Individual Plant Selection in Nematode-Infested Soil[1]

D. L. DONEY and E. D. WHITNEY[2]

Received for publication August 20, 1973

The sugarbeet nematode, *Heterodera schachtii* Schmidt., is one of the major pests of the sugarbeet, *Beta vulgaris* L. Several methods of selection for nematode resistance have been attempted (2, 4-10)[3] which have met with only limited success (2, 5, 6). One of the difficulties encountered in selection methods has been the large micro-variation in nematode populations and the resultant variation in infection. This variation has been sufficiently large to mask any real differences in resistance or tolerance (2).

This study was begun to reduce or control environmental variation so that real differences in resistance or tolerance to the sugarbeet nematode could be detected.

Materials and Methods

In 1968, a field relatively free of nematodes was selected for this study. Holes two feet apart, 10 per plot were dug with a posthole digger. The plots were infected by filling these 6-inch-diameter, 4-inch-deep holes with uniformly mixed nematode-infested soil (230 viable cysts per 100 g soil). Eight heterozygous lines, a uniform hybrid, and an inbred were planted in each plot, one to a hole. Lines were randomized within each of the 144 replications. Seed was planted directly into the nematode soil; seedlings were later thinned to one plant per hole. At harvest, roots were cone topped, numbered, weighed, and sampled for sucrose analysis.

Means and variances for each line were calculated for root yield, sugar percentage, and gross sugar. A small correlation between the mean and variance for root yield and gross sugar was present. Because 8 of the 10 lines were segregating populations, transformation of the data was not desirable. This relationship was removed by the use of the regression of variances on means from the two non-segregating lines (inbred and uniform hybrid) (3). This regression was used to estimate the environmental variances of the segregating lines. Genetic

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[1]Cooperative investigations of the Agricultural Research Service, U. S. Department of Agriculture; the Beet Sugar Development Foundation; and the Utah Agricultural Experiment Station, Logan, Utah.

[2]Research Geneticist, Agricultural Research Service, USDA, Crops Research Lab, Utah State University, Logan, Utah 84322; and Research Plant Pathologist, Agricultural Research Service, USDA, P.O. Box 5098, Salinas, California 93901.

[3]Numbers in parentheses refer to literature cited.

variances were estimated by subtracting the estimated environmental variance from the total variance of each segregating line.

Broad sense heritabilities were calculated from these variances for root yield, sugar percentage, and gross sugar of each segregating line (Table 1). From these estimates, lines Acc 107, D2, B889, and RW 467 were picked as having the greatest selection potential for increased yield and gross sugar. Lines 590-1 and 590-9 carried curly top resistance and were also included for selection.

For each of the above lines, genetic deviate probabilities were placed on each root for root yield, sugar percentage, and gross sugar. These probabilities were obtained from a standard t table and are the probabilities of each individual beet differing from the mean of the parent line. A part of these probabilities for line D2 is shown in Table 2. Roots with high probabilities for root yield and gross sugar and not differing from the parent in sugar percentage were selected from each line.

Seed from each selected root was produced in 1969. Because all plants were self-sterile, roots from each line were planted in a separate crossing block and allowed to interpollinate within lines. Seed was harvested separately from each plant.

Field tests were conducted for selections of lines Acc 107 and RW 467 at Salinas, California, in 1970 and for selections of lines 590-1 and 590-9 at Farmington, Utah, in 1970 and 1971. Selections of lines D2 and B889 produced insufficient seed for field testing. The test at Salinas, California, was in nematode-infested soil, whereas the tests at Farmington, Utah, were in soil free of nematodes. Parental lines were included in all field tests. All tests were in a randomized block design.

Probabilities were computed for each selection relative to its parental line. The probabilities of the original root selections (predicted probabilities) were calculated from an adjusted mean of each selection tested relative to its parental mean.

Table 1.—Broad sense heritability estimates for root yield, sugar percentage, and gross sugar for each segregating line.

Lines	Source	Root Yield	% Sugar	Gross Sugar
B889	G.W. Sugar Co.	46	63	40
Acc 107	G. J. Curtis (England)	42	63	33
D2	Poland	40	53	44
590-9	USDA	36	34	04
590-1	USDA	34	61	05
C877	G.W. Sugar Co.	26	69	26
RW467	H. Reitberg (The Netherlands)	23	51	35
L24	USDA	15	51	27

Table 2.—A portion of the D2 population showing the probabilities for individual beets for root yield, sugar percentage, and gross sugar.

Beet Number	Root Yield	% Sugar	Gross Sugar
1	.005	−.005	.005
2	.5	.2	.2
3	.01	.5	.005
5	.2	.05	.05
6	.05	.5	.05
7	.5	.5	.5
9	.005	−.05	.05
10	.005	−.2	.01
11	−.1	.5	−.1
13	.05	.1	.0005
14	−.2	.5	−.1
15	.5	.1	.5
16	.05	.5	.05
18	−.05	.2	−.05
19	−.2	.05	.5
20	.5	−.01	−.2

*This table can be read (using beet number 10 as an example) as follows: The probability of another beet having a sugar percentage as low or lower than that of beet No. 10 by chance alone is .2 (2 out of 10); of it having a root yield as large or larger than that of beet No. 10 by chance alone is .005 (5 out of 1,000); and of its having as much or more gross sugar than beet No. 10 by chance alone is .01 (1 out of 100).

The adjusted mean for each selection was calculated as follows:

$$\text{adjusted mean} = \sum_{i=1}^{n} \frac{X_{ij}}{n} + \frac{X_j}{2}$$

where n = the number of selections within the crossing block,
X_{ij} = yield of the ith selection in the crossing block of which the jth selection was present
X_j = yield of the jth selection

The assumption was made that each of the pollinators within the crossing block contributed pollen equally.

Results

All selections yielded more than their respective parents in root yield and gross sugar (Tables 3, 4, and 5). However, yields of some of the individual selections were not significantly larger than their parents (Table 6). There was little difference in sugar percentage between the parents and selections. This confirms the fact that selection was not for increased sugar percentage, but to maintain the parental sugar percentage. Selections outyielded their parents in both soil types. Thus, selection increased vigor and yield potential, whether the soil was nematode infested or nematode free.

The probabilities of the original root selections (predicted probabilities) and the resultant progenies (actual probabilities) are

Table 3.—Root yields, sugar percentage, and gross sugar of selections and parents. Trial was conducted in 1970 at Salinas, California, in nematode-infested soil.

Selection No.	Parent	Root yield Tons/acre	% Sugar	Gross sugar lb/acre
0104	RW 467	18.9	15.2	5,789
1503	RW 467	18.2	15.5	5,621
5801	RW 467	17.8	15.6	5,574
3809	RW 467	17.6	15.4	5,434
RW 467		16.0	15.2	4,872
5806	Acc 107	17.5	14.2	4,938
4502	Acc 107	15.7	15.0	4,751
5409	Acc 107	15.1	13.3	4,237
3810	Acc 107	14.9	14.9	4,424
Acc 107		14.2	14.1	4,059
LSD .05		3.0	0.8	973

Note RW 467 was a nematode resistant selection obtained from Henk Rietberg, the Netherlands. Acc 107 was a mixture of nematode selections obtained from G. J. Curtis, Cambridge, England.

Table 4.—Root yields, sugar percentage, and gross sugar of selections and parents. Trial was conducted in 1970 at Farmington, Utah, in nematode-free soil.

Selection No.	Parent	Root yield Tons/acre	% Sugar	Gross sugar lb/acre
2006	590-1	33.5	15.1	10,144
6805	590-1	31.3	16.4	10,230
0109	590-1	29.1	15.5	9,042
590-1		29.1	15.2	8,826
5407	590-9	37.2	15.2	11,302
4809	590-9	36.2	15.2	11,018
3804	590-9	35.6	14.9	10,603
7701	590-9	31.4	15.3	9,781
590-9		28.9	16.1	9,289
LSD .05		4.8	0.6	1,496

Note Lines 590-1 and 590-9 are nematode resistant selections made by Charles Price, USDA.

Table 5.—Root yield, sugar percentage, and gross sugar of selections and parents. Trial was conducted in 1971 at Farmington, Utah, in nematode-free soil.

Selection No.	Parent	Root yield tons/acre	% Sugar	Gross sugar lb/acre
0707	590-1	37.9	14.0	10,575
2006	590-1	37.9	13.3	10,084
6805	590-1	37.4	13.6	10,151
0109	590-1	37.4	13.9	10,406
4405	590-1	36.1	13.7	9,854
590-1		35.4	13.3	9,404
4809	590-9	42.3	13.5	11,408
3804	590-9	39.1	13.5	10,586
7701	590-9	37.3	13.8	10,283
590-9		37.5	13.4	10,096
LSD .05		2.5	0.5	837

given in Table 6. These probabilities are for the superiority of the selections over their respective parent mean.

The actual probabilities are not as high as the original probabilities (Table 6). This could be the result of an overestimation of the genetic variance or an underestimation of environmental variation in the original selections. There was, however, a close agreement between the two probabilities; i.e., a high predicted probability resulted in a high actual probability and vice versa (Table 6). A highly significant correlation of .73 was obtained between the two probabilities for individual selections.

Predicted genetic advance (1) was not calculated for several reasons; first, selection was based on probabilities and not on a predetermined percentage; second, not all selections were tested; and third, the predicted advance for 1 year at one location could not be compared with actual gains measured another year at another location because of differences in means and variances. Probabilities are based on the variances and means relative to the parental line and are therefore comparable.

This use of probabilities can be extended to other types of selection pressure. Under most types of selection schemes, the plant breeder is faced with the problem of selecting genetically superior plants (genetic deviates). When environmental variances are large relative to genetic variances, they can mask genetic deviates. In such situations, selection by individual plant weights will produce mostly environmental deviates. The use of probabilities can overcome this problem by giving the breeder assurance of selecting genetically superior genotypes.

Space planting in the field in uniformly mixed nematode-infested soil reduced the environmental variation such that genetically superior

Table 6.—Means of parents and selections, and actual and predicted probabilities for root yield, sugar percentage, and gross sugar.

Measurement	590-1		590-9		Acc 107	RW 467
	1970	1971	1970	1971	1970	1970
Root yield						
Selections $\bar{x}$	31.3	37.3	35.1	39.6	15.8	18.1
Parent $\bar{x}$	29.1	35.4	28.9	37.4	14.2	16.0
Actual Prob.	.18	.06	.001	.04	.18	.07
Predicted Prob.	.03	.02	.01	.01	.04	.01
% Sugar						
Selections $\bar{x}$	15.7	13.7	15.2	13.6	14.4	15.4
Parents $\bar{x}$	15.2	13.3	16.1	13.4	14.1	15.2
Actual Prob.	.35	.06	.60	.35	.45	.50
Predicted Prob.	.50	.50	.40	.30	.50	.10
Gross Sugar						
Selections $\bar{x}$	9,805	10,214	10,676	10,758	4.592	5,605
Parents $\bar{x}$	8,826	9,404	9,289	10,095	4.059	4,872
Actual Prob.	.08	.015	.01	.06	.15	.06
Predicted Prob.	.02	.02	.001	.001	.02	.001

genotypes could be detected. Yields, however, were increased in nematode-free as well as in nematode-infested soil. These increased yields suggest that selection resulted in overall plant vigor rather than nematode tolerance.

Summary

Selection for nematode tolerance in the sugarbeet was carried out in a space-planted field trial in which seed was planted directly into uniformly mixed nematode-infested soil. Selection was based on individual plant probabilities rather than raw data. Progeny tests were conducted in nematode-infested and nematode-free soil in 1970 and 1971. Selections outyielded their parents in all tests. Actual probabilities (from the progeny trials) were in the same relationship as the predicted probabilities of the original selections. Environmental variation was reduced, allowing selection of superior genotypes. Selection resulted in increased overall plant vigor. The use of probabilities as a selection procedure gives the breeder assurance of selecting genetically superior genotypes.

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