9] (1996)	1.0 - 10.0	US 607, 644, 730	B'ridge, US 508, 643, 652, 657, 667, 851
Yield balance[10] (1995)	1.0 - 9.3	n.a.[11]	Patriot, US 693, 696, 702, 703, 845
Yield balance (1996)	0.0 - 10.0	n.a.	B'crop, Sunrise, US 612, 665, 676, 723, 729
Deficiency symptoms[12] (1996)	3.5 - 9.2	B'ridge, Patriot, Sierra, US 607, 654, 659, 665, 6/1	B'crop, C' Fear, N'country, Polaris, US 673, 693, 723, 729, 845, 848

[1]Range of genotype means, each calculated over four replications.
[2]B'--, C', L' and N'-- are contractions for Blue-- Cape, Little and North--, respectively; clusters contain 5 genotypes each, except where ties in genotypic means occurred ; all means for genotypes within the lowest 10% cluster of final height, final volume, volume increase and fruit yield/volume are significantly different (P = 0.05) from those in the highest 10% cluster as determined by Duncan's New Multiple Range Test (full data set not shown).
[3]Final height and volume measurements taken 19 Sept 1996.
[4]F-values for genotype and replicate are significant at $P =\leq 0.001$.
[5]Volume increase = final volume (1996) – initial volume (1993).
[6]Fruit yield/volume = fruit yield (1995) ÷ volume (1995).
[7]Vegetative vigor rating scale: 1 = no new growth visible; 10 = volume of new growth is exceptionally high in relation to extant hardwood.
[8]Fruit/foliage rating scale: 1 = extremely sparse foliage inadequate to mature the crop or to insure optimum flower bud initiation ; S = optimum foliage to fruit ratio, good balance between reproductive and vegetative growth; 10 = extremely vegetative, capable of maturing a heavier crop than was set.
[9]Only three genotypes were judged to be overcropped in 1996.
[10]Yield balance scores derived from fruit/foliage ratings using the following formulae: for fruit/foliage ratings of 5.0 - 10.0, yield balance = [(10 - fruit foliage) X 2]; for fruit foliage ratings of 1 - 4.9, yield balance = fruit/foliage X 2. Yield balance scale: 1 = severely overcropped or undercropped plant; 10 = excellent balance between vegetative vigor and fruit yield.
[11]n.a. = not applicable due to the nature of the yield balance scale.
[12]Nutritional deficiency symptoms rating scale: 1 = all foliage apparently nutrient deficient; 10 = all foliage free of necrosis or discoloration.

crease were closely-related variables (i.e., $r_p = +0.90$); individuals classified as extreme performers were similar for each variable (Table 3).

Differences in canopy volume increase among heritage groups were nearly significant (Table 4), even though variability among individuals within groups was substantial in some instances (e.g., the nine selections in Group 5 ranged in canopy volume increase from 0.146 - 0.766). Mean volume increases were greatest for US 693 (US 226 selfed, Group 8), selections derived from crosses of NJUS 11 and US 75 (Group 6), and those obtained from crosses of NJUS 11 and G 362 (Group 3).

While studying the diallel cross-generated seedling populations from which some of Draper's elite selections were obtained, Chandler et al. (2) and Erb et al. (8) also found superior growth rates associated with progeny of NJUS 11 X US 75 and of G 362 X NJUS 11. Both former research teams reported high levels of general combining ability (GCA) for growth rate on mineral soils associated with NJUS 11 and US 75, suggesting that these interspecific parents possessed a cache of additive genetic variance for mineral soil adaptation from their feral ancestors (Table 1). However, in their studies, the specific combining ability (SCA) of NJUS 11 X US 226 for canopy volume increase was low, and the poor performance of the resultant seedlings was mirrored by the lack of growth herein among the elite selections derived from this cross (i.e., US 696 and US 714, the two members of Group 7) (Table 4). Maternal effects upon growth rate were also reported by Chandler et al. (2). The combination of NJUS 11 X US 75 exhibited greater specific combining ability for canopy volume increase than its reciprocal US 75 X NJUS 11, and herein, Group 6 genotypes US 720 and 723 (NJUS 11 X US 75) were 33% greater in final volume and accumulated 22% more volume over the course of this study than progeny from the reciprocal cross (Group 6 genotypes US 729 and US 730).

Although a genotype's growth rate in mineral soil is a practical measure of its adaptation response, canopy volume increases must be considered relative to the individual's form type (e.g., half-high or high-bush) when assessing suitability for mineral soil growing conditions. Both Chandler et al. (2) and Erb et al. (8) noted the ability of NJUS 64, the product of two lowbush species (*V. angustifolium* and *V. myrsinites*) to confer mineral soil adaptation to its offspring. However, in the study by Erb and colleagues (8) offspring of NJUS 64 and G 362 were generally short statured plants which achieved modest canopy volume increases, and as stated above, the four elite selection from this progeny studied herein (i.e., selections in Group 4) exhibited similar form types. The short stature and modest growth rate of these plants, in and of themselves, did not reflect a lack of ability to prosper on mineral soils.

Subjective evaluations of vegetative vigor (the ability to produce new shoots in proportion to existing plant mass) were made in order to compensate for differences in form type when assessing mineral adaptation response. Over all, 1996 vegetative vigor scores were significantly correlated with canopy volume increases ($r_s = +0.46$), and individuals that exhibited extreme values within the canopy volume increase range (e.g., 'Blueridge,' US 643) were often those that received ratings for vegetative vigor that were extreme in both 1995 and 1996 (Table 3). However, the relationship between the two variables was not strong enough to preclude the identification of some shorter-statured genotypes such as US 845 and 847 as vegetatively vigorous. The 1996 mean vegetative rating (i.e., 10) of these *V. elliottii* hybrids (intermediate form types) were equal to that of US 643, the genotype displaying the largest canopy volume increase in the trial, even though their growth rates were only 62 and 24% as great, respectively. The rating of vegetative vigor also uncovered genotypes such as 'Patriot' which exhibited a canopy volume increase near mid-range, but had essentially stopped growing in the mineral soil environment by 1996. Conversely, some genotypes (e.g., US 696) that had grown very little throughout the trial began to grow in 1996; these individuals were also identified by their vegetative vigor scores. Vegetative vigor scores obtained in 1995 were significantly correlated (r_s = +0.60) with those recorded in 1996. The lack of a stronger relationship reflected season-by-season changes in vigor among individuals similar to those described above. With respect to growth, genotypes such as US 643 and US 772 which exhibit sustained vegetative vigor over time may be more mineral soil-adapted than those which perform inconsistently.

Mean vegetative vigor ratings were significantly different among heritage groups (Table 5). Similar to canopy volume increase trends among groups, US 693 (US 226 selfed, Group 8) and the progeny of NJUS 11 and US 75 (Group 6) demonstrated relatively high levels of vegetative vigor in 1995 and 1996. However, although Group 3 (progeny of NJUS 11 and G 362) means for canopy volume increase were relatively high, (presumably due to the high GCA for this trait associated with NJUS 11), its mean vegetative vigor ratings were intermediate in both years. Levels of vegetative vigor displayed by Group 4 genotypes (progeny of G 362 and US 64) were intermediate in 1995 and relatively high in 1996, although the mean rating (8.1) in 1996 was not significantly different from other group means. Again, variability in ratings among individuals within groups (e.g., 5.1 - 9.6 in 1995 and 5.0 - 10.0 in 1996 for Group 5) prevented clearer associations of vegetative vigor with heritage groups.

Fruit yield/volume, fruit/foliage ratio and yield balance: According to Erb et al. (8), the fruit yield/volume ratio estimates a genotype's propensity for partitioning photosynthate to fruit production and is one measure of a genotype's mineral soil adaptation response. Successful cultivars are obviously efficient at this process, but because growth flushes and floral initiation are concurrent with fruit ripening in blueberry, mineral soil-adapted selections with commercial potential might also be expected to balance the partitioning of energy between developing fruit and vegetative growth/floral induction in order to ensure sustained growth and fruit production simultaneously. In this study, genotypes with high fruit yield/volume ratios tended to be small (r_p = –0.47 for fruit yield/volume vs. 1995 canopy volume) and unfortunately, to lack vegetative vigor (r_s = –0.42 for fruit yield volume vs. 1995 vegetative vigor ratings). Extremely small plants such as 'Northblue' inherently had a greater fruit yield/volume than extremely large plants (e.g., US 643), but it was their extremes in vegetative vigor scores that suggested these individuals to be overcropped and undercropped, respectively (Table 3).

Fruit/foliage ratings were obtained in 1995 and 1996 in order to assess simultaneously, the interrelated factors of fruit yield/volume, plant size and vegetative vigor, and thus to uncover genotypes within the population which balanced vegetative vigor and reproductive capacity in a mineral soil environment regardless of their form. The fruit/foliage ratios did appear to be useful in this regard; in 1995, fruit/foliage ratings were still associated with fruit/yield volume measurements (r_s = +0.48), but were more strongly related to vegetative vigor scores (r_s = +0.68). Additionally, only weak relationships were observed between fruit/foliage values and canopy volume measurements (r_s = +0.32 and –0.35 for 1995 and 1996, respectively), suggesting that shorter-statured plants with optimized fruit weight/volume and relatively high vigor scores were identified by this variable.

Fruit/foliage scores among years were not significantly correlated (i.e., r_s = –0.22). In 1995, plants that were considered to be undercropped (i.e., possess fruit/foliage values >6.0), to express a balanced ratio of fruit/foliage (i.e., scoring from 4.0 - 6.0) or to be overcropped (i.e., displaying values <4.0) comprised 32%, 51% and 17% of the population, re-

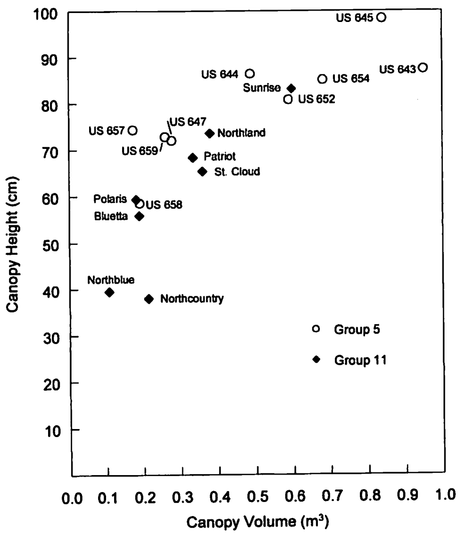

Figure 1. Diversity in blueberry plant form (1996) within the population of cultivars and elite interspecific hybrids as illustrated by variability in plant height and plant canopy volume among members of Heritage Groups 5 and 11.

spectively. By 1996, a general decline in cropping ability among genotypes resulted in 62%, 32% and 6% of the population being classed as undercropped, balanced and overcropped, respectively. Many genotypes within the population displayed a fruiting pattern reminiscent of the alternate bearing habit found in some tree fruit crops. For instance, among the nine genotypes that were judged to be overcropped in 1995 (mean fruit/foliage ratio = 3.4 ± 0.1), all but one were considered to be undercropped in 1996 (mean fruit/foliage ratio = 7.6 ± 0.4). Along with reductions in fruiting, vegetative vigor scores increased among this group during the 1996 (mean vegetative vigor score = 6.9 ± 0.6) over those recorded for 1995 (mean vegetative vigor score = 4.0 ± 0.6). Although this alternate bearing-type behavior (i.e., "on" year/low vegetative vigor, "off" year/high vegetative vigor) could also be found among genotypes classed as balanced fruiting or undercropped in 1995, it was not universal. For instance, among the 17 genotypes undercropped in 1995, nearly half were also found to be undercropped in 1996 as well, and vegetative vigor scores among this group changed very little from year to year (i.e., mean vegetative vigor scores in 1995 and 1996 8.1 ± 0.3 and 8.2 ± 0.8, respectively). Genotypes with consistently high fruit/foliage ratios (i.e., US 643) presumably are so highly vegetative that floral development is continually suppressed. Conversely, some genotypes such as US 652 and US 654 seemed to be losing the ability to crop, even though they exhibited adequate vegetative vigor scores in both years (mean = 7.5). Fruiting behavior in 1995 obviously affected the fruit/foliage balance ratings in 1996, but its effect was complex and may have been exacerbated by a general decline in both vigor (canopy volume increases) and fruiting capacity due to increased levels of stress associated with the mineral soil environment.

An arithmetic transformation of fruit/foliage ratios to yield balance scores facilitated the identification of individuals which performed well at balancing vegetative and reproductive development, and the inclusion of this parameter in multiple factor comparisons that assessed overall mineral soil adaptation responses. Individuals rated superior for yield balance (Table 3) scored above 9.5 for this trait, but genotypes attaining superior status in 1995 differed from those listed in 1996, reflecting the year to year variation in fruit/foliage ratios discussed above. Nevertheless, 'Bluecrop,' 'Jersey,' 'Patriot,' 'Sunrise,' US 665, US 675, US 676, US 679 and US 845 were consistently successful at balancing yield and vegetative growth (individual data not shown), displaying 1995 and 1996 yield balance scores greater than 8.0 (i.e., fruit/foliage values between 4.0 and 6.0). Yield balance scores were correlated with fruit yield/volume measurements (r_s = +0.47) in 1995, the year in which both data sets were obtained, still suggesting that larger plants tended to exhibit a greater yield balance. However, among genotypes recorded as superior for yield

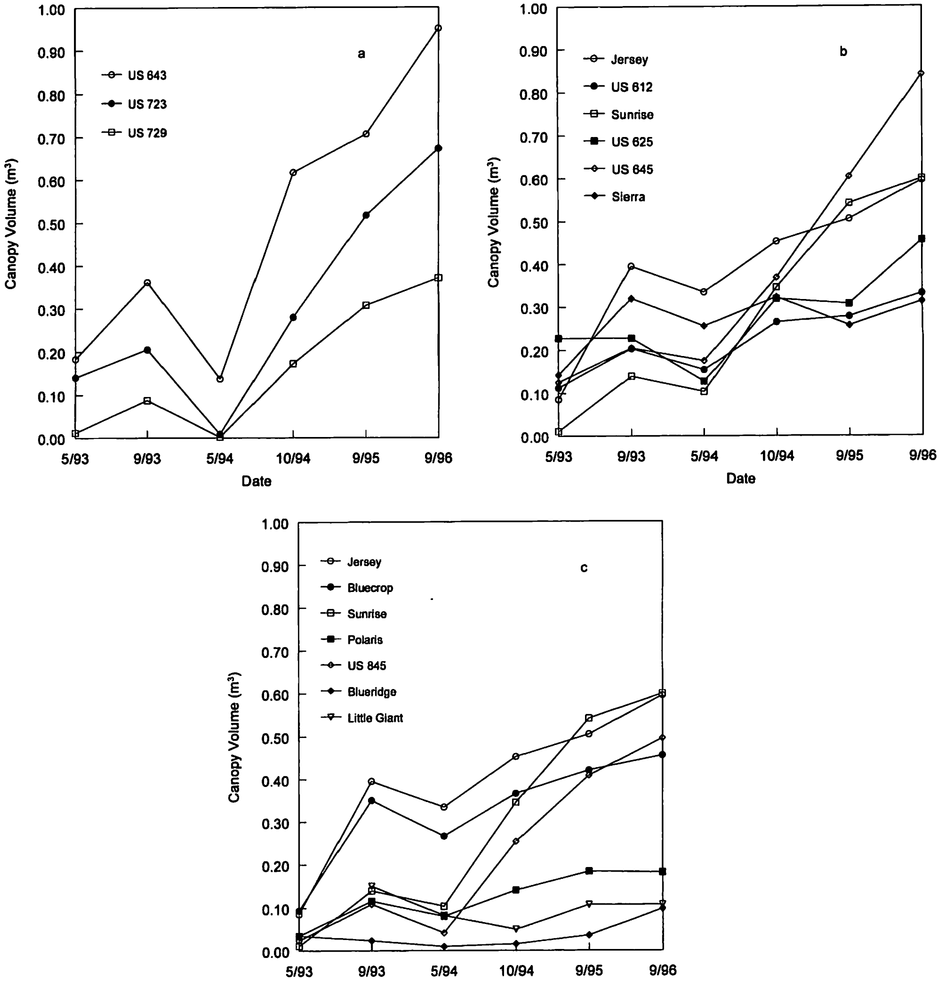

Figure 2. Growth patterns (1993-1996) of selected blueberry genotypes illustrating the variability found within the population of cultivars and elite interspecific hybrids: a) genotypes damaged severely by winter damage during the 1993-1994 season; b) genotypes affected less severely winter damage during the 1993-1 994 season; c) genotypes representing various plant forms.

balance in 1995 or 1996 (Table 3) or those listed above as consistent for this trait, 'Patriot,' US 612, US 696, US 702, US 703, US 729 and US 845 were relatively small plants, having final volumes less than 0.5 m^3.

In 1995, both mean fruit yield/volume measurements and mean fruit/foliage scores differed significantly among heritage groups (Tables 4 and 5). For *fruit* yield/volume, differences among Group 1-7 means followed those reported by Erb et al. (8); the ranking of progeny means in their study was nearly identical to that obtained herein for corresponding groups of elite selections. For instance, these authors characterized G 362 (a high-yielding, large fruited *V. corymbosum* clone)

Table 4. Heritage group means for stature, growth and fruiting parameters of *Vaccinium* cultivars and interspecific hybrids.

Gp	Heritage	Number in gp	Final height (cm)[1]	Final volume (m^3)[1]	Volume increase (m^3)[2]	Fruit yield/ volume (g/m^3)[3]
1	G 362, US 75	4	74.8 a-c[4]	0.47	0.30	1833 a-b
2	G 362, US 226	2	87.9 a	0.42	0.29	2309 a
3	G 362, NJUS 11	4	79.2 a-c	0.60	0.44	911 c
4	G 362, NJUS64	4	50.0 d	0.21	0.14	3116 a
5	US 75, US 226	9	79.5 a-b	0.50	0.37	1576 a-b
6	US 75, NJUS 11	4	80.5 a-b	0.56	0.43	655 c
7	US 226, NJUS 11	2	65.7 b-d	0.32	0.10	1224 a-c
8	US 226 selfed	1	81.0 a-b	0.63	0.48	1608 a-b
9	Ell hybrids[5]	7	67.9 b-d	0.45	0.39	1108 b-c
10	Cor cultivars	3	76.7 a-c	0.44	0.34	2504 a
11	Cor-Ang cultivars	8	60.3 b-d	0.30	0.24	3002 a
12	Cor-Dar cultivars/hybrids	5	69.2 b-c	0.29	0.18	1756 a-b
13	Ash-Con cultivar	1	55.7 c-d	0.11	0.02	1197 b-c
Kruskal-Wallis T[6]			24.40*	20.16^{ns}	20.57^{ns}	23.66*

[1]Final height and volume measurements taken 19 Sept 1996.
[2]Volume increase final volume – initial volume.
[3]Fruit yield/volume fruit yield (1995) ÷ volume (1995).
[4]Multiple comparisons between means accomplished by the Kruskal-Wallis procedure; means with similar letter designations are not significantly different (P = 0.05).
[5]Species designations as follows: Ang = *V. angustifolium;* Ash = *V. ashei;* Con = *V. constablaei;* Cor = *V. corymbosum;* Dar = *V. darrowi;* Ell = *V. elliottii.*
[6]Significance of T based on comparisons with the X^2 distribution; ^{ns}, * and ** indicate probability levels of >0.05, ≤0.05 and ≤0.0l, respectively.

and US 226 as possessing high GCA and US 226 X G 362 as displaying high SCA for fruit yield/volume, which is reflected by the relatively high mean values for this trait found for Groups l, 2 and 4. Variation in fruit/foliage values among individuals within groups prevented a clear interpretation of the effects of heritage on fruit/foliage balance in 1996.

Nutrient deficiency symptom ratings: From their work and those of others, Korcak and colleagues (21) discussed aspects of the mineral soil environment that may negatively impact blueberry growth and fruiting which include: pH values higher than 5.2; base saturations with high percentages of Ca; low levels of organic matter resulting in low CECs and poor moisture holding capacity; and soil imbalances among micronutrient or Ca and micronutrients. In this study, the pre-plant treatment with granular sulfur successfully lowered the pH value of the soil to an acceptable range (pH = 5.2) and plants were irrigated prior to the onset of moisture stress. However the base saturation Ca percentage remained high, and because organic matter was not added, the CEC at the site remained relatively low.

Nutrient deficiency symptoms were increasingly evident during 1996 season, primarily those suggesting mineral soil-induced stress from the lack of micronutrients and perhaps potassium. Nutrient deficiency symptom ratings were weakly associated to canopy volume increase measurements (r_s = +0.30) but more strongly correlated to 1996 vegetative vigor scores (r_s = +0.64) suggesting that nutrient stress may have had its most profound effect on individual performance in the latter years of the study. Nutritional deficiency symptom scores were not significantly correlated with 1996 fruit/foliage ratios.

As with other parameters, nutrient deficiency symptom ratings varied among genotypes; performance extremes are displayed in Table 3. 'Bluecrop,' perhaps the most broadly-adapted V *corymbosum* cul-

Table 5. Heritage group means for vegetative vigor, fruit/foliage ratio, nutritional deficiency symptom ratings and mineral soil adaptation indices of *Vaccinium* cultivars and interspecific hybrids.

Gp	Heritage	Number in gp	Vegetative vigor[1] 1995	Vegetative vigor[1] 1996	Fruit/foliage ratio[2] 1995	Fruit/foliage ratio[2] 1996	Deficiency symptoms[4] 1996	Mineral soil adaptation index[5]
1	G 362, US 75	4	7.0 a-c[6]	5.9 c	5.5 a-c	5.4	5.0	6.2
2	G 362, US 226	2	4.8 c-d	5.5 c	3.8 c	5.5	5.5	6.2
3	G 362, NJUS 11	4	6.0 b-d	6.8 b-c	6.0 a-b	5.2	6.9	7.3
4	G 362, NJUS 64	4	5.9 b-d	8.1 a-c	4.8 b-c	6.4	6.9	7.4
5	US 75, US 226	9	6.5 a-d	7.5 b-c	5.9 a-b	7.1	6.8	6.6
6	US 75, NJUS 11	4	8.4 a	9.5 a	7.7 a	5.0	7.9	7.8
7	US 226, NJUS 11	2	6.6 a-d	7.8 a-c	6.0 a-b	6.8	6.4	7.1
8	US 226 selfed	1	8.5 a-b	8.7 a-b	5.1 a-c	8.7	8.7	7.8
9	Ell hybrids[7]	7	7.9 a-b	8.5 a-b	6.5 a-b	6.9	7.8	7.2
10	Cor cultivars	3	4.9 cd	6.8 c	4.4 b-c	6.5	7.7	6.9
11	Cor-Ang cultivars	8	4.2 d	7.1 b-c	4.4 b-c	7.1	7.1	6.4
12	Cor-Dar cultivars/hybrids	5	4.0 d	5.7 c	4.4 b-c	8.0	5.9	5.5
13	Ash-Con cultivar	1	2.8 d	6.0 c	4.3 b-c	6.8	6.5	6.1
Kruskal-Wallis *T*[8]			26.48**	24.08*	25.51*	9.91^{ns}	14.26^{ns}	16.95^{ns}

[1]Vegetative vigor rating scale: 1 = no new growth visible; 10 = volume of new growth is exceptionally high in relation to extant hardwood.
[2]Fruit/foliage rating scale: 1 = exemely sparse foliage presumed to be inadequate to mature a crop or insure adequate flower bud initiation; 5 = optimum foliage to fruit ratio, good balance between reproductive and vegetative growth; 10 = extremely vegetative, maturing a very light crop in relation to foliage present.
[3]Yield balance rating scale derived from fruit/foliage rating scale as follows: for fruit/foliage ratings of 5.0 - 10.0, yield balance rating = (10 – fruit/foliage rating) X 2; for fruit/foliage ratings of 1 - 4.9, yield balance rating = fruit/foliage rating X 2. Yield balance rating scale: l = extremely undercropped or overcropped (i.e., corresponds to fruit/foliage ratings of 1 or 10); 10 = vegetative growth and fruiting well-balanced (i.e., corresponds to fruit foliage rating of 5).
[4]Deficiency symptom rating scale: 1 = all foliage apparently nutrient deficient, little or not green leaf surface; 10 = almost all foliage green and free ofnecrosis or discoloration.
[5]Mineral soil adaptation score = Σ mean ratings for vegetative vigor (1995 and 1996), yield balance (1995 and 1996) and nutritional status ÷ 5.
[6]Multiple comparisons between means accomplished by the Kruskal-Wallis procedure; means with similar letter designations are not significantly different (P = 0.05).
[7]Species designations as follows: Ang = *V. angustifolium;* Ash = *V. ashei;* Con = *V. constablaei;* Cor = *V. corymbosum;* Dar = *V. darrowi;* Ell = *V. elliottii.*
[8]Significance of *T* based on comparisons with the X^2 distribution; ^{ns}, * and ** indicate probability levels of >0.05, ≤0.05 and ≤0.0l, respectively.

tivar, was included in the list of genotypes which were relatively free of deficiency symptoms. Heritage group means for nutrient deficiency symptom ratings were not statistically different (Table 5), again due to significant within group variability for this trait. Variability for nutritional deficiency symptom ratings was perhaps greatest in Group 12, where individual scores ranged from 3.5 for 'Blueridge' to 8.5 for 'Cape Fear.' In contrast, all Group 1 (75% *V. corymbosum*) individuals received identical ratings of 5.0.

Mineral soil adaptation indices: Mineral soil adaptation in blueberry is a complex phenomenon, involving the capacity for sustained growth and vigor (2, 8, 21), the ability to consistently balance energy expended for new shoot growth and floral initiation with that expended for fruit maturation (8), the capability to sequester balanced levels of essential nutrients from high pH, low organic matter, low CEC soils containing relatively high levels of calcium (20), and the efficiency to optimize photosynthesis under water and/or heat stress (9, 10, 26, 27). Therefore, to identify mineral soil-adapted genotypes within this population of cultivars and elite interspecific hybrids, performance for several traits must be considered simultaneously. In a preliminary attempt to integrate the data at hand for this purpose, mineral soil adaptation indices were cal-

Table 6. Upland soil adaptation indices of *Vaccinium* cultivars and interspecific hybrids and their characteristics.

Mineral soil adaptation index[1]	Cultivars or interspecific hybrids[2]	Characteristic ranges: Height (cm)[3]	Volume (m^3)[3]	Volume increase (m^3)[4]	Fruit yield/volume (kg/m^3)[5]
8.0 - 8.9	Jersey, US 723, 730, 845, 848	72.3 - 82.0	0.50-0.60	0.44-0.53	0.78-2.16
7.5 - 7.9	Sunrise, US 612, 645, 665, 673, 676, 693, 702, 714	45.0 - 96.0	0.18-0.84	0.09-0.71	0.69-3.98
7.0 - 7.4	B'crop, C' Fear, G 344, US 644, 647, 652, 679, 703, 720, 729, 734, 772, 846	52.5 - 89.3	0.18-0.82	0.14-0.73	0.36-2.89
6.5 - 6.9	N'country, Polaris, Patriot, US 654, 671, 717	38.0 - 85.0	0.16-0.68	0.14-0.43	2.12-5.28
6.0 - 6.4	B'tta, L' Giant, N'land, US 621, 625, 643, 675, 696, 847	55.7 - 90.8	0.11-0.95	–0.01-0.77	0.37-6.27
5.5 - 5.9	N'blue, Sierra, St. Cloud, US 657, 659	39.5 - 80.8	0.11-0.36	0.06-0.25	1.02-5.77
2.8 - 5.4	B'ridge, Spartan, US 508, 607, 667, 851	47.7 - 79.8	0.10-0.52	–0.08-0.32	1.29-3.95

[1]Mineral soil adaptation score = Σ mean ratings for vegetative vigor (1995 and 1996), yield balance (1995 and 1996) and nutritional status ÷ 5.
[2]B'--, C,' L' and N'-- are contractions for Blue--, Cape, Little and North--, respectively.
[3]Final height and volume measurements taken 19 Sept. 1996.
[4]Volume increase = final volume (1996) - initial volume (1993).
[5]Fruit yield/volume = fruit yield (1995) + volume (1995).

culated based on vegetative vigor, yield balance, and nutrient deficiency symptom ratings.

Individual mineral soil adaptation indices varied continuously within the population, ranging from 2.8 to 8.9, but were partitioned into seven categories of approximately 0.5 units for ease of data presentation (Table 6). Individuals displaying indices ≥7.5 (i.e., those considered to exhibit a moderate level of mineral soil adaptation) comprised about 26% of the total population and varied considerably in form, growth rate and fruit yield/volume measurements. Most of these "adapted" genotypes were considered to be large plants, but US 612, US 702 and US 714 were relatively compact (volume <0.35

Table 7. Proportion of germplasm within upland soil adaptation index categories for each *Vaccinium* species.

Mineral soil adaptation index[1]	Distribution of genes among groups (%)[2]: Ang[3]	Ash	Atr	Con	Cor	Dar	Ell	Myr	Mys	Ten
8.0 - 8.9	1	18	9	12	8	16	25	0	0	20
7.5 - 7.9	21	23	29	0	14	7	0	26	50	0
7.0 - 7.4	11	25	26	0	22	35	37	23	25	40
6.5 - 6.9	31	0	4	0	15	7	0	7	25	0
6.0 - 6.4	19	30	24	70	14	8	13	26	0	20
5.5 - 5.9	18	3	8	18	10	11	0	14	0	0
2.8 - 5.4	0	1	0	0	17	16	25	4	0	20
Total	100	100	100	100	100	100	100	100	100	100

[1]Mineral soil adaptation score = Σ mean ratings for vegetative vigor (1995 and 1996), yield balance (1995 and 1996) and nutritional status ÷ 5.
[2] Genetic contribution expressed to the nearest whole percentage.
[3]Species designations as follows: Ang = *V. angustifolium;* Ash = *V. ashei;* Atr = *V. atrococcum;* Con = *V. constablaei;* Cor = *V. corymbosum;* Dar = *V. darrowi;* Ell = *V. elliottii;* Myr = *V. myrtilloides;* Mys = *V. myrsinites;* Ten = *V. tenellum.*

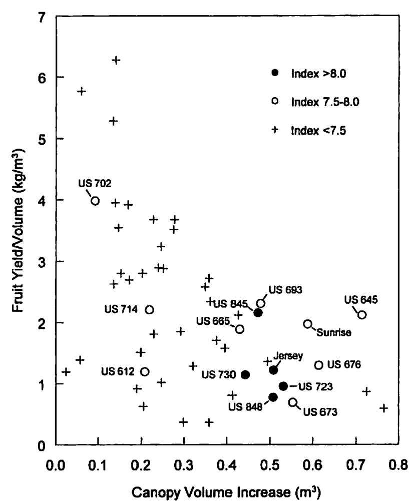

Figure 3. Relationships among mineral soil adaptation index, canopy volume increase and fruit yield/volume measurement within the population of blueberry cultivars and elite interspecific hybrids.

m^3, Fig. 3). There was also a high level of variability within the "adapted categories" for fruit yield/volume, even among plants of similar form, growth rate and genetic constitution (e.g., US 845 and US 849, displaying measurements of 2.16 and 0.78 kg/m^3, respectively).

Members within index categories varied greatly with respect to their heritage (Tables 2 and 6), and mean mineral soil adaptation indices were not significantly different among heritage groups (Table 5). Moreover, when the distribution of genetic material among index categories was arrayed for each species (Table 7), few discernable patterns were uncovered. These results suggest that genes contributing to positive mineral soil adaptation responses may be acquired from a variety of sources and that specific combinations of genes (i.e., SCA) may be of paramount importance to performance in mineral soils. Species traditionally acclaimed as good sources of mineral soil adaptation genes such as *V. ashei*, *V. atrococcum*, *V. elliottii* or by *V. myrsinites* (11, 14) did tend to confer adaptability to their heirs, as greater than 60% of the genes contributed by each of these species were concentrated in genotypes with mineral soil adaptation indices ≥ 7.0. However, it was interesting to note that 'Jersey' and 'Bluecrop' (100% *V. corymbosum*) exhibited mineral soil adaptation indices of 8.4 and 7.4, respectively, even though their parent species is not generally regarded as being mineral soil adapted.

Conclusions

Results from this study confirmed earlier reports (1, 2, 5, 6, 8, 9, 12, 14, 16, 17, 20, 21, 25, 26, 27, 28, 32) that mineral soil adaptability is heritable and can be transferred from feral species to cultivated types. Heritage effects were significant for individual components of mineral soil adaptation, (i.e., height and fruit yield/ volume measurements and for vegetative vigor and fruit/foliage scores). However, substantial variability in mineral soil adaptation response within heritage groups suggested the probability of significant levels of SCA associated with the inheritance of this trait within the germplasm pool studied. Therefore, optimal growth and yield characteristics can likely be recovered from progenies of a variety of interspecific crosses, if the number of individuals evaluated is sufficiently large.

The use of mineral soil adaptation indices herein, probably identified a number of promising genotypes, each with some degree of mineral soil adaptation. Positive adaptation responses (as indicated by indices) still should be considered relative to the entire population and the condition of the site. Definitive studies comparing the growth and yield performance of the supposed mineral soil-adapted genotypes on amended and unamended sites have yet to be undertaken, and the genotypes best adapted to mineral soils may still perform better with added organic matter. Moreover, some of the adapted genotypes with high vegetative vigor displayed relatively low fruit yields/volume and may not provide sufficient crop to be commercially viable. Poor fruit quality characteristics or susceptibility to winter injury of some adapted individuals may also preclude them from being considered for potential release (17, 31). Still, of the 12 elite selections identified by this study as potential commercial cultivars, ornamental cultivars and/or future breeding material (i.e., G 344, US 612, 645, 673, 676, 693, 714, 717, 720, 845, 848 and 851), eight were among those most adapted to the mineral soil environment, displaying mineral soil adaptation indices >7.5 (Table 6).

Acknowledgments

We wish to thank the USDA Small Fruit Germplasm Coordinating Committee for funding this research, Arlen D. Draper and De Grandchamp's Blueberry Farm Inc, South Haven, MI for providing genetic material, Gregory L. Brenneman, Judith F. Stetson, Sandra A. Scheerens, Deanna Cooper, Ellen A. McComb for technical assistance, and Bert L. Bishop for statistical consultation.

Literature Cited

1. Ballington, J. R. 1990. Germplasm resources available to meet future needs for blueberry cultivar improvement. Fruit Var. J. 44:54-62.
2. Chandler, C. K., A. D. Draper, G. J. Galletta, and J. C. Bouwkamp. 1985. Combining ability of blueberry interspecific hybrids for growth on upland soils. HortSci. 20:257-258.
3. Chandler, C. K., R. F. Korcak and A. D. Draper. 1984. Correlation between two nondestructive growth measurements and the above-ground weight of blueberry seedlings. HortSci. 19:590 Abstr.
4. Conover, W. J. 1980. Practical nonparametric statistics. John Wiley and Sons, New York, NY.
5. Darrow, G. M. and W. H. Camp. 1945. *Vaccinium* hybrids and the development of new horticultural types. Bull. Torrey Bot. Club 72:1-21.
6. Draper, A. D. 1995. In search of the perfect blueberry, pp. 17-20. In: R. E. Gough and R. F. Korcak (eds.) Blueberries, a century of research. Food Products Press, Binghampton, NY.
7. Eck, P. 1988. Advances in breeding, pp. 10-21. In: Blueberry science. Rutgers Univ. Press, New Brunswick, NJ.
8. Erb, W. A., A. D. Draper, G. J. Galletta and H. J. Swartz. 1990. Combining ability for plant and fruit traits of interspecific blueberry progenies on mineral soils. J. Amer. Soc. Hort. Sci. 115:1025-1028.
9. Erb, W. A., A. D. Draper and H. J. Swartz. 1988. Screening interspecific blueberry seedling populations for drought resistance. J. Amer. Soc. Hort. Sci. 113:599-604.
10. Erb, W. A., A. D. Draper and H. J. Swartz. 1991. Combining ability for canopy growth and gas exchange of interspecific blueberries under moderate water deficit. J. Amer. Soc. Hort. Sci. 116:569-573.
11. Erb, W. A., A. D. Draper and H. J. Swartz. 1994. Combining ability for seedling root system size and shoot vigor in interspecific blueberry progenies. J. Amer. Soc. Hort. Sci. 119:793-797.
12. Erb, W. A., B. L. Goulart, J. F. Hancock and J. C. Scheerens. Blueberry hybrids with complex genetic backgrounds evaluated on mineral soils: Growth rate, yield, and seasonal and diurnal gas exchange. HortSci (in press).
13. Finn, C. E., J. J. Luby and D. K. Wildung. 1990. Half-high blueberry cultivars. Fruit Var. J. 44:63-68.
14. Galletta, G. J. and J. R. Ballington 1996. Blueberries, cranberries and lingonberries, pp.1-107. In: J. Janick and J. N. Moore (eds.) Fruit breeding (vol II.), vine and small fruits. John Wiley and Sons, New York, NY.
15. Goulart, B. L., M. Brittingham, J. K. Harper, P. Heinemann and W. K. Hock. 1996. Small fruit production and pest management guide 1996-98. Penn. State Univ., Penn State Coop. Ext. Svc., University Park, PA.
16. Hancock, J. R., W. A. Erb, B. L. Goulart and J. C. Scheerens. 1995. Utilization of wild blueberry germplasm: the legacy of Arlen Draper, pp. 1-16. In: R. E. Gough and R. F. Korcak (eds.) Blueberries, a century of research. Food Products Press, Binghampton, NY.
17. Hancock, J. F., B. L. Goulart, W. A. Erb and J. C. Scheerens. 1997. Blueberry hybrids with complex genetic backgrounds evaluated on mineral soils: Cold hardiness as influenced by parental species and location. Acta Hortic. 446:389-396.
18. Hancock, J. F. and S. J. Krebs. 1986. Cytoplasms of highbush blueberry cultivars. Fruit Var. J. 40:49-50.
19. Hancock, J. F. and J. H. Siefker. 1982. Levels of inbreeding in highbush blueberry cultivars. HortSci. 17:363-366.
20. Korcak, R. F. 1986. Adaptability of blueberry species to various soil types: I. growth and initial flowering. J. Amer. Soc. Hort. Sci. 111:816-821.
21. Korcak, R. F. 1986. Adaptability of blueberry species to various soil types: II. leaf and soil analysis. J. Amer. Soc. Hort. Sd. 111:822-828.

22. Luby, J. J. 1991. Breeding cold-hardy fruit crops in Minnesota. HortSci. 26:507-512.
23. Luby, J. J., J. R. Ballington, A. D. Draper, K. Pliszka and M. E. Austin. 1991. Blueberries and cranberries, pp. 393-456. In: J. N. Moore and J. R. Ballington (eds.) Genetic Resources of temperate fruit and nut crops. Intl. Soc. Hort. Sci., Wageningen, The Netherlands.
24. Lyrene, P. M. 1990. Low-chill highbush blueberries. Fruit Var. J. 44:82-86.
25. Lyrene, P. M. and J. R. Ballington. 1986. Wide hybridization in *Vaccinium* HortSci. 21:52-57.
26. Moon, J. W., Jr., J. A. Flore and J. F. Hancock, Jr. 1987. A comparison of carbon and water vapor gas exchange characteristics between a diploid and highbush blueberry. J. Amer. Soc. Hort. Sci. 112:125-130.
27. Moon, J. W., Jr., J. F. Hancock, Jr., A. D. Draper and J. A. Flore. 1987. Genotypic differences in the effect of temperature on CO_2 assimilation and water use efficient in blueberry. J. Amer. Soc. Hort. Sci. 112:170-172.
28. Moore, J. N. 1966. Breeding, pp. 45-74. In: P. Eck and N. F. Childers (eds.) Blueberry culture. Rutgers Univ. Press, New Brunswick, NJ.
29. SAS. 1985. SAS/STAT user's guide, version 5. ed. SAS Inst., Cary, NC.
30. Scheerens, J. C., W. A. Erb, B. L. Goulart and J. F. Hancock. 1999. Blueberry hybrids with complex genetic backgrounds evaluated on mineral soils: Flowering, fruit development, yield and yield components as influenced by parental species. Fruit Var. J. 53(2):91-104.
31. Scheerens, J. C., B. L. Goulart, W. A. Erb and J. F. Hancock. 1999. Blueberry hybrids with complex genetic backgrounds evaluated on mineral soils: Fresh fruit quality and storage/shelf life performance as influenced by parental species. Fruit Var. J. (in press).

Fruit Varieties Journal 53(2):90 1999

Rootstock Guide

BY S. J. WERTHEIM
Fruit Research Station, Wilhelminadorp, The Netherlands

The Fruit Research Station at Wilhelminadorp, The Netherlands, has published Bulletin Number 25, entitled 'Rootstock Guide.' This book of 140 pages is written in English and contains a wealth of information on the many rootstocks used in the growing of Apple, Pear, Cherry and European Plum.

The first chapter of the book consists of a general introduction to rootstocks. This is followed by four chapters, each covering one of the fruit crops mentioned above. These chapters follow the same pattern: a short introduction and a historical sketch is followed by paragraphs on incompatibility, interstems, high budding, soil aspects, and pests and diseases. Past and present rootstocks are then pomologically characterized in alphabetical order. Each fruit crop chapter ends with a short paragraph on current developments in the world, limited trial data and a list of references.

This publication is an important source of information for all involved in fruit growing and can be obtained by payment of a remittance of Hfl. 80.00 either to the publisher: Fruit Research Station, Wilhelminadorp, The Netherlands. Postal Bank Number 49 50 17 or Amro-bank Goes, The Netherlands. Nr. 472 1748 78 or to: Mr. H. H. Jansen, Rabobank Nederweert, The Netherlands. Nr. 1355 915 70 and mentioning Bulletin nr. 25.

This book contains descriptions of many rootstocks tested only in Europe and is based on the many trials conducted by Dr. Wertheim. It is clearly and concisely written and will provide a welcome reference for both researchers and growers.

David C. Ferree