Variability of Sugar Beet Plants Grown in Pots Without Competition for Light, Water and Nutrients

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Individual sugar beet plants of an open-pollinated variety may differ greatly from one another in size and sugar content when grown side by side in the field and in the greenhouse (3, 7)[2]. The great variability in plants is particularly noticeable down the row just prior to harvest. Neighboring plants may differ in root size by a factor of two and at times by as much as ten or more (3). Depending upon the antecedent conditions this variability in size and in sugar content may often be correlated with such factors as disease, insects or plant spacing. Closely spaced plants will be small because of competition for light (8), nutrients or water; whereas widely spaced plants, because of less competition, will be much larger in size and much lower in sucrose concentration, but the plants growing in any one spacing will still differ considerably from one another.

In addition to the variability associated primarily with environmental factors, there is also the variabilty due to genetic composition. In widely spaced plants much of the variability from plant to plant for open-pollinated varieties is undoubtedly of genetic origin (4, 5) and this determines to a large extent the size and chemical composition of the beet plant at harvest. For closely spaced plants the major source of variation may also be genetic rather than environmental. Here, a young seedling with excellent genetic composition will grow faster at the start; the roots will absorb more nutrients, the tops will produce more leaves and absorb more light energy, and once this plant has taken the lead it will stay ahead in size and crowd out its neighbors.

In contrast to this situation due to genetic dominance, a beet seedling of identical genetic composition may be located by chance on a more favorable spot, and because of better nutrition, aeration and less disease can forge ahead of its neighbors. Because of this interplay of environmental and genetic factors operating in the field, their effects cannot be readily separated from one another as long as beet plants are closely spaced. However, a fairly good estimate of genetic variability can be obtained

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[2] Numbers in parentheses refer to literature cited.

from widely spaced plants (4, 5) in fertile fields or from plants grown outdoors singly in pots without competition for light, water and nutrients. The magnitude of these differences for plants grown in pots without competition is the subject matter of this paper.

Methods and Procedures

The sugar beet plants were grown in 207 pots placed outdoors in full sunlight on a concrete slab at Berkeley, California. All conditions and cultural practices were kept the same so that the effects of environmental variation were at a minimum and the opportunities for genetic expression were at a maximum. The four gallon pots used for the study were painted on the outside with aluminum paint and on the inside with Amercoat Number 33. Drainage was provided for by four holes drilled near the outer edge at the bottom of the pot. Vermiculite number 2 was added a teacup full at a time in rotation until all pots were filled simultaneously. The vermiculite was packed firmly by adding nutrient solution until drainage occurred, followed by dropping each pot five times on the concrete slab. More vermiculite was added to fill the pots to the proper level. Seed of the variety US 75 was planted on May 18, 1954, after treatment with Phygon XL at the rate of 1% by weight. Ten seed balls were planted to a depth of 2 cm at the center of the pot in a circle 9 cm in diameter.

The seeds, seedlings and plants were watered daily with ½ strength modified Hoagland's nutrient solution (9). At each watering sufficient solution was added to allow for some drainage through the holes. During germination and final thinning, the pots were placed in contact with each other in groups of 24 pots, three columns of eight pots each. After the final thinning the pots were separated by a minimum distance of 20 inches on the concrete slab. This spacing was sufficient to prevent an overlap of foliage from neighboring plants for the entire growth period.

Thinning of plants to one plant per pot was done gradually. On June 7, at the 2- to early 3-leaf stage, the plants were thinned to 1 seedling per seedball and 6 seedlings per pot. The subsequent thinnings were on June 11, 15, 17, 21 and 22, and on these dates the plants were approximately in the 4-, 6-, 8-, 10- and 11-leaf stages of growth, respectively. After the final thinning a single plant, uniform in size and development, remained near the center of each pot. Old leaves, less than 50% functional, were removed biweekly and included in the total dry weight of leaves produced. Spraying with Ortho-mite 15W[3] and Isotox garden spray M[3], at regular intervals kept red spider and aphid infestations, respectively, under control.

The sugar beet plants were inspected for curly top, virus yellows, mosaic and "red-spot" diseases a few days before the plants were harvested. At the time of harvest on October 26, 1954, the height of the tallest recently matured leaf for each plant was measured and five recently matured leaves were taken per plant and separated into petioles and blades. The remaining leaves on each plant were "shaved off," leaving only the meristematic and axillary buds, which made it possible to produce seed the following year from the roots selected as mother beets. All fresh material was weighed immediately and then dried in a forced draft oven at 80° C. After the dry material was weighed, the petioles and blades were ground in an intermediate Wiley mill to pass a 40 mesh sieve and analyzed for NO_3-N, PO_4-P, K and Na (2).

The beet roots were washed free of vermiculite, freed of fibrous roots and wiped free of moisture before weighing. Beet root weights included root and crown tissues. Fresh beet pulp samples for sucrose determination contained root tissue only and were obtained by removing a V-shaped wedge of root tissue with a Kiel rasp. Three 26.0 gram samples of pulp for a root were weighed, placed individually in 4″ x 2″ x 4″ polyethylene bags, sealed with a heat sealer, and frozen immediately by contact with dry ice (10). The frozen samples were transferred to a deep freeze cabinet maintained at −19° C and analyzed later for sucrose by the hot digestion method (1). A fourth 26.0 gram sample of pulp was dried at 80° C, weighed and ground for chemical analysis.

Results

A detailed inspection of the sugar beet plants before harvest revealed that 14 of 207 plants had a "red-spot" disease of genetic origin and 193 plants were without the "red-spot" disease. Of the 193 plants, 78 were classified as normal, 55 as mildly affected by virus yellows, 10 as mildly affected by sugar beet mosaic, 14 as "severely" affected by sugar beet mosaic and 8 by a combination of virus yellows and sugar beet mosaic. None of the diseases, in spite of their presence, had a significant effect on top growth, beet root size, sucrose concentration or on amount of sugar produced (Table 1). Because of the mildness of the diseases, the 193 beet plants were considered as being "normal" for these

[3] California Spray-Chemical Corporation.

Table 1.—Effect of disease on sucrose concentration, weight of roots, tops and sugar for single plants per pot.

Disease	Number of plants	Beet Root grams	Sucrose %	Sucrose grams	Living Tops Fresh grams	Living Tops Dry grams	Tops total dry matter grams
None	78	2815	13.4	377	997	133	202
Yellows, mild	55	2840	13.3	378	1000	133	204
Mosaic, mild	10	2812	13.6	382	986	134	196
Mosaic, mild recent	28	2758	13.7	380	922	125	193
Mosaic, severe	14	2741	13.5	370	883	121	181
Yellows and mosaic	8	2704	13.5	362	843	117	197
Overall mean	193	2804	13.4	377	972	131	199
F-value[1]	—	0.46	0.62	0.20	1.15	0.75	1.14
Standard deviation, (s)	—	347.6	1.14	55.0	266	34.9	38.0
C.V.[2]	—	12.4	8.4	14.6	27.4	26.7	19.1
Red spot, mild	6	2585	13.3	342	814	114	195
Red spot, severe	8	2001	12.3	246	821	111	191
Red spot, mild and severe	14	2252	12.7	288	817	112	193
F-value[3]	—	27.0	3.62	26.8	4.73	0.30	0.55

[1] Disease variance (normal plus all diseases exclusive of red spot) divided by error variance. Required F-value at 5% and 1% levels of significance are 2.26 and 3.11.

[2] Coefficient of variability.

[3] Disease variance (normal plus red spot) divided by error variance. Required F-values at the 5% and 1% levels of significance are 3.95 and 6.92.

measurements and for the mineral content of the pulp and of the petioles and blades of the recently matured leaves. Since the "red-spot" disease caused a distinct decrease in beet root weight, top weight, sucrose concentration and in sugar produced (Table 1), these plants were not included in the variability study proper as summarized in Table 2.

The beet root weights for the "normal" plants ranged from 1,607 to 3,667 grams per plant, with a mean value of 2,804, and a coefficient of variation of 12.3 (Table 2). This compares with a range of 129 to 2,315 grams per beet for consecutive plants down the row for the US 33 variety at two locations in a field near Woodland, California (Table 3), and 104 to 2,134 grams per beet for consecutive plants harvested within a row for the Am. #5 variety near the coastal area of Los Angeles County (Table 4). The corresponding coefficients of variability for root weight ranged from 60 to 65 in the two fields. If these variations are typical of field grown beets of open-pollinated varieties such as US 33 and Am. #5, then beet root variability in the field is much greater than for beets grown singly in pots. The coefficient of variability of 12.3 for the pot grown plants also compares favorably to a value of 27.9 calculated from the data of Powers et al. (5) (see their Tables 4 and 10) for the F_1 hybrid grown noncompetitively in the field and averaging 1.88 lb (853 grams).

The sucrose concentrations of the 193 beets (Table 2) ranged from 10.5 to values as high as 16.0 percent, even though the plants were high in nutrients, including nitrogen. In the field near Los Angeles (Table 4) under a nitrogen and phosphorus deficiency condition, the values ranged from 14.4 to an exceedingly high value of 23.6 percent. The coefficients of variation

Table 2.—Mean, range, standard deviation, coefficient of variability and required number of replications for measurements made on sugar beet plants grown outdoors in pots without competition.

Measurement	Mean	Range	s[1]	CV[2]	Number needed for 10% difference P = 0.05
Beet (g)	2804	1607-3667	345.1	12.3	13
Sucrose (%)	13.4	10.5-16.0	1.13	8.4	7
Sucrose (g)	377	207-507	54.4	14.4	17
Fresh tops (g)	972	239-1803	266.1	27.4	60
Fresh blades (g)	407	113-703	106.6	26.2	50
Fresh residue (g)	557	125-1149	176.0	31.6	70+
Dry tops (g)	130.5	37-223	34.8	26.6	55
Dry blades (g)	63.8	19-109	16.2	25.3	49
Dry residue (g)	66.7	18-132	20.7	31.1	70+
Old leaves (g)	68.5	23-116	19.7	28.8	65
Dry tops + old leaves (g)	199.1	87-314	37.9	19.1	28
Dry pulp (%)	20.4	16.8-24.3	1.31	6.4	6
Leaf count	220.8	60-430	68.2	30.9	70
Height (cm)	27.5	12-40	4.1	14.9	19
NO_3-N (ppm) dry petioles	5552	1530-11,000	1967	35.4	70+
NO_3-N (ppm) dry pulp	1377	530-3040	455	33.0	70+
PO_4-P (ppm) dry petioles	2276	1020-3740	591	26.0	53
PO_4-P (ppm) dry pulp	1651	950-2370	251	15.2	19
K (%) petioles	5.76	3.36-9.18	1.00	17.3	23
K (%) blades	6.05	3.71-9.65	0.843	13.9	17
K (%) dry pulp	1.62	0.74-2.66	0.305	18.9	28
K (%) dry pulp (sugar free basis)	1.87	0.89-2.97	0.329	17.6	24

[1] s, the standard deviation, is the square root of the variance for an individual plant.
[2] CV is the coefficient of variability.

for percent sucrose for the pot and field experiment were 8.4 and 7.5, respectively. These values for variability are somewhat higher than the 5.4 value for the F_1 hybrid of Powers et al. (5) but are much lower than those for the field near Woodland (Table 3), where some plants were deficient and some nondeficient in nitrogen. Here the sucrose concentrations ranged from 4.4 to 17.2 percent and the coefficients of variation from 20.9 to 21.9 percent. The ranges and coefficients of variation for the amount of sugar per beet root are appreciably higher than for the corre-

Table 3.—Variability of sugar beets growing consecutively within the row at two locations near Woodland, California, 1948.

Measurement	Location	Mean[1]	Range	s[2]	C.V.[3]
Sucrose, %	I	12.7	4.4-17.2	2.65	20.9
	II	11.8	6.3-15.7	2.55	21.6
Beets, grams	I	568	129-1816	339	59.7
	II	699	140-2315	452	64.7
Sucrose, grams	I	74.7	11-249	50.9	68.1
	II	84.4	11-306	59.9	71.0
NO_3-N, ppm	I	1950	320-9000	1768	90.7
	II	2404	170-6200	1984	82.5
PO_4-P, ppm	I	1430	110-5100	943	65.9
	II	1202	430-2750	572	47.6
K, %	I	3.88	1.97-6.08	1.12	28.9
	II	4.76	1.13-7.38	1.35	28.4

[1] Mean of 50 consecutive plants at each location.
[2] s, the standard deviation, is the square root of the variance for an individual plant.
[3] C.V. is the coefficient of variability.

Table 4.—Variability of sugar beets growing consecutively within the row at same location near Dominguez, Californa, (August 21, 1950).

Measurement	N	Mean	Range	s[1]	C.V.[2]
Sucrose, %	1-48	18.5	14.4-21.1	1.38	7.5
	49-96	18.6	15.0-23.6	1.40	7.5
Beets, grams	1-48	590	104-1740	373	63.1
	49-96	591	112-2134	355	60.0
Sucrose, grams	1-48	106	20-260	61.9	58.4
	49-96	109	20-320	65.0	59.6
NO_3-N, ppm	1-48	511	70-2030	481	94.1
	49-96	581	60-2250	556	95.7
PO_4-P, ppm	1-48	512	340-730	90.1	17.6
	49-96	509	330-750	94.9	18.6
K, %	1-48	5.43	2.50-8.50	1.14	21.0
	49-96	6.22	2.40-8.72	1.35	21.7

[1] s, the standard deviation, is the square root of the variance for an individual plant.
[2] C.V. is the coefficient of variability.

sponding values for sucrose concentration and slightly higher than for beet-root weight since the amount of sugar per beet is calculated from the product of these values.

A further indication of the variability of sugar beet plants in pots (Table 2) is afforded by the results for top growth, leaf count, plant height, percent dry weight of pulp and for the mineral content of the petioles, blades and pulp. Tops varied in fresh weight from 239 to 1803 grams and in total dry matter from 87 to 314 grams per plant. Coefficients of variation for fresh and dry weight of tops were less than for any of its parts, except for the fresh and dry weight of the leaf blades. An exceptionally low coefficient of variability was registered for percent dry weight of pulp and an intermediate value for plant height. The greatest variability was observed for the fresh and dry weights of the residue material and for the leaf count. The coefficients of variability for the mineral content of the pulp ranged from 15.2 percent for phosphate-phosphorus to 33.0 percent for nitrate-nitrogen. The coefficients of variability for the petioles and blades were the lowest for potassium and the highest for nitrate-nitrogen.

These differences in variability reflect, in part, the precision of the analytical method used and the variability of the constituent within the plant part itself. The greater source of variability is quite likely associated with the plant because the analytical error is so much smaller than the variation among petioles, blades, or pulp. In dry pulp the lowest to highest nitrate value differed by a factor of nearly six fold and for the petioles by approximately seven fold, whereas the corresponding values for potassium are about three fold for pulp, petioles and blades. The relative range of values for phosphate-phosphorus is about the same as for potassium. For field grown beets (Tables 3 and 4), the variability of the petioles in nitrate and potassium, and at times, for phosphate, is greater than the variability for the corresponding values of plants in pots (Table 2). The range of values is also, as a rule, greater for the field than for the pot grown beets.

Discussion of Results

The experimental results for the open-pollinated sugar beet variety, US 75, have shown that there is still a high degree of variability among individual plants in sugar content, size and mineral constituents even when the plants have been cultured carefully in pots by a standardized technique that eliminates completely any competition for light, water, and nutrients. The variability, however, is much less than that found under field conditions or normally found in greenhouse experiments. In order to detect a difference of 10% between two means at a probability level of 0.05, the required numbers of beets are 9, 31 and 70 for coefficients of variability of 10, 20 and 30%, respectively (6). To detect a difference of 15 and 20% between means, the numbers of beets for coefficients of variability of 10, 20 and 30% drop to 5, 15 and 31, and 4, 9 and 19, respectively. In the present variability trial only 7 beets are required to detect a difference of 10% in sucrose concentration (one to two percentage units), 13 for beet root weight and 17 for amount of sugar per beet root (Table 2). In actual trial runs with two plants per pot, significant differences among closely related sugar beet varieties have been detected at the 5% and 1% levels of significance for changes in sucrose concentrations of 0.7 and 0.9 percentage units, in root weight of 7.8 and 10.3% and in amount of sucrose per beet root of 8.7 and 11.5%, respectively, with only 11 replications (unpublished results of this laboratory). The number of replications required to detect significant differences in top weight and in mineral constituents of pulp and leaf parts tends to be higher (Table 2).

Variation among individual beet plants in the present uniformity trial, can be separated into at least two main categories, one genetic and the other environmental. The environmental variability associated with disease was nonsignificant (Table 1) and from insects was very minor in nature, leaving experimental and genetic variability as the primary causes of variation among the beet plants. At first glance, one might assume that the bulk of the variation would have been due to the nonuniformity of the genetic material and not to the environment. Tests for positional variability were also nonsignificant, again leaving only genetic variability as the primary cause of variation among individuals. However, it is not completely logical to assume that environmental variability, in this case cultural variability, is nonexistent. A measure of genetic and environmental variability could have been obtained by a comparison of an open-pollinated variety with an equally good F_1 hybrid, as suggested by the recent work of Powers (4) and Powers, et al. (5), but at the time of the test in 1954 a comparable hybrid was not available for experimental use. The use of F_1 hybrids in future physiological studies is a step in the right direction and will lead to a further reduction in experimental variability. The growing of two plants per pot and of analyzing the results statistically on a pot basis will reduce the pot to pot variability by a factor of 0.71, one divided by the square root of two, or a gain in precision of approximately 41%.

Summary

Sugar beet plants of the open-pollinated variety, US 75, were grown outdoors in vermiculite as single plants per pot without competition for light, water or nutrients. Diseases and pests were kept to a minimum and had no significant effect upon the plants. Variability due to environmental factors was kept to a minimum, and yet the coefficients of variability (mostly genetic) remained quite high. The values were: beet root weight, 12.3%; sucrose concentration, 8.4%; sucrose per beet, 14.4%; petiole nitrate-nitrogen, 35.4%; petiole phosphate-phosphorus, 26.0%; and petiole potassium, 17.3%. Considerably higher values were observed as a rule for the same measurements for field grown beets growing consecutively in the row, e.g., 59.7 to 64.7%; 7.5 to 21.6%; 58.2 to 71.0%; 82.5 to 95.7%; 17.6 to 65.9%; and 21.1 to 28.9%, respectively. In spite of the relatively high coefficients of variability for pot grown sugar beet plants, the numbers of beets required to detect a difference of 10% between means at the 5% level of significance were only 13 for beet root weight, 7 for sucrose percent and 17 for amount of sucrose per beet root. To detect a difference of 10% in nutrient content of the petioles among varieties from 19 to 70 or more beets appeared necessary. F_1 hybrids and two plants per pot were suggested as further means of reducing pot to pot variability for sugar beet plants.

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