Effect of Competition on Sugar Beet Plants
In Pot Experiments

ALBERT ULRICH

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A study of the effects of crowding on plants in pots and in the field is of interest to plant physiologists and agronomists alike. Fundamentally, space above ground is necessary to plants for light, warmth, carbon dioxide and oxygen. Excessive crowding may deprive adjacent plants of adequate supplies of these growth factors as well as actual space for growth. Even an individual plant may compete excessively for light with its own leaves and so it may grow less favorably than another plant or variety with a better leaf pattern. In the sub-surface part of the sugar beet plant, the storage and secondary roots may compete not only for living room and available oxygen but for water and nutrients in the soil as well.

Agronomists have generally concluded from the results of spacing experiments that yields per acre decrease whenever the rows are spaced more than 20 inches apart (3, 21, 18, 6, 8). Spacing within the row is important for rows spaced less than 20 inches apart (13, 3) but for rows spaced 20 inches or more, yields are largely independent of spacing within the row providing the spacings are not much less than 6 inches or more than 16 inches (5, 20, 17, 9, 10, 19). Within these limits, yields do not change appreciably whether the individual plants are spaced evenly or have as many as 25% to 50% doubles per unit length of row (3, 10, 7, 15, 17). This implies that the beet root yields are relatively constant per unit length of row and that the size of the individual roots increases directly as the spacing within the row increases up to the 16 inch spacing. Beyond the 16 inch spacing, root sizes become relatively constant, which implies that the yields per acre decrease as the distance between beets, i.e., unoccupied row space increases (7). This idea agrees with the earlier conclusions of Brewbaker and Deming (1), namely, that yields for a given spacing are approximately linear to the stand of beets and that the stand of beets under field conditions has a greater effect on the final yield than the particular row width or spacing used.

The smaller beet roots in the closer spacings have been found in some studies a slightly higher sucrose concentration than the larger roots in the wider spacings within the row (1, 11). It is not clear whether this is a matter of root size alone or is

1 Plant Physiologist, University of California, Berkeley 4, California.
2 Numbers in parentheses refer to literature cited.
associated with a more efficient utilization of plant nutrients, particularly nitrogen, or to a better utilization of light by the beet plant itself. The increased top growth with closer spacing reported by Garner and Sanders (11) tends to support the latter explanation.

The effects of crowding or rather competition per se unencumbered by possible nutritional and moisture problems has seldom, if ever, been studied for sugar beets. By growing beet plants in pots containing vermiculite as a substrate and by watering the plants daily with a full nutrient solution, competition for water and plant nutrients would be reduced to a minimum. Under these conditions, the effects of crowding on top growth, root development and on sucrose concentration of the beet root would be associated primarily with light and possibly with carbon dioxide and oxygen availability. The variability in root weight, sucrose concentration and top growth from pot to pot would be a function of the number of plants per pot and not of soil nutrients or moisture. It is the purpose of this paper to report the findings for sugar beet plants grown at the rate of one, two, three, four or five plants per pot and to relate the results to pot experimentation and to spacing problems in the field.

Methods and Procedures

Seeds of the variety US 75 dusted with the fungicide Phygon XL at the rate of 1% were planted on May 2, 1955, at a depth of 3/4” in 5 gallon pots filled with vermiculite No. 2. The pots were 11” in diameter, 13” deep, and had four holes drilled at the side near the bottom for drainage. The vermiculite was added by the cupful in rotation until the pots were all filled simultaneously. The pots were watered with half strength modified Hoagland’s nutrient solution (23), tamped down several times to settle the moist vermiculite by dropping the pots onto a hard surface and refilled to capacity.

Ten seedballs were planted in a circle 51/2 inches in diameter for the 1 and 2 plants per pot and twenty seedballs for the 3 to 5 plants per pot. After planting the seeds, the pots were watered daily with nutrient solution until the plants were harvested. On May 9 the cotyledons emerged above the vermiculite surface and by May 20 the seedlings were in the two-leaf stage. In the 3 to 4 leaf stage, the plants were thinned to one seedling per seedball with the best seedling remaining. In the second thinning on May 27 the plants were thinned to 4. 5. 7. 9. and 11 seedlings for the pots with the 1. 2. 3. 4. and 5 plants per pot respectively. The best plants were left in all cases. The final thinnings were
done on June 1 when the plants were in the 6-leaf stage. The single plants per pot were left at random in the planted circle and in the pots with 2, 3, 4, and 5 plants, the plants were thinned evenly in a circle. During the growing season, the old leaves were removed periodically, dried in the oven at 70°C, and weighed at the end of the harvest. In the experiment there were 28, 20, 15, 15, and 15 pots for the one to five plants per pot, respectively.

**Harvest**: Individual fresh weights of tops and beet root were taken when plants were harvested on October 18, 1955. The plants were separated into recently matured blades and petioles, residue material, and beet roots. The fresh weight of the tops included all fresh material above the oldest living leaf and the beet root consisted of crown plus root. Twenty recently matured leaves per pot were selected equally among the plants for all pots except for the 3 plants per pot in which 21 were taken for tissue analysis. The remaining portions of the tops after sampling were classified as the residue. All the fresh top material was dried at 70°C in a forced draft oven and then weighed.

Pulp for sucrose analysis was obtained from each beet (plus crown) separately by means of a Kiel rasp. It was thoroughly mixed with an electric mixer. Three 26.0 gram samples were quick frozen with dry ice and placed in a deep freeze cabinet maintained at -2°F. (24). Percent sucrose was determined by the 80°C hot water digestion method described by Browne and Zerban (2). Nitrate in the dried, finely ground petiole material was determined by the phenoldisulfonic acid method (14).

**Results**

The results for the pot experiment are presented in Table 1 and Figures 1 and 2. The beet root weights, which include the crown, increased significantly for the pots with two plants per pot over those with one plant per pot but thereafter the weights on a per pot basis remained relatively constant. On a per plant basis, however, the individual root weights decreased as the number of plants per pot was increased. Starting with two plants per pot this decrease was nearly linear to the number of plants per pot, with the individual beet roots in the four plants per pot weighing approximately one-half of those with two plants per pot.

Apparently beet root size can be controlled without a loss in total root weight produced per pot. This fact has important practical implications, namely, the beet root yield per unit area or unit length of row fully occupied by plants is a constant. From the standpoint of marketability, however, extremes in close spacing should be avoided, especially on soils of low fertility or
Table 1.—Effects of Competition on the Sugar Beet Plant.

<table>
<thead>
<tr>
<th>Plants per Pot</th>
<th>No. of Pots</th>
<th>Beet Root Weight Gm/Pot</th>
<th>Crown Weight Gm Plant</th>
<th>Sucrose %</th>
<th>Tops Fresh Gm Pot</th>
<th>Dry Gm Pot</th>
<th>Old Leaves Dry Gm Pot</th>
<th>Tops Dry Gm Pot</th>
<th>OL NO:N p.p.m.</th>
<th>Petiole NO:N (Dry Basis) p.p.m.</th>
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<td>3520</td>
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<td>263</td>
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<td>2</td>
<td>20</td>
<td>5910</td>
<td>1955</td>
<td>12.37</td>
<td>1900</td>
<td>214</td>
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<td>15</td>
<td>3800</td>
<td>1267</td>
<td>12.41</td>
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<td>213</td>
<td>121</td>
<td>365</td>
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<tr>
<td>4</td>
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<td>5710</td>
<td>928</td>
<td>12.61</td>
<td>2600</td>
<td>278</td>
<td>132</td>
<td>110</td>
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<td>3830</td>
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<td>289</td>
<td>125</td>
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LSD 5% level: 400

F-value*: 4.4

*Required F-value at the 5% level is 2.47, at the 1% level, 3.33. n.s.—not significant.

Error Mean Squares

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<tr>
<th>Plants per Pot</th>
<th>No. of Pots</th>
<th>Beet Root Weight Gm/Pot</th>
<th>Crown Weight Gm Plant</th>
<th>Sucrose %</th>
<th>Tops Fresh Gm Pot</th>
<th>Dry Gm Pot</th>
<th>Old Leaves Dry Gm Pot</th>
<th>Tops Dry Gm Pot</th>
<th>OL NO:N p.p.m.</th>
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<td>630</td>
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*All mean square values in column to be multiplied by 1000.

Coefficient of Variability

<table>
<thead>
<tr>
<th>Plants per Pot</th>
<th>No. of Pots</th>
<th>Beet Root Weight Gm/Pot</th>
<th>Crown Weight Gm Plant</th>
<th>Sucrose %</th>
<th>Tops Fresh Gm Pot</th>
<th>Dry Gm Pot</th>
<th>Old Leaves Dry Gm Pot</th>
<th>Tops Dry Gm Pot</th>
<th>OL NO:N p.p.m.</th>
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<tr>
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<td>13.8</td>
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<td>11.9</td>
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in areas with marginal climates. In the present pot experiment, all beets were marketable even at the closest spacing (Figure 2), although a few beet roots weighed less than half a pound and were in the doubtful range (4).

A special point of interest is the significantly lower beet root weight per pot for the single plants as compared to two or more plants per pot. The lower beet root weight for the single plants per pot is probably the result of three factors, one, an incomplete utilization of the space available for growth, two, an inferior growth potential, and three, possible disease or insect damage. With two plants per pot there are more leaves per pot and a larger effective leaf spread than with a single plant and thereby the aerial space is utilized more effectively for photosynthesis and growth than by a single plant per pot. With two plants per pot, the poor growth of one plant with an inferior genetic composition is often almost fully compensated for by the second plant. Similarly, a plant damaged slightly by disease or insects could very well be compensated for by its companion plant. However, in this study, neither disease nor insect damage was of significance, and accordingly, these factors are not important relative to the variability of the plants from pot to pot. As expected,
the variability for beet root weight on a pot basis for two plants per pot was considerably less than for one plant per pot. This is indicated by the reductions in mean squares and in the coefficients of variability for one and two plants per pot (Table 1).

With three or more plants per pot there is a further reduction in variability from pot to pot in beet root weight but the decrease is not sufficient to compensate for the extra work associated with the larger number of plants per pot. To detect a difference in beet root weight of 10% at the 5% level, approximately 31 replications are necessary for one plant per pot, and 8 to 13 replications for 2 to 5 plants per pot (16, Table VII).

*Percent sucrose:* The weighted sucrose percentages of the beet roots increased slowly from 1 to 4 plants per pot and then by a half of a percentage unit from 4 to 5 plants per pot (Table 1, Figure 1). The reason for this relatively large increase is unknown, although it is possible that a change in climate favoring sucrose accumulation may have occurred just before harvest.
and increased the sucrose concentration of the smaller beets more rapidly than the larger ones. The converse would of course take place during unfavorable weather, and here, large beets would have a higher sucrose concentration than small beets.

Again the mean squares for error (Table 1) decreased quite sharply for two plants per pot. Thereafter, there were no large changes in error mean square or in the coefficients of variability. Thus, when testing sugar beet plants for sugar and yield in pot experiments, two plants per pot appear ideal. To detect a difference of only 5% in sucrose concentration of the beet root at the 5% level approximately 21 replications are necessary for pots with one plant per pot and only 7 to 13 replications for pots with 2 to 5 plants per pot (16, Table VII).

**Gross Sugar:** The sucrose stored by the beet plants followed the same general pattern as that of the root weights and not of the weighted sucrose concentrations (Table 1, Figure 1). Hence, as in the beet root weights only the increase in gross sugar from one to two plants per pot was significant statistically. With two or more plants per pot sugar yields were constant. This implies that the same amount of sugar is produced within a given area as long as the area is fully occupied by plants.

From the standpoint of technique the use of two plants per pot rather than one, or more than two, is again indicated. If a difference in gross sugar of 10% is to be detected at a probability level of 5%, approximately 15 replications of two plants per pot will be required. For all three measurements, beet root weight, sucrose concentration, and gross sugar, 15 replications per treatment seems to be a relatively safe number to use to detect a difference of 5 to 10% at the 5% level of significance.

**Top Growth:** The fresh weight of the tops, in a contrast to the beet root weights, increased with the number of plants per pot until there were four plants per pot (Table 1, Figure 1). Closer spacing in the field has likewise increased the size of the tops (11). Apparently, the point of saturation for top growth is at a higher level than for beet root growth. Having more tops per unit area may account for the maintenance of total beet root growth and the gradual increase in sucrose concentration of the storage root itself.

The dry weights of the tops, either with or without the old leaves, were in accord with the fresh weights of the tops (Table 1). Old leaf production, regardless of the number of plants per pot, constituted approximately one-third of the total dry weight of the leaves produced during the five and one-half months of growth. Thus, it appears that leaf senescence is directly related to top weight, and also, reaches a maximum value with four to five plants per pot.
**Petiole-nitrate-nitrogen:** The nitrate-nitrogen values for the petioles of recently matured leaves (young, fully expanded leaves) were well above the critical value of 1,000 p.p.m. nitrate-nitrogen (22) and did not differ significantly from each other (Table 1). Apparently, all plants, regardless of the degree of crowding, were equally well supplied with nutrients, if we use the nitrate values as a criterion of the adequacy of all nutrients. Water was also adequate at all times even for the pots with five plants to a pot.

**Discussion**

The extent to which the results of pot experiments apply to field conditions is problematical. Much depends upon the kind of information obtained and upon the use to be made of the results. In the present instance the finding that the beet root yields for areas fully covered by leaves is a constant per unit area is of interest in two ways, one for applying corrections to beet root weights in field experiments from plots with missing plants, and the other, to provide information about the kind of stand to be sought for maximum sugar production from hand or mechanical thinning operations.

The present results from the pot experiments indicate quite clearly that corrections for missing plants within a row on high fertility soils should be made on the basis of the area unoccupied by leaves of adjacent plants. The reduction in beet root yield in fertile soils appears primarily a matter of sunlight unused for photosynthesis and not of a shortage of nutrients or of water for growth. In a low fertility soil the corrections to be made must take into consideration the extra plant food made available to the plants on each side of the gap. In some instances the extra supply of nitrogen in the gap of a low nitrogen soil might compensate fully for the unused light in the unoccupied space of the beet row, especially if the gap is relatively small. Because of the smaller tops of nitrogen deficient plants, closer spacing may be required for full utilization of the incident light, although if the nitrogen deficiency is acute the losses from the small unmarketable beets left in the field might become appreciable. Corrections for sucrose concentration might also be necessary for some nutrient deficiencies, especially for nitrogen. Beet plants adjacent to gaps would have a larger supply of nitrogen for growth and this could lower sucrose concentrations significantly in comparison to beets not next to gaps.

The amount of compensation from neighboring beets for beet root weight lost due to a single gap in a row may be nearly complete under some field conditions. Brewbaker and Deming (1) reported compensations up to 96.2%, and Garner
and Sanders (12) 80 to 89% during a dry year and from 41 to 84% in a wet year. Such high compensations can be readily explained for fields high in fertility if the loss of light in the unoccupied space is prevented by an early cover of leaves from neighboring plants. In fields of low fertility growth would not be limited by light and under these conditions compensation would depend upon the ability of neighboring plants to absorb and fully utilize the nutrients that would have been absorbed and utilized by the missing plant. Quite likely full utilization of the nutrients could never take place and so the loss in yield would never be completely compensated. The degree of compensation would be still less for more than one gap within a row and from this it follows that the use of a simple mathematical equation for the correction of all “stands” seems unlikely. If a correction for yield must be made, the best correction appears to be that calculated from the regression of stand on yield for each situation (13).

Judging from the results of the present pot experiment spacing in the field should provide for a maximum leaf coverage for as much of the growing season as is compatible with modern cultural practices. From this standpoint certain beet varieties may have distinct advantages over others in leaf spread and pattern. Gaps, whatever their cause, should be reduced to a minimum at all times and it might well be, that a good stand is more important than a particular spacing (1) providing the leaves cover the field effectively for a maximum period during the growing season. Spacing within the row appears to be unimportant unless the plants are spaced too close together or too far apart.

Summary

Sugar beet plants from one to five plants per pot were grown outdoors in vermiculite by the open pot culture technique, using a complete nutrient solution added daily. In this way competition for water and nutrients was removed and only the inherent variations in growth potential and the differences in ability to compete for light and possibly for carbon dioxide, oxygen and thermal energy remained. Under these conditions beet root weight and gross sugar per pot increased appreciably from one to two plants per pot and thereafter remained relatively constant. Sucrose concentrations increased as the plants per pot were increased, with the largest increase taking place from 4 to 5 plants per pot. Fresh weights of tops increased appreciably from one to four plants per pot, with no change from four to five plants per pot. Variability in beet root weight, sucrose concentration, gross sugar and top weight decreased sharply from pot to pot for
one to two plants per pot. The decreases in variability for three to five plants per pot were not worthwhile experimentally in most instances.

The constancy of beet root yields per unit area for areas fully occupied by leaves implies that a uniform spacing within the row is unnecessary as long as the spacing is neither too close nor too far apart. A full leaf coverage should be sought at all times, especially on fertile fields, if maximum production is to be attained, otherwise, losses approximately proportional to the area unoccupied by leaves appear likely.

**Literature Cited**


