Reprinted from *Crop Science*
Vol. 22, May-June 1982, p. 641-645

Breeding for Resistance to the Sugarbeet Root Maggot[1]

J. C. Theurer, C. C. Blickenstaff, G. G. Mahrt, and Devon L. Doney[2]

ABSTRACT

Thirty-six genetically diverse sugarbeet (*Beta vulgaris* L.) lines were evaluated to determine their potential resistance to the sugarbeet root maggot, *Tetanops myopaeformis Roder*. Significant and relatively consistent differences in maggot damage were noted over 3 years. Damage ratings of F_1 crosses of resistant × susceptible lines tended to be intermediate between those of the parents. Selection for high- and low-maggot damage showed a linear trend in increasing and decreasing maggot damage, respectively. The average decline in the low-damage selection was approximately 5% per cycle. After five cycles of selection, there was no change in the rate of decline, indicating that further selection progress can be made. A greenhouse test confirmed field designations of resistant and susceptible genotypes. A low-damage inbred had lower maggot survival, smaller maggot weight, lower damage ratings, and greater root weight than a susceptible line.

Additional index words: Beta vulgaris L., *Tetanops myopaeformis Roder*, Breeding for insect resistance, Divergent selection, Mass selection.

The sugarbeet root maggot (SBRM), *Tetanops myopaeformis Roder* is one of the most serious insect pests of sugarbeets in the western United States and Canada. Its distribution coincides, with few exceptions, with the major sugarbeet growing areas of the western United States and Canada. It has been reported from the states of California, Colorado, Idaho, Minnesota, Montana, Nebraska, New Mexico, North Dakota, Oregon, Utah, Washington, and Wyoming; and from Alberta, British Columbia, Manitoba, and Saskatchewan provinces of Canada (9). Approximately 38% of the U.S. sugarbeet acreage is subject to damage. We estimate the current average annual loss from SBRM to be about 2% of the yield, or 481,000 metric tons.

The prime method of controlling this insect has been with chemical pesticides (3). However, these can be expensive, and there is the possibility that the insect could develop resistance to insecticides. Plant resistance to insects has been developed by breeding in many crops and is one of the most efficient and economical methods of control when available.

In the United States, several reports indicate that differences exist among sugarbeet genotypes for damage caused by the sugarbeet root aphid, *Pemphigus populivenae* Fitch (1, 4, 5, 15, 16), the green peach aphid, *Myzus persicae* (Sulzer) (5, 13), the bean aphid, *Aphis fabae* Scopoli (12, 13), and spider mites *Tetranychus spp* (13). However, none of these have played an important role in sugarbeet breeding program in the United States. In England, considerable research on plant resistance in sugarbeets has been reported for the green peach aphid (6, 7, 8, 14) and to some extent for the bean aphid (6, 8). It is apparent that the potential exists for developing resistance to sugarbeet insect and mite pests.

Maxwell and Jennings (11) recently reviewed principles and techniques of insect control and pointed out that incorporation of plant resistance to insects should be an integral part of a breeding program for any crop. Success in identifying sources of resistance is directly related to the diversity of germplasm available and the probability of resistance occurring in these populations. Finding a source of resistance is the first step for further biochemical and genetic studies. Our study was undertaken to determine if resistance of sugarbeets to the SBRM could be found and to determine the degree of resistance and the feasibility of selection for resistance to SBRM in a sugarbeet breeding program.

METHODS AND MATERIALS

Field and laboratory evaluations of sugarbeets and selections for resistance to the sugarbeet root maggot were carried out by personnel of the USDA/ARS Entolomology Laboratory, Kimberly, Idaho. Seed propagation and crosses were made by USDA/ARS plant geneticists at Logan, Utah, and plant breeders from the Amalgamated Sugar Co. (TASCO), Nyssa, Ore.

Equipment 1

In 1974, 36 diverse inbred and open-pollinated lines of sugarbeets were selected for SBRM evaluation. Seeds were planted in the greenhouse, and after emergence the young seedlings were transplanted to field plots. Entries were planted in single-row plots consisting of five plants, spaced 30 cm in the row and 56 cm between rows. The test was a randomized block design with six replications. Plants were subject to a natural infestation of SBRM flies. In mid-July, the beet roots and a surrounding soil core (20 cm diam and 30 cm deep) were dug for evaluation. The soil from each sample was sifted through a double screen to recover maggots and to rate the entries.

Ten lines covering the complete range of root maggot damage found in 1974 were re-evaluated in 1975 and 1976 to determine the repeatability and accuracy of the 1974 evaluations. The 1975 test was seeded again in the greenhouse and transplaced to the field. In 1976, seed was handplanted in the field in hills and later thinned to one plant per hill. The 1975 and 1976 test plots were single rows of each entry consisting of 10 plants spaced 30 cm apart in 56-cm rows. There were six replicates each year. During these years, the natural fly population was augmented by release of a large population of SBRM flies in the test area. Damage was assessed in mid-July by digging all plants and rating the roots on a damage scale of 0 to 5 (0 = no damage, 5 = severe damage) as outlined by Blickenstaff et al. (2).

Experiment 2

Crosses were made between six inbreds that were rated high, intermediate, or low damage in 1974 and 1975. These F_1 hybrids and the parental lines were tested in 1976 in eight replicates of a field planting. Seed of each entry was direct seeded in a hill

[1]Contribution of USDA/ARS and the Idaho and Utah Agric. Exp. Stns. Received 31 July 1981.
[2]Research geneticist, USDA/ARS, Logan, UT 84322; research entomologist and agricultural research technician (insects), USDA/ARS, Kimberly, ID, 83341; research geneticist, USDA/ARS, Logan, UT.

planting and later thinned to one plant per hill. Plot layout and evaluation of each plant were similar to the 1976 inbred test of Exp. 1.

Experiment 3

In 1975, two highly heterogeneous broadbase populations (one developed by the USDA at Logan and the other developed by plant breeders from TASCO, Nyssa, Ore.), were planted at Kimberly to estimate their genetic variability and to initiate a selection and breeding program for plant resistance to SBRM. An inbred line was included in the test to obtain an estimate of the environmental variance.

Seed of each entry was planted in paper pots (3 × 13 cm) in the greenhouse on 27 March using a commercial potting soil. Seedlings were transplanted to the field on 13 to 15 May. Individual plots consisted of 2 rows, 56 cm apart, with eight plants 30 cm apart in each row. Each plot row contained, at random, two plants of the check and six plants of each of two broadbased lines. There were 40 replicates. The natural fly population was augmented by the release of about 60,000 flies in the test area. Each plant was dug in mid-July and classified for maggot damage using the previously reported rating scale (2). Divergent high- and low-damage selections were made from these broadbased populations by saving approximately 5% of the high- and 5% of the low-damage roots from each population. In 1976, selection also was initiated in a third broadbase population, 25D47.48. This population had approximately 50% of the same basic germplasm as population 25A1.

Beet roots were selected for high or low damage in mid- or late July and were sent to USDA/ARS geneticists at Logan or to the TASCO plant breeders at Nyssa, Ore., for seed production. Seed was returned to Kimberly the following spring for the next cycle of evaluation and selection.

Open-pollinated seed of the high and low selections, the Logan parent population, and the inbred check L19 were planted for each selection cycle. Seed was planted in 10-hill rows with hills 30 cm apart in rows 56 cm apart.

Individual 3-row plots for each entry were randomized in 20 replicates. Evaluation and selection as noted has been repeated for five cycles in both the USDA/ARS population 25A1 and the TASCO population from 1975 to 1980. The third population, 25D47.48, had been evaluated and selected for only three cycles.

Experiment 4

In 1978, a test was conducted in the greenhouse to verify previous results from field and laboratory tests which had characterized the inbred L29 as resistant and the inbred L89 as susceptible to the SBRM (10). An inbred Check, L19, also was included in the test.

Plots were single plants grown in 10-cm diam and 10 cm-deep paper pots, filled with a soil mixture of 40% vermiculite, 40% washed mortar sand, and 20% peat. Approximately 300 g of 6-10-4 fertilizer was added to each m^3 of soil mixture.

Plants were infested artifically with SBRM eggs collected in the laboratory and placed around the base of each plant. There were three treatments: 0, 25, and 50 eggs per plant. Plants were placed on tables in a greenhouse in a randomized block design with 20 replications for the 25- and 50-egg infestation level and 10 replications for the 25- and 50-egg infestation level and 10 replications for the 0-egg infestation. Approximately 8 weeks after plants were infested with eggs, the following data were taken from each plant: number of maggots, maggot weight and length, leaf area, fresh leaf weight, fresh root weight, and damage rating.

Table 1. Evaluation of USDA sugarbeet inbred lines for root maggot damage.

Entry	Mean damage rating			
	1974	1975	1976	Mean
L35	0.2 a*	0.6 a	1.9 a	0.9 a
L29	0.2 a	1.1 ab	1.8 a	1.0 ab
EL39	0.3 a	1.2 ab	2.3 ab	1.3 abc
961RF	0.5 ab	1.1 ab	2.2 ab	1.3 abc
4608	0.9 ab	1.0 ab	2.1 ab	1.3 abc
L19	0.5 ab	1.2 ab	2.7 b	1.4 abcd
L53	1.0 abc	1.3 ab	2.3 ab	1.5 bcd
L37	1.0 abc	1.3 ab	2.3 ab	1.5 bcd
L28	1.1 bc	1.3 ab	2.4 ab	1.6 cd
L89	1.3 c	1.4 b	2.8 b	1.8 d
Mean	0.7	1.2	2.3	1.4
C.V., %	32.7	40.0	23.8	19.0

* Values followed by the same letters do not differ significantly at the 5% level of probability.

RESULTS AND DISCUSSION

Experiment 1

The 36 entries included in the 1974 field test were selected to represent divergent germplasm that was available at Logan. Most of the entries were inbreds, but a few were open-pollinated lines.

We depended upon the natural fly population in the field plot area, and as a result, all replicates were subject to a light infestation. There were, however, significant differences between the entries for the number of maggots isolated from the individual roots and soil around them. The average number of maggots per root ranged from 0.02 to 3.12. Eleven entries had less than one maggot per 5-root plot, and three entries exceeded 10 maggots per 5-root plot.

The mean damage rating for 10 entries evaluated for 3 years was higher in 1976 than that observed in 1974 and 1975 (Table 1). This was caused by a greater infestation of flies in 1976. Otherwise, the data analysis showed relatively similar results for the 10 USDA lines. There was a significant difference in damage ratings between the highest and the lowest entry each year. Inbreds L29 and L35 consistently showed low damage, where L28 and L89 consistently rated high in damage. Rank correlations between years were 0.80** for 1974 with 1975, 0.77** for 1975 with 1976, and 0.65* for 1974 with 1976.

Experiment 2

The 1976 damage rating of six F_1 hybrids and their inbred mid-parent values showed little difference (Table 2). This result might be expected based upon the relatively small differences between the parent lines even though they were classified as resistant, intermediate, and susceptible in the 1974 and 1975 tests (Table 1). The cross L29 × L89 was the only one with parental lines that were significantly different in maggot damage ratings. This cross showed the highest root maggot damage of the crosses. Although there were inconsistencies, the hybrids, tended to have a damage rating near the mean of the parents. There were some tendencies for interaction between genotypes. Correlation between the crosses and their mid-parent values was not significant (r = 0.37). Inbred L35 crosses tended to show a dominant effect with higher

Table 2. Sugarbeet root maggot rating of single crosses compared to the mean of their inbred parents, Kimberly, Idaho, 1976.

Cross	Tentative designation†	Damage rating‡ Cross	Mean of parents
L35 × L29	R × R	2.2	1.9
L53 × L29	I × R	2.0	2.1
L35 × L53	R × I	2.4	2.1
L53 × L37	I × I	2.1	2.3
L37 × L28	I × I	2.3	2.3
L29 × L89	R × S	2.4	2.3
Mean		2.2	2.2

† R = resistant, I = intermediate, and S = susceptible based on average 1974 and 1975 damage ratings (Table 1).
‡ There are no significant differences among these values.

Table 3. Root maggot damage rating means and variances for two broadbase sugarbeet synthetics and a uniform inbred.

Population	Mean	Variance
25A1	1.3 b*	0.63
TASCO	1.5 a	0.72
L19 Inbred	1.4 ab	0.44

* Values followed by the same letters do not differ significantly at the 5% level of probability.

damage ratings than expected based on the mid-parent means. Additional research is needed to determine more fully the inheritance and breeding behavior of plant resistance to root maggot.

Experiment 3

The two broadbase populations tested in 1975 were significantly different in mean root maggot damage (Table 3). The inbred check mean value was intermediate and not different from that of either population. The important statistic in this test is the variance estimate. Both broadbase synthetics had larger variances than the uniform inbred check indicating that genetic variation existed in these populations for resistance to root maggot. We felt that sufficient variability existed to make divergent selection for maggot resistance and susceptibility. Consequently, from each population, we selected 15 to 20 low-damage roots (scored 1) and 15 to 20 high-damage roots (scored 4) for seed increase, field evaluation, and recurrent mass selection. The progress made from five cycles of selection in the 25A1 and the TASCO populations and from three cycles of selection in population 25D47.48 is summarized in Table 4. A photograph of the selections made in 1978 is shown in Fig. 1.

The three populations showed similar changes due to selection pressure for low SBRM damage. The percent change shown for the progeny of the two USDA populations (25A1 and 25D47.48) was a comparison with the original parent populations that were grown in each selection cycle. Low-damage selections in 25A1 populations resulted in a change of −24.5% in five cycles of selection compared with the parent by linear regression, showing 4.65% change per cycle (Fig. 2). Population 25D47.48 showed a change in the low-damage selection of −17.2% in three cycles of selection. Correlation coefficients were −0.95 for 25A1 and −0.50 for 25D47.48.

Performance of the high-damage selection progenies was more erratic, but showed a similar parallel regression trend away from the parent population (Fig. 2). Progress in selecting for high damage could not be expected to proceed as rapidly, or to the same extent, as in selecting for low damage since the most heavily damaged plants die or are so stunted that they cannot be utilized for seed propagation.

The fact that selection pressures in opposite directions were effective in moving the population means suggests that additive genetic variance exists for resistance to SBRM.

Unfortunately, we cannot accurately determine the degree of progress made by selection in the TASCO population since the parent synthetic was not included in the field trials. The percent change reflected in Table 4 for TASCO selections is a comparison with the USDA inbred L19 used as a check. The data show a similar linear response to selection for the low-damage selection to that of the USDA 25A1 population (Table 4). Selection for high damage was ineffective in this population. In comparison with the L19 check, after five cycles, the low-damage selection of TASCO showed a change of −33.8% or an average of −6.7% per cycle. Selections from the TASCO population started at a higher level of damage than the USDA 25A1 population (Table 4); however, selection progress through five cycles was essentially at the

Table 4. Sugarbeet root maggot damage rating and the percentage of change through three to five cycles (C) of selection for high and low damage for three sugarbeet populations, Kimberly, Idaho, 1976–80.

Population and year of first selection		C1 SBRM rating	C1 % change†	C2 SBRM rating	C2 % change†	C3 SBRM rating	C3 % change†	C4 SBRM rating	C4 % change†	C5 SBRM rating	C5 % change†
25A1 (1975)	parent	2.4 a*		3.1 b		2.0 a		3.4 b		2.0 b	
	low	2.3 a	−4.1	2.4 a	−13.6	1.8 a	−11.4	2.8 a	−19.1	1.5 a	−24.5
	high	2.8 a	16.0	3.2 b	2.9	2.5 b	21.3	3.9 c	14.7	2.7 c	32.5
25D47-48 (1976)	parent	3.1 b		2.0 a		3.4 b					
	low	2.7 a	−13.3	1.8 a	−9.4	2.8 a	−17.2				
	high	3.0 b	−2.3	2.4 b	16.3	3.7 b	8.5				
TASCO (1975)	low	2.8 a	4.4	2.7 a	−5.3	2.1 a	−18.2	3.2 a	−19.1	1.9 a	−33.8
	high	3.0 a	12.6	3.0 b	0.5	2.6 b	2.4	3.9 b	−1.3		
	L19	2.7 a		2.8 ab		2.5 b		3.9 b		2.9 b	

† Change compared with original parent for populations 25A1 and 25D47-48 and compared with L19 check for TASCO population.
* Values for each population and cycle followed by the same letter do not differ significantly at the 5% level of probability.

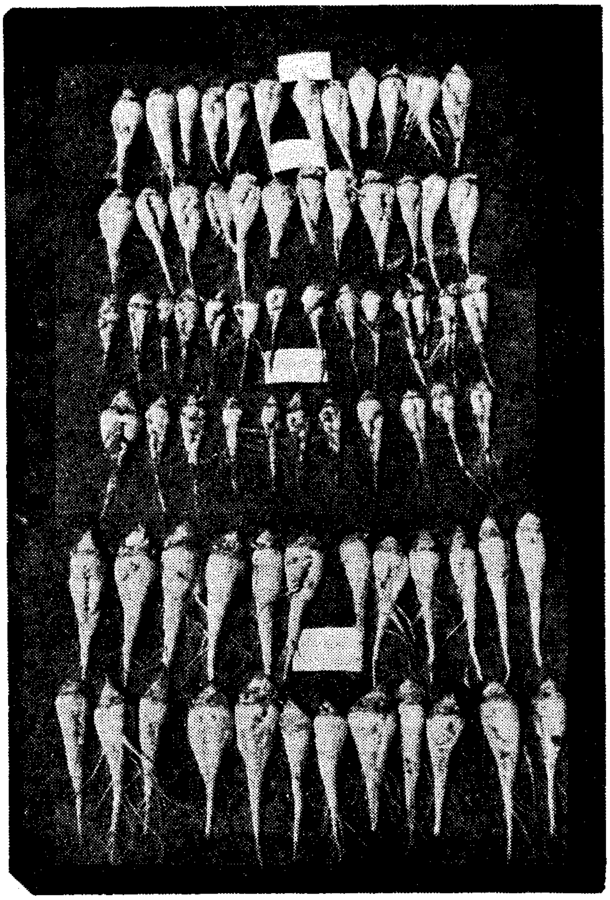

Fig. 1. Low-damage and high-damage sugarbeet root maggot selections in 1978. 40G3 = Low Damage 25D47.48 (Top); 40G5 = High Damage 25A1 (Center); 40G4 = Low Damage 25A1 (Bottom).

same rate when both populations are compared to L19 checks, the average being approximately 7% per cycle.

Experiment 4

A test on oviposition in the greenhouse (10) showed L89 receiving significantly more eggs than either L29 or L19. These results were confirmed by those of an additional test summarized in Table 5. At the higher rate of infestation (50 eggs per plant), L29 tended to have fewer maggots and significantly smaller maggots when compared to L89. The damage rating was significantly less and the root weight significantly greater for L29. In addition, root weight reduction over untreated checks was less for L29 (45%) than the L89 inbred (60%). The percentage of root weight reduction per maggot also was less for L29. At the lower rate of infestation (25 eggs per plant), trends were the same as for the higher rate of infestation for all measurements, but the differences often were less significant. Leaf weight and leaf area did not differ significantly at any rate of infestation. Both characters were reduced consistently as egg infestation levels increased but to a lesser extent on L29 than on L89. The L19 check tended to be intermediate for all measurements and not significantly different from L89.

The number of maggots produced per 100 eggs averaged over the three inbreds was 75.7 at the 25-egg level of infestation and 63.3 for the 50-egg level of infestation, or a difference of 12.4%. Maggots also were smaller at the higher level of infestation. This could be caused by either overcrowding or lack of food.

Because root weight, leaf weight, and leaf area did not differ significantly among the three untreated inbred lines, the differences in root weight associated with infestations

Table 5. Comparisons made in the greenhouse of sugarbeet inbred L29 (resistant), L89 (susceptible), and L19 (check) after infestation with sugarbeet root maggot eggs at three rates, Kimberly, Idaho, 1978.

Measurement	Egg infest. rate	Inbred		
		L29	L89	L19
No. maggots/plant	25	16.9 a*	19.8 a	19.9 a
	50	30.8 a	33.3 a	30.5 a
Maggot wt., mg	25	15.4 a	19.4 b	16.3 a
	50	13.1 a	16.3 b	16.0 b
Maggot length, mm	25	7.5 a	8.1 a	7.6 a
	50	7.0 a	7.7 b	7.6 b
Damage rating	25	1.6 a	2.8 b	2.4 b
	50	2.1 a	3.8 b	3.2 b
Root wt., g/plant	0‡	3.0 a	2.9 a	2.3 a
	25	2.0 (33) a†	1.5 (47) a	1.6 (34) a
	50	1.6 (45) a	1.1 (60) b	1.0 (58) b
Leaf wt., g/plant	0‡	3.1 a	3.5 a	3.3 a
	25	2.4 (21) a	2.7 (23) a	2.8 (15) a
	50	2.2 (27) a	1.9 (46) a	2.1 (36) a
Leaf area, cm^2	0‡	362 a	421 a	366 a
	25	338 (7) a	385 (8) a	355 (3) a
	50	329 (9) a	280 (10) a	285 (22) a

* Means (compared horizontally) with the same letter do not differ significantly at the 5% level.
† Values in parentheses are percent reduction from 0-egg level.
‡ 10 replicates; 20 replicates for others.

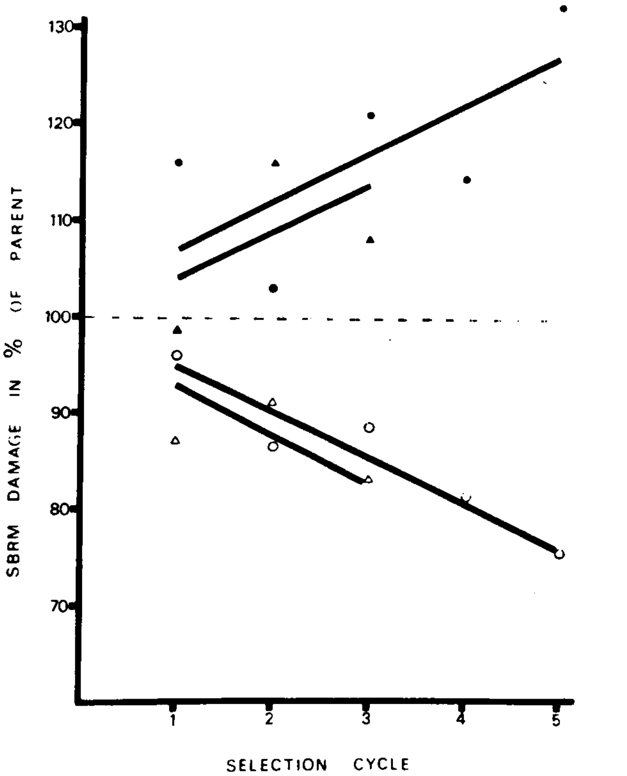

Fig. 2. Progress in selection for plant resistance and susceptibility to the sugarbeet root maggot, Kimberly, Idaho, 1976-1980.

in the greenhouse studies are considered to be real. Hence, results of greenhouse tests confirm the differences we observed among the inbred lines in damage ratings given previously under field conditions.

In conclusion, the results of field and greenhouse experiments have shown that genetic factors for resistance to the sugarbeet root maggot exist. Both tolerance and antibiois were indicated in the mechanism for resistance. After five cycles of selection, there was no evidence that the rate of decline in SBRM damage had changed, strongly indicating that further improvement can be made through selection and breeding.

ACKNOWLEDGMENT

We appreciate the cooperation and suggestions received from the plant breeding staff of The Amalgamated Sugar Company.

REFERENCES

1. Anonymous. 1980. Research News Report, AD-19, 14 Nov. 1980. Texas A & M Univ., Agric. Res. and Ext. Ctr. Amarillo, Tex.
2. Blickenstaff, C. C., R. E. Peckenpaugh, and G. G. Mahrt. 1977. Rating sugarbeets for damage by the sugarbeet root maggot. J. Am. Soc. Sugar Beet Technol. 19:188-191.
3. ----, Del Traveler, and D. C. Stallings. 1981. Insecticide tests for control of the sugarbeet root maggot, 1968-78. USDA Agric. Res. Results, Western Series, No. 18.
4. Harper, A. M. 1964. Varietal resistance of sugarbeets to the sugarbeet root ahid, *Pemphigus betae* Doane (Homoptera:Aphididae). Can. Entomol. 96:520-522.
5. Lange, W. H. 1971. Insects and mites and their control. p. 288-333. *In* R. T. Johnson, J. T. Alexander, G. E. Rush, and G. R. Hawkes (ed.) Advances in sugarbeet production. The Iowa State Univ. Press, Ames.
6. Lowe, H. J. B. 1974. Testing sugarbeet for aphid-resistance in the glasshouse: A method and some limiting factors. Z. Angew. Entomol. 76:311-321.
7. ----. 1975. Infestation of aphid-resistant and susceptible sugarbeet by *Myzus persicae* in the field. Z. Angew. Entomol. 79:376-383.
8. ----, and G. E. Russell. 1974. Probing by aphids in the leaf tissues of resistant and susceptible sugar beet. Entomol. Exp. Appl. 17:468-476.
9. Mahrt, G. G. 1978. Host plants of the sugarbeet root maggot *Tetanops myopaeformis* (Roder). M.S. Thesis, Utah State Univ., Logan.
10. ----, and C. C. Blickenstaff. 1979. Host plants of the sugarbeet root maggot, *Tetanops myopaeformis*. Ann. Entomol. Soc. Am. 72:627-631.
11. Maxwell, F. G., and P. R. Jennings. 1980. Breeding plants resistant to insects. John Wiley and Sons. New York.
12. McFarlane, J. S. 1954. New non-bolting and mildew-resistant seed releases. Proc. Am. Soc. Sugar Beet Technol. 8:88-89.
13. ----. 1971. Variety development. p. 402-435. *In* R. T. Johnson, J. T. Alexander, G. E. Rush, and G. R. Hawkes (ed.) Advances in sugarbeet production. The Iowa State Univ. Press, Ames.
14. Russell, G. E. 1965. Preliminary studies in breeding for aphid-resistance in beets. Proc. Instit. Int. Recherches Betteravieres 1:117-125, 28th Winter Congr., Brussels, Belgium.
15. Wallis, R. L., and J. O. Gaskill. 1963. Sugarbeet root aphid resistance in sugarbeet. J. Am. Soc. Sugar Beet Technol. 12:571-572.
16. ----, and J. E. Turner. 1968. Resistance of sugarbeets to sugarbeet root aphids, *Pemphigus populivenae* Fitch. J. Am. Soc. Sugar Beet Technol. 14:671-673.