Paired-Plant Crosses in Sugar Beets

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The maintenance of selected genotypes is one of the main concerns of most sugar beet breeders who are using self-sterile material. Self-fertilized seed may be obtained from some pseudo-self sterile plants providing the proper environment is maintained (5)[2]. Attempts to maintain genotypes by self fertilization and cuttings at this station have been disappointing because of the effort involved to preserve a limited number of plants. The incorporation of the self-fertile gene into the populations has been considered but not attempted because of the difficulties involved in producing hybrids.

A scheme for plant population improvement involving a limited amount of controlled pollination and record keeping was initiated in 1961. One version of the scheme was suggested by Harland (2) although no data were reported. Lonnquist (3, 4) reported on the results of one selection cycle. The method consisted of crossing plants in pairs within a varietal population. The crosses are grown in performance trials and remnant seed of the superior crosses are composited to form the next cycle population. The premises on which this scheme is based are:

1. A variety of sugar beets is composed of a wide array of yield genotypes whose mean yield is that of the variety itself.
2. The yield genotypes represented will probably show a normal distribution with half being above and half below the population mean.
3. Crossing plants by pairs should result in high $\times$ high, high $\times$ low, and low $\times$ low yield genotypes in a population of about 1:2:1.
4. If such crosses are grown in replicated trials the upper yielding 25 percent of the crosses should include a good number of the high $\times$ high genotype combinations. Their selection would result in an increased frequency of favorable genes in the new population with a resulting improvement in performance.

Paired-Plant Breeding Schemes

Several modifications of the breeding scheme previously discussed are possible. Figure 1 shows a scheme using mass selection.

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[2] Numbers in parentheses refer to literature cited.

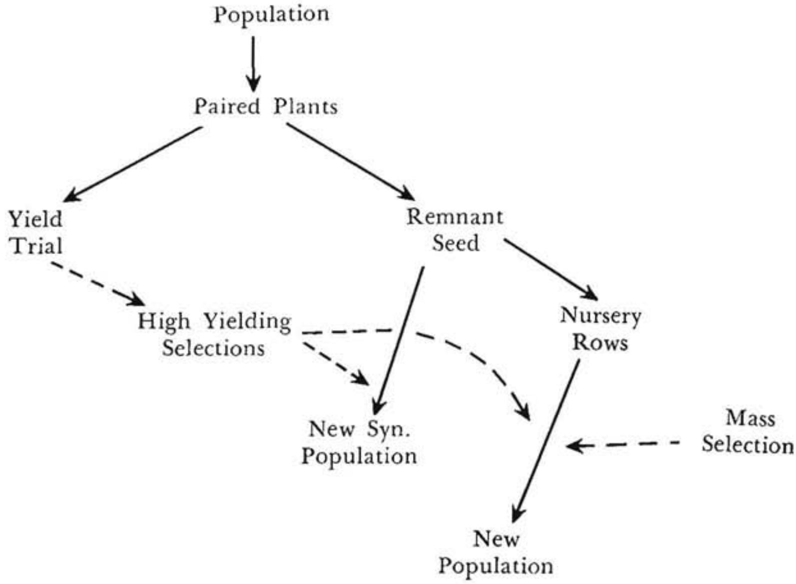

Figure 1.—Modified paired-plant scheme using mass selection within the selected plants to form the next cycle.

The sib pollinated seed is planted in short rows the same year that the yield trial results are obtained. Mother beets can be harvested from all the sib rows prior to harvesting the yield trial. Results of the yield trial will indicate which rows to further analyze and make the selections for the next population. Should environmental conditions permit, the results of the yield trial could be obtained, first, and only the selected nursery rows dug for mother beet analysis. This cycling method should utilize the additive genetic variance present in sugar beet varieties.

Figure 2 shows the paired-plant scheme designed to utilize specific combining ability and the non-additive gene effects. This modification is designed to follow the first scheme after the additive genetic effects are utilized to their fullest. Paired plants obtained at random are crossed with male-sterile tester plants. The yield trials indicate the better sib pairs which can be formed into synthetic populations for future cross to the male sterile, utilized as commercial varieties or crossed by family pairs to the male sterile. The latter scheme would probably be the more productive because it would enable the breeder to select within the progeny of sib pairs and develop a specific hybrid.

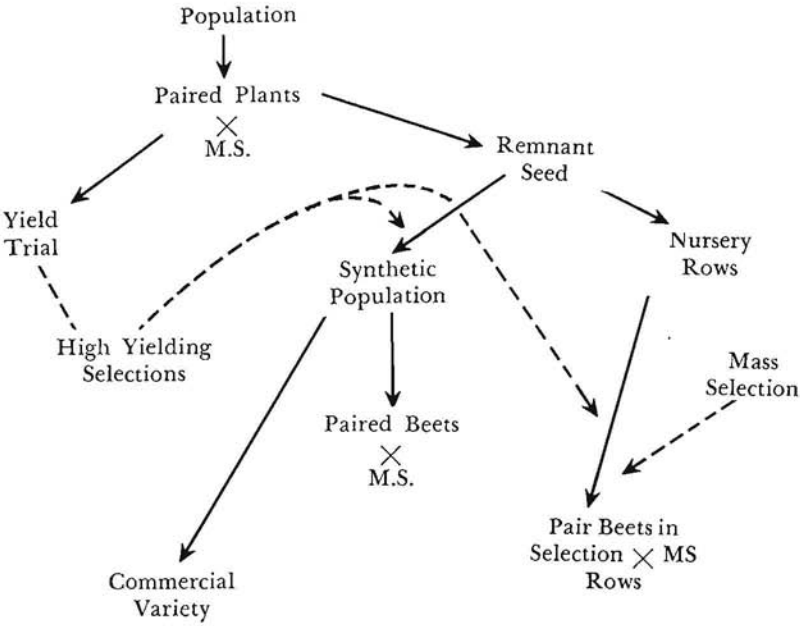

Figure 2.—Modified paired-plant scheme using male sterile top cross to evaluate pairs.

Materials and Methods

The open-pollinated variety selected to be the male parent was 61-307 an American #2 type. Two male-sterile lines, F59-507H1 and the F_1 of 515 × C 9561, were chosen as the female parents. The parental populations were sent to Phoenix, Arizona in 1960 and stecklings were returned for planting in the spring of 1961. Fifty pairs of each male sterile were paired with one hundred pairs of 61-307. Because of faulty bolting caused by severe hail only thirty-five pairs crossed to F59-507H1 and twenty-one pairs crossed to 515 × C 9561 set sufficient quantities of seed for yield trials. The seed from the female plants was included in yield trials and the seed of the sib pairs was grown in nursery rows during the summer of 1962. Stands in the yield trials were erratic, thus the data for tons per acre were adjusted by regression to a uniform stand.

The pairing and crossing was accomplished by using plastic covered cages. These cages are approximately twenty-four inches square and five and one-half feet high. The tops are open to prevent a heat build-up within the cage. Some crossing between cages is possible but it was felt to be negligible.

Experimental Results

The results reported in this paper are not conclusive as the data for a complete cycle are not available. However, it was thought desirable to report on the methods and the data available to date.

Table 1 shows the means of the yield factors for the two male steriles, Group I (F59-507H1), Group II (515 × C 9561) and the parental parent (61-307). No statistical differences were detectable between these population means. Thus, no expression of heterosis would be evident, if the open pollinated population, 61-307, were crossed with these male steriles. However, examination of the individual pairs within each group indicates considerable heterosis for certain pairs. The highest pair was 4.6% better than the paternal parent for sucrose percent while the tonnage pair was 22.9% better than the paternal parent.

Table 1.—Means of the yield factors for the two male-steriles (Group I and Group II) and the paternal parent (61-307).

Yield factors	Group I	Group II	♂ Parent
Lbs. sugar per acre	6199	5853	6420
Tons per acre	20.62	19.72	20.60
Percent sucrose	15.03	14.81	15.60
n	35	21	

Table 2 shows the number of sib pairs that were in the high × high group based on the 1:2:1 hypothesis. Larger populations of the sib pairs would have given a greater latitude for selection. The use of a paternal parent that gave an indication of heterosis when crossed to a specific male sterile would also have increased the possibility of yield increases due to certain specific pairs giving higher yields.

Table 2.—Number of sib pairs in the high × high class for yield factors.

Yield factors	Group I	Group II
Lbs. sugar per acre	7	5
Tons per acre	4	5
Percent sucrose	7	3
Tonnage + Sugar	0	2

Chi Square values were calculated to test the 1:2:1 ratio of the low × low, low × high, and high × high hypothesis (Table 3). The expected values for the calculation of the Chi Square values were obtained by dividing the range of yields for a particular factor into fourths and combining the two middle quartiles. The observed were obtained by counting the number of pairs that fell within each quartile. As shown in Table 3, all Chi Square values except the combined group for tons per acre fit a 1:2:1 ratio. The hypothesis of normal distribution appears to be functioning in the paired plant method.

Table 3.—Chi square values calculated for goodness of fit to a 1:2:1 hypothesis ratio proposed for random pairs crossed to male-sterile testers for several yield factors.

Yield factors	Group I	Group II	Combined groups I & II
Lbs. sugar per acre	3.44	0.05	4.33
Tons per acre	3.50	0.01	9.67[1]
Percent sucrose	1.67	0.96	3.76

[1] Failed to fit a 1:2:1 ratio

5% Rejection level = 5.99

Discussion

The population cycling data if available would be the conclusive evidence that the paired system was either working or not working in sugar beets. The cycles were attempted by planting the sib seed of the pairs and taking selected mother beets from the higher yielding pairs. For two years curly top in the mother beets prevented the production of seed in the second cycle, thus most of the material was subsequently lost. Since then, the selected pairs have been propagated as stecklings, a method that appears to be working.

The need of maintaining the genotype in any hybrid program is of prime importance. The effort involved to obtain a small quantity of seed on a few plants by self pollination stimulated the search for a more adaptable method. Sib pollination is an alternative method of genotype maintenance and has been used to maintain sugar beet inbred lines (1). Self pollination being quite severe fixes the genotype quite rapidly. Sib pollination fixes the genotype at a slower rate enabling the plant breeder to observe more combinations of genotypes while selecting the better ones. Two other advantages of sib pollination are reduced plant deterioration connected with self pollination and the production of sufficient quantities of seed for yield trials and disease nurseries.

The necessity of having homozygous material to produce heterotic responses is debatable. However, a certain amount of genotype fixing is necessary in order to approximately duplicate each plant in the hybrid population. Hybrids selected by the proposed cycling methods should be good yielders because of the selection and progeny testing in each cycle and the utilization of additive and nonadditive gene action. The reduced genotype fixing involved in sib matings should give a greater yield flexibility in a genotype $\times$ environmental situation.

Sib pairing for preservation of type "O" beets as suggested by Owen (6) has been used in the male-sterile program of American Crystal. The genotype maintenance of the primary "O" type screening has been done mainly by steckling reversion and self pollination. The secondary screenings and purification of the semi "O" types have been done by sib mating with substantial success. Hybridization of "O" types and selection within their segregating progeny using the pair system described in Figure 2 is in the combining ability phase of this program at the present.

The only data that are available on a complete cycle of a sib mating system comes from the Nebraska Corn Project. Lonnquist (4) reports the results of one cycle of paired-plant crosses from the synthetic variety Krug. This synthetic had previously been subjected to three cycles of recurrent selection and three increases (Syn-3) from the KIII selection. Plants of the parent KIII Syn-3 were crossed by pairs, yields obtained and the 13 high yielding and 13 low yielding pairs selected. At the same time the fourth cycle of divergent recurrent selection was being conducted. The results of this experiment are shown in Table 4. The 13 selected high pairs exceeded the yield of the parent by 7.6 bushels and the fourth cycle synthetic by 4.5 bushels. The low paired selection was also more effective in lowering the yields than the recurrent selection cycle. From these data it would appear that pair-plant selection was effective in corn.

Table 4.—Performance of selected high and low yielding parental paired-plant crosses together with the syn-2 generation synthetic resulting from their intercrosses—Lincoln, 1959 (Lonnquist).

Population	Acre yield
Parental KIII Syn-3	88.6
Selected High 13 Crosses	96.2
KIV (c) High Yiell Syn-2	91.7
Selected Low 13 Crosses	76.4
KIV (c) Low Yield Syn-2	83.2

The improvement of a cross pollinated species is dependent on the ability of the plant breeder to select on the basis of additive gene effects. The success of hybridization is believed to be largely due to one's ability to capitalize on nonadditive gene effects over and above the chance additive portion of the selected lines. Cycling methods of accumulating these additive effects such as recurrent selection and paired crossing would give the hydridizer superior source populations from which to develop lines.

Summary

Methods of using paired-plant crosses were discussed. One cycling method is designated to accumulate the additive genetic effects. The second method which follows the first is designed to capitalize on heterosis and the non-additive genetic effects.

Preliminary data pertaining to the expected frequency of low × low, low × high, and high × high combinations from pair crosses are presented.

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