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EFFECTIVENESS OF SELECTION METHODS FOR YIELD IN SOYBEAN CROSSES

by

Robert Lee Voigt

A Dissertation Submitted to the
Graduate Faculty in Partial Fulfillment of
The Requirements for the Degree of
DOCTOR OF PHILOSOPHY

Major Subject: Crop Breeding

Approved:

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1959

INTRODUCTION

Most present commercial soybean varieties are the result of reasonably homozygous lines selected from the hybridization of two or more strains or varieties. Hybridization and recombination of genetic factors controlling desirable attributes is necessary in any crop to obtain genetically variable populations from which to make superior selections. It is generally desirable to isolate segregates suitable in all attributes as early in the breeding program as the rate of approach to homozygosity will permit. A self-fertilized crop, such as soybeans, has a rapid rate of approach to homozygosity that will vary among characters according to the number of controlling genes and linkage.

Effectiveness of selection for seed yield is perhaps one of the foremost and difficult problems in the breeding of soybeans and many other crops. If a particular breeding procedure is more effective than others on some characters, it is obvious that time and effort may be used most efficiently in testing a maximum number of desirable and a minimum number of undesirable selections.

The first of three objectives of this study was to evaluate a method of early generation testing for seed yield with concurrent phenotypic spaced-plant selection with the standard bulk and pedigree methods of breeding. The second objective was to apply these three methods to five hybrid soybean crosses to test for interactions of methods with genetic populations. The last objective was to obtain superior high yielding selections suitable in maturity, height, and lodging.

LITERATURE REVIEW

Various forms of early generation testing for seed yield in soybeans have given variable results.

Kalton (3) found no significant correlations among the yields of F_2 plants and their F_3 and F_4 lines from four soybean crosses, nor were the yields of the bulk populations consistent for the same generations and crosses. He concluded that neither the bulk nor the pedigree method of early generation testing for yield, as used, was very reliable for estimating the yield potentialities of the four soybean crosses, at least before the F_4 generation. He found maturity and height determinations on single plants from early segregating generations to be generally useful for predicting the performance of progeny from single plants. Yield and lodging of single plants were of moderate to poor value for selection purposes.

Patel (8) through graphical presentation showed correlation among yields of F_2 single plants, F_3 rows, F_3 single plants and F_4 row yields. Weatherspoon (14) found no significant yield correlation for F_7 plants, their F_8 single rows, and subsequent F_9 replicated plots and concluded that single-plant and single-row yield data were practically useless from the standpoint of selection.

Mahmud and Kramer (6) found little association for seed yield in soybeans of F_3 lines and their F_4 selections when different spacing and seasons were involved. They reported a high association of F_4 bulks and their F_3 progenitors when tested in the same year under the same conditions and reasoned that F_3 lines would provide good estimates of their F_4 yield if genetic shift and interactions of generations with environmental factors were controlled.

Weiss, Weber, and Kalton (18) reported maturity date determinations for spaced F_2 plants were highly indicative of the maturity of subsequent progenies. Yield determinations gave moderate estimates and lodging scores poor estimates of progeny performance. Replicated progeny tests of F_2 and F_3 plants provided reliable prediction values for maturity, plant height, and lodging resistance. They found fewer significant yield differences in the F_4 than in the F_3 for paired selections from 51 lines. They reasoned that factors conditioning yield appeared to have attained a high degree of fixation in the F_4 generation and retention of more than one selection from an F_4 line would not seem justifiable.

Weiss (17) summarized the results of early generation testing of soybeans with the observations that F_3 line tests permit effective selection among lines for maturity, height, and lodging. The F_3 lines were poor and the F_4 lines moderate in predictive value for yield of subsequent selections.

The essential features and procedures of the standard bulk and pedigree systems of plant breeding in self-fertilized crops were reviewed by Hayes, Immer, and Smith (2) and Love (5).

Investigations by Harlan and Martini (1) with barley and Laude and Swanson (4) with winter wheat showed a rapid elimination for the less adapted varieties when grown in varietal mixtures in successive years. Suneson and Wiebe (12) and Suneson (11) reported that high yield of a pure line was no assurance of its ability to survive in a heterogeneous bulk population. Mumaw and Weber (7) found the same true for soybeans with the better competitive varieties in simulated bulk populations possessing taller height, later maturity, more lodging, and greater branching habit.

Torrie (13) found few significant differences for seed yield and no differences for plant height and lodging index in a comparison of F_6 lines selected by the bulk and pedigree methods in six soybean crosses. He reasoned that the nonsignificant difference in mean lodging indices between lines selected by the two procedures indicated that as much progress could be made in selecting for this character in one year compared to several years, providing differential lodging occurs. Bulk selections averaged one to four days later in maturity than the pedigree selections.

Raeber and Weber (9) found no difference in the F_6 generation between the average performance of selections developed using the bulk and pedigree methods for seed yield, plant height, and lodging resistance in four soybean crosses. They did note appreciable genic fixation for yield in the F_4 generation. They suggested that the greatest genetic advance for seed yield could be made by testing lines in replicated trials in the F_3 and subsequent generations and simultaneously selecting phenotypically superior plants grown in a space-planted nursery. Based on the agronomic performance of replicated drilled-plantings, phenotypically selected spaced-plants would form the materials for testing the next generation.

MATERIALS AND METHODS

Segregating populations from five hybrid crosses involving five soybean varieties were utilized in three selection procedures for seed yield, maturity, height, and lodging to evaluate the procedures. The five varieties used in the crosses in order of maturity from early to late were Harosoy, Hawkeye, Adams, Lincoln, and Clark. These parents were selected for their high yield and other desirable agronomic characteristics. All varieties differed in maturity by about three days with the exception of Clark which was seven days later than Lincoln. Hawkeye was best adapted for general agronomic performance and was utilized as the check variety. All selections in the three procedures were made for Hawkeye maturity.

All crosses, selections, and evaluations were made at Ames, Iowa. The five crosses made in 1952 were as follows:

Cross	Parentage
AX50	Hawkeye x Clark
AX55	Hawkeye x Harosoy
AX56	Adams x Harosoy
AX57	Lincoln x Harosoy
AX58	Harosoy x Clark

The F_1's were grown in 1953 and the seed kept in cold storage until the F_2 generation was grown in 1955. Seventy-five F_2 plants were selected from each cross in 1955 from three-inch, spaced plantings. Seed of each of the 75 F_2 single plants per cross was divided so that each of the three selection procedures used subsequently was operating on the same genetic germ plasm base.

The bulk method of breeding, referred to as method B, consisted of compositing two seeds from each of the selected 75 F_2 plants per cross. This composite for each cross was grown as a bulk population through the F_3 (1956) and F_4 (1957) generations. The F_4 bulk populations were thinned to four-inch spacing between plants after emergence and again in July by selecting for Hawkeye flowering time. At maturity, 20 single plants were selected in each cross with good phenotypic agronomic expression and Hawkeye maturity. These selections formed method B materials for evaluation in F_5 replicated tests to compare with other selection methods.

The remaining seed from each F_2 plant was planted in a twelve-foot F_3 plant row. The first half of each row was used for selecting three agronomically desirable plants with Hawkeye maturity for the pedigree method of breeding, referred to as method P. These selections were planted in twelve-foot F_4 plant rows with the first four feet drilled for observation and line selection purposes. The last eight feet was space-planted eight inches apart for concurrent plant selection and for seed purposes. Agronomically desirable F_4 plants with Hawkeye maturity were selected from the spaced portion so that each of the 20 lines selected within each cross traced to a different F_2 plant. These selections formed method P materials for evaluation in F_5 replicated tests to compare with the other two selection methods.

Three agronomically desirable F_3 plants with the maturity of Hawkeye were selected from the second half of each F_3 plant row mentioned above for the family method of breeding, referred to as method F. Each of the three plants from each F_3 row (F_3 family) was used as a "replicate" in an F_4 test. A randomized complete block design was employed for each cross with 60 families and four Hawkeye checks. All entries were drilled in eight-foot rows 40 inches apart. The three F_4 plant rows from an F_3 line were considered as three replications representing the average yield and performance of the F_3 line (F_3 family) tracing to an F_2 plant.

On the basis of the F_4 test in method F, 20 highest yielding F_3 families were selected within each cross with maturity approximating Hawkeye. One F_4 plant selection was made from each replicate in each family and cross, but only the plant selected from the highest yielding replicate of each selected family was utilized as method F material for evaluation in F_5 replicated tests to compare with selection methods B and P in 1958.

The 20 F_4 plants selected in each of the methods B, P, and F in each cross were arranged for the F_5 test in a compact randomized complete block design together with four Hawkeye entries. All 64 entries per cross were randomized, then crosses were randomized. Three replications were used with each entry drilled in eight-foot rows 40 inches apart.

The characters were evaluated by the following methods:

<u>Yield</u> Seed was air-dried to uniform moisture before weighing. Plot yields were recorded in grams and converted to bushels per acre.

<u>Maturity</u> Plants or plots were considered mature when 95 to 100 per cent of the pods had turned brown. Maturity was recorded as the

number of days after August 31.

Height Measured in inches on mature rows from the ground level to the highest part of the main stem.

Lodging After maturity, progeny rows were scored from one, where most plants in a row were almost erect, to five, where most plants were prostrate.

During the course of this study (1955-1958), all plantings were made in May. All plots were kept weed-free. Early fall frost did not interfere with normal maturity and harvesting was completed on time under generally good conditions.

Standard statistical procedures were used throughout the course of this investigation.

EXPERIMENTAL RESULTS

There was reasonably good agronomic expression of maturity, height, and lodging for selection purposes in 1955 in spite of some dry weather. In 1956, continued dry conditions further depleted the supply of subsoil moisture and caused subnormal plant growth. This made it more difficult to make plant selections for methods P and F and still maintain the expected accuracy of selection for such highly heritable characters as maturity and height.

In 1957, ample moisture and temperature permitted good growth response and normal expression of agronomic characters. This environment facilitated selection of F_4 plants in methods B, P, and F. In addition, the 1957 season was conducive for good expression of yield, maturity, height, and lodging on all entries in the F_4 test of method F.

The analyses of variance, means and coefficients of variation for characters in each cross in the F_4 test of method F, excluding Hawkeye checks, are given in Table 1.

The magnitudes of the replication variances differed considerably among crosses for all characters. These replication variances among F_4 sister lines from F_3 families may be partially genetic in nature because each F_4 sister line within a family was a "replicate". The mean squares for F_3 families within crosses were generally large and similar among crosses within characters. The error terms (replications x families) for all characters and crosses were slightly larger than expected, probably due in part to the genetic variation among replications. AX57 had the largest error term for all characters and

Table 1. Analyses of variance, means, and coefficients of variation for yield, maturity, height, and lodging of F_4 sister lines (F_3 families) in five crosses for method F test in 1957

Source of variation	D.F.	Mean squares AX50	AX55	AX56	AX57	AX58
			Yield			
Reps. (lines)	2	427.70**	281.18**	90.00*	28.70	3.96
Families	59	19.96*	33.43**	34.96*	47.90**	30.48
Reps. x fams. (error)	118	13.78	16.80	22.09	26.67	25.93
Mean (bu./A.)		57.0	55.9	56.2	55.8	56.3
Coefficient of variation (%)		6.5	7.3	8.4	9.2	9.0
			Maturity			
Reps. (lines)	2	12.06*	46.00**	10.42	6.29	11.82
Families	59	17.44**	11.76**	11.47**	21.32**	19.00**
Reps. x fams. (error)	118	3.90	3.25	3.98	9.84	7.13
Mean (days)		26.4	26.7	28.0	30.1	27.0
Coefficient of variation (%)		7.5	6.8	7.1	10.4	9.9
			Height			
Reps. (lines)	2	42.52**	43.12**	18.96*	22.32*	105.02**
Families	59	22.36**	12.36**	10.29**	18.32**	15.77**
Reps. x fams. (error)	118	4.88	3.94	5.38	7.15	5.21
Mean (inches)		41.5	44.3	46.8	45.7	42.6
Coefficient of variation (%)		5.3	4.5	5.0	5.8	5.4
			Lodging			
Reps. (lines)	2	.22*	.20*	.06	.56*	.38*
Families	59	.10**	.12**	.10**	.43**	.14
Reps. x fams. (error)	118	.05	.06	.06	.12	.11
Mean (score)		1.7	1.9	2.1	2.1	1.9
Coefficient of variation (%)		12.7	13.4	11.5	16.8	16.9

*F value exceeds 5% level.

**F value exceeds 1% level.

consequently the largest coefficient of variation for all characters with the exception of lodging. The coefficients of variation were reasonably uniform among the crosses within characters. AX57 had the lowest average yield, latest maturity, and largest lodging score.

Correlation coefficients were computed for yield and maturity in each cross. All correlations were highly significant, but AX57 was the smallest, as might be expected from its performance of the lowest yield and latest maturity.

The analyses of variance, means, and coefficients of variation for characters of F_4 sister lines combined for all crosses are given in Table 2. The corresponding analyses of variance for the Hawkeye checks, analyzed separately, are also given in Table 2. All variances for all characters of Hawkeye were non-significant and smaller than corresponding variances for lines. This would indicate that significant sources of variation for lines were of a genetic nature.

The non-significant variance among crosses for seed yield was only slightly larger than the corresponding variance for Hawkeye. This showed that differences among cross yields for lines were essentially the same as Hawkeye. A highly significant difference existed among crosses for maturity, height, and lodging of lines. A highly significant variance was shown among families in crosses for all characters. This variance was a measure of the genetic differences among F_3 families resulting from F_2 plants. These genetic differences for any character are necessary for the selection of lines superior for that character.

The mean of all crosses averaged essentially the same as Hawkeye in yield, height, and lodging, but was two days later in maturity than

Table 2. Analyses of variance, means, and coefficients of variation for yield, maturity, height and lodging of F_4 sister lines (F_3 families) combining crosses in method F test in 1957

Source of variation	D.F.	Mean Squares: Yield	Maturity	Height	Lodging
		Lines			
Reps. (lines)	2	43.61	24.89	86.48	.20
Crosses	4	37.21	407.19**	834.23**	4.57**
Reps. x crosses (error a)	8	196.98	15.43	36.36	.30
Families in crosses	295	33.35**	16.20**	15.82**	.18**
Families in AX50	59	19.96*	17.44**	22.36**	.10**
Families in AX55	59	33.43**	11.76**	12.36**	.12**
Families in AX56	59	34.96*	11.47**	10.29**	.10**
Families in AX57	59	47.90**	21.32**	18.32**	.43**
Families in AX58	59	30.48	19.00**	15.77**	.14
Reps. x fams. in crosses (error b)	590	21.05	5.62	5.31	.08
Reps. x fams. in AX50	118	13.78	3.90	4.88	.05
Reps. x fams. in AX55	118	16.80	3.25	3.94	.06
Reps. x fams. in AX56	118	22.09	3.98	5.38	.06
Reps. x fams. in AX57	118	26.67	9.84	7.15	.12
Reps. x fams. in AX58	118	25.93	7.13	5.21	.11
Mean		56.2	27.7	44.2	1.9
Coefficient of variation (%)		8.2	8.6	5.2	14.6
		Hawkeye checks			
Reps. (lines)	2	38.18	.62	8.72	.04
Crosses	4	29.87	1.89	.86	.03
Reps. x crosses (error a)	8	29.85	1.18	4.51	.06
Families in crosses	15	11.15	.66	3.63	.06
Reps. x fams. in crosses (error b)	30	7.27	.62	2.22	.04
Mean		56.4	25.6	44.0	1.6
Coefficient of variation (%)		4.8	3.1	3.4	12.3

*F value exceeds 5% level.

**F value exceeds 1% level.

Hawkeye. The coefficient of variation for each character of the F_4 sister lines exceeded that of Hawkeye. This was expected due to the higher error terms for lines.

The 1958 season was conducive for good expression of agronomic characters evaluated on F_5 lines selected by methods B, P, and F in the five crosses.

The analyses of variance, means, and coefficients of variation for yield, maturity, height, and lodging of lines selected within each method in the five hybrid populations are presented in Tables 3, 4, 5, and 6. There were no significant differences among selection methods for seed yield within any of the five crosses. Lines in methods F, B, and P, combining all crosses, yielded 45.1, 44.5, and 44.2 bushels per acre, respectively. Methods were significantly different for maturity and height in four crosses and for lodging in all five crosses. The one day's difference in maturity among methods was considered inconsequential. Lines in methods F, P, and B, combining all crosses, had heights of 40.9, 41.4, and 42.1 inches and lodging scores of 2.5, 2.6, and 2.9, respectively.

There was a lack of constancy for the magnitudes of replication variances for methods within crosses and for combined methods among crosses in all characters. There was reasonable uniformity of error mean squares and of coefficients of variation among selection methods within crosses for all agronomic characters.

The analysis of variance combining methods and crosses for each character is given in Table 7. On an individual degree of freedom basis, the mean yield of lines selected by method F exceeded the five

Table 3. Analyses of variance, means, and coefficients of variation for yield of F_5 lines from three selection methods in five crosses in 1958

Source of variation	D.F.	Mean squares: Method B	Method P	Method F	Combined methods
		AX50			
Replications	2	3.06	22.04	47.60*	6.02
Methods	2				44.86
Replications x methods	4				33.34
Lines	19	38.92**	26.16	35.78**	
Lines in methods	57				33.62**
Replications x lines	38	10.01	15.02	12.80	
Reps. x lines in methods	114				12.61
Mean (bu./A.)		44.1	44.5	45.7	44.8
Coefficient of variation (%)		7.2	8.7	7.8	7.9
		AX55			
Replications	2	174.21**	291.64**	178.20**	614.85**
Methods	2				65.19
Replications x methods	4				14.61
Lines	19	22.65	46.73**	31.46	
Lines in methods	57				33.61**
Replications x lines	38	14.34	16.98	21.97	
Reps. x lines in methods	114				17.76
Mean (bu./A.)		44.7	45.6	46.7	45.6
Coefficient of variation (%)		8.5	9.0	10.0	9.2
		AX56			
Replications	2	69.37*	1.62	18.98	50.19*
Methods	2				21.83
Replications x methods	4				19.89
Lines	19	29.37*	34.42**	28.10**	
Lines in methods	57				30.63**
Replications x lines	38	15.56	12.01	10.93	
Reps. x lines in methods	114				12.83
Mean (bu./A.)		45.0	43.9	44.8	44.6
Coefficient of variation (%)		8.8	7.9	7.4	8.0
		AX57			
Replications	2	303.74**	116.81**	246.36**	586.06**
Methods	2				31.64
Replications x methods	4				40.42
Lines	19	63.11**	64.83**	45.79**	
Lines in methods	57				57.91**
Replications x lines	38	11.58	9.32	10.92	
Reps. x lines in methods	114				10.61
Mean (bu./A.)		43.1	41.8	43.0	42.6
Coefficient of variation (%)		7.9	7.3	7.7	7.6
		AX58			
Replications	2	87.41**	121.44**	241.13**	412.20**
Methods	2				6.46
Replications x methods	4				18.89
Lines	19	39.26**	65.31**	25.65	
Lines in methods	57				43.41**
Replications x lines	38	9.28	12.90	16.10	
Reps. x lines in methods	114				12.76
Mean (bu./A.)		45.8	45.2	45.3	45.5
Coefficient of variation (%)		6.6	7.9	8.8	7.8
Grand mean (bu./A.)		44.5	44.2	45.1	44.6

*F value exceeds 5% level.

**F value exceeds 1% level.

Table 4. Analyses of variance, means, and coefficients of variation for maturity of F_5 lines from three selection methods in five crosses in 1958.

Source of variation	D.F.	Mean squares: Method B	Method P	Method F	Combined methods
		AX50			
Replications	2	.45	.32	.02	.52
Methods	2				21.66**
Replications x methods	4				.14
Lines	19	6.58**	14.44**	5.60**	
Lines in methods	57				8.87**
Replications x lines	38	.62	1.47	1.17	
Reps. x lines in methods	114				1.09
Mean (days)		25.2	26.3	25.5	25.6
Coefficient of variation (%)		3.1	4.6	4.2	4.1
		AX55			
Replications	2	43.46**	20.22**	16.22**	75.12**
Methods	2				38.60*
Replications x methods	4				2.39
Lines	19	18.06**	15.97**	24.79**	
Lines in methods	57				19.60**
Replications x lines	38	2.84	2.44	2.08	
Reps. x lines in methods	114				2.45
Mean (days)		27.9	27.2	28.8	28.0
Coefficient of variation (%)		6.0	5.7	5.0	5.6
		AX56			
Replications	2	1.85	5.60	1.66	6.80
Methods	2				4.54
Replications x methods	4				1.16
Lines	19	35.58**	44.50**	28.47**	
Lines in methods	57				36.18**
Replications x lines	38	4.25	1.95	1.58	
Reps. x lines in methods	114				2.59
Mean (days)		29.1	28.6	28.8	28.8
Coefficient of variation (%)		7.1	4.9	4.4	5.6
		AX57			
Replications	2	22.32**	8.75**	4.85	31.09**
Methods	2				71.21**
Replications x methods	4				2.41
Lines	19	16.37**	31.14**	48.42**	
Lines in methods	57				31.98**
Replications x lines	38	2.76	1.38	2.34	
Reps. x lines in methods	114				2.16
Mean (days)		26.2	24.4	26.3	25.6
Coefficient of variation (%)		6.3	4.8	5.8	5.7
		AX58			
Replications	2	3.52*	4.05*	4.55*	11.50**
Methods	2				11.90**
Replications x methods	4				.30
Lines	19	4.67**	19.64**	6.19**	
Lines in methods	57				10.17**
Replications x lines	38	.71	1.00	1.02	
Reps. x lines in methods	114				.91
Mean (days)		24.4	25.2	25.2	24.9
Coefficient of variation (%)		3.4	4.0	4.0	3.8
Grand mean (days)		26.6	26.3	26.9	26.6

*F value exceeds 5% level.

**F value exceeds 1% level.

Table 5. Analyses of variance, means, and coefficients of variation for height of F_5 lines from three selection methods in five crosses in 1958

Source of variation	D.F.	Mean squares: Method B	Method P	Method F	Combined methods
		AX50			
Replications	2	22.82**	28.46**	8.12	55.10**
Methods	2				55.70**
Replications x methods	4				2.15
Lines	19	11.27**	7.46**	20.86**	
Lines in methods	57				13.19**
Replications x lines	38	1.55	1.43	2.59	
Reps. x lines in methods	114				1.86
Mean (inches)		41.2	41.0	39.5	40.6
Coefficient of variation (%)		3.0	2.9	4.1	3.4
		AX55			
Replications	2	27.52**	15.35*	36.20**	69.24**
Methods	2				35.70*
Replications x methods	4				4.92
Lines	19	5.00	6.16*	8.75**	
Lines in methods	57				6.64**
Replications x lines	38	4.41	3.16	3.38	
Reps. x lines in methods	114				3.65
Mean (inches)		42.7	41.4	41.4	41.8
Coefficient of variation (%)		4.9	4.3	4.4	4.6
		AX56			
Replications	2	9.80*	1.55	6.02	13.34**
Methods	2				5.28
Replications x methods	4				2.01
Lines	19	8.35**	8.35**	6.54*	
Lines in methods	57				7.74**
Replications x lines	38	2.08	1.86	3.10	
Reps. x lines in methods	114				2.35
Mean (inches)		42.9	42.7	43.3	43.0
Coefficient of variation (%)		3.4	3.2	4.1	3.6
		AX57			
Replications	2	12.62*	36.86**	23.32**	66.27**
Methods	2				59.60**
Replications x methods	4				3.26
Lines	19	8.98*	8.92**	11.10**	
Lines in methods	57				9.67**
Replications x lines	38	3.76	2.15	1.88	
Reps. x lines in methods	114				2.59
Mean (inches)		41.8	40.4	39.8	40.7
Coefficient of variation (%)		4.6	3.6	3.4	4.0
		AX58			
Replications	2	25.02**	4.05	19.35**	40.68**
Methods	2				38.10*
Replications x methods	4				3.86
Lines	19	9.61*	7.48**	18.09**	
Lines in methods	57				11.73**
Replications x lines	38	4.79	2.17	2.49	
Reps. x lines in methods	114				3.15
Mean (inches)		42.1	41.4	40.5	41.3
Coefficient of variation (%)		5.2	3.6	3.9	4.3
Grand mean (inches)		42.1	41.4	40.9	41.5

*F value exceeds 5% level.

**F value exceeds 1% level.

Table 6. Analyses of variance, means, and coefficients of variation for lodging of F_5 lines from three selection methods in five crosses in 1958

Source of variation	D.F.	Mean squares: Method B	Method P	Method F	Combined methods
		AX50			
Replications	2	.80**	3.27**	1.64**	5.25**
Methods	2				7.49**
Replications x methods	4				.23
Lines	19	.45**	.47*	.56**	
Lines in methods	57				.49**
Replications x lines	38	.11	.22	.14	
Reps. x lines in methods	114				.16
Mean (score)		2.8	2.5	2.1	2.4
Coefficient of variation (%)		11.9	18.8	18.0	16.3
		AX55			
Replications	2	1.22**	2.43**	.84**	4.25**
Methods	2				3.16**
Replications x methods	4				.12
Lines	19	.58**	.74**	1.22**	
Lines in methods	57				.85**
Replications x lines	38	.14	.23	.14	
Reps. x lines in methods	114				.17
Mean (score)		3.1	2.6	2.7	2.8
Coefficient of variation (%)		12.2	18.1	14.0	14.7
		AX56			
Replications	2	1.65**	1.98**	1.54**	5.08**
Methods	2				1.35**
Replications x methods	4				.04
Lines	19	.71**	.55**	.61**	
Lines in methods	57				.62**
Replications x lines	38	.16	.11	.12	
Reps. x lines in methods	114				.13
Mean (score)		2.8	2.6	2.5	2.6
Coefficient of variation (%)		14.5	12.7	14.1	13.8
		AX57			
Replications	2	.61*	.69*	.76*	1.59
Methods	2				5.62**
Replications x methods	4				.24
Lines	19	.42**	.83**	1.13**	
Lines in methods	57				.80**
Replications x lines	38	.13	.17	.17	
Reps. x lines in methods	114				.16
Mean (score)		3.0	2.5	2.5	2.7
Coefficient of variation (%)		11.9	16.3	16.7	15.0
		AX58			
Replications	2	.43*	1.57**	1.93**	3.41
Methods	2				4.36*
Replications x methods	4				.26
Lines	19	1.06**	.72**	1.07**	
Lines in methods	57				.95**
Replications x lines	38	.10	.18	.16	
Reps. x lines in methods	114				.14
Mean (score)		3.0	2.5	2.6	2.7
Coefficient of variation (%)		10.5	17.0	15.4	13.8
Grand mean		2.9	2.6	2.5	2.6

*F value exceeds 5% level.

**F value exceeds 1% level.

Table 7. Analyses of variance, means, and coefficients of variation for agronomic characters of F_5 lines combining three selection methods and five crosses in 1958

Source of variation	D.F.	Mean squares Yield	Maturity	Height	Lodging
Replications	2	679.72**	21.12**	16.17**	13.58**
Crosses	4	263.01	519.98**	171.96	3.00
Reps. x crosses (error a)	8	247.40	25.98	57.12	1.50
Methods	2	65.80	25.76*	117.10**	18.52**
Method F vs method P	1	128.62*	50.46**	35.53*	1.57*
Method F vs method B	1	51.39	19.80*	230.64**	33.46**
Method P vs method B	1	17.41	7.04	85.13**	20.54**
Method F vs methods P + B	1	114.21*	44.49*	149.07**	16.51**
Reps. x methods (error b)	4	11.02	2.38	3.91	.11
Methods x crosses	8	26.04	30.54**	19.32**	.86**
Reps. x methods x crosses (error c)	16	29.03	1.01	3.07	.19
Lines in methods	285	39.84**	21.36**	9.79**	.74**
Lines in method B	95	38.66**	16.25**	8.64**	.64**
Lines in method P	95	47.49**	25.14**	7.67**	.66**
Lines in method F	95	33.36**	22.69**	13.07**	.92**
Reps. x lines in methods (error d)	570	13.32	1.84	2.72	.15
Reps. x lines in method B	190	12.16	2.24	3.32	.13
Reps. x lines in method P	190	13.24	1.65	2.15	.18
Reps. x lines in method F	190	14.54	1.64	2.69	.14
General means		44.6	26.6	41.5	2.6
Coefficient of variation (%)		8.2	5.1	4.0	14.7

*F value exceeds 5% level.

**F value exceeds 1% level.

percent level of probability from the mean yield of lines from method P and from the combined yield of methods P and B. Significant differences among methods were shown for maturity, height, and lodging, however, the actual differences were inconsequential except perhaps for lodging of method B which was greater than the other methods. Crosses responded differently to methods only for maturity. Methods and crosses interacted significantly for all characters except yield. The magnitude of the coefficient of variation for each character was near the expected.

Analyses of variance for F_5 lines comparable to the analyses of variance for the Hawkeye checks were computed by combining certain sums of squares for lines in the previous analyses of variance. These analogous analyses of variance, means, and coefficients of variation for agronomic characters of Hawkeye and F_5 lines are given in Table 8. Hawkeye showed significant differences only among replications for yield and for lodging. The error mean squares for Hawkeye and lines were similar in magnitude within characters except for replications x crosses of lines which greatly exceeded those of Hawkeye. The variances for replications, crosses, and lines in crosses for all characters were larger for lines than for Hawkeye.

The Hawkeye and line means were similar for each character, except yield, where the lines outyielded Hawkeye by 2.0 bushels per acre. The coefficient of variation for lines compared with Hawkeye was lower for yield, height, and lodging, but higher for maturity.

The number of lines in each selection method deviating at the five percent level of probability above and below their respective cross mean yield, together with their mean agronomic performance, is given

Table 8. Analyses of variance, means, and coefficients of variation for agronomic characters of Hawkeye and F_5 lines combining crosses in 1958

Source of variation	D.F.		Mean squares							
			Yield		Maturity		Height		Lodging	
	Hawkeye	Lines	Hawkeye	Lines	Hawkeye	Lines	Hawkeye	Lines	Hawkeye	Lines
Replications	2	2	53.14*	679.72**	.86	21.12**	7.22	16.17**	2.52**	13.58**
Crosses	4	4	4.44	263.01	.50	519.98**	1.89	171.96	.28	3.00
Lines in crosses	15	295	6.88	39.64**	.84	21.64**	3.34	10.78**	.14	.87**
Error	38	598	16.27	16.85	1.02	2.14	4.08	3.46	.23	.17
Reps. x crosses	8	8	23.16	247.40	.98	25.98	6.47	57.12	.27	1.50
Reps. x lines in crosses	30	590	14.44	13.73	1.04	1.82	3.44	2.74	.22	.15
General mean			42.6	44.6	26.3	26.6	41.5	41.5	2.6	2.6
Coefficient of variation (%)			9.5	9.2	3.8	5.5	4.9	4.5	18.2	15.6

*F value exceeds 5% level.

**F value exceeds 1% level.

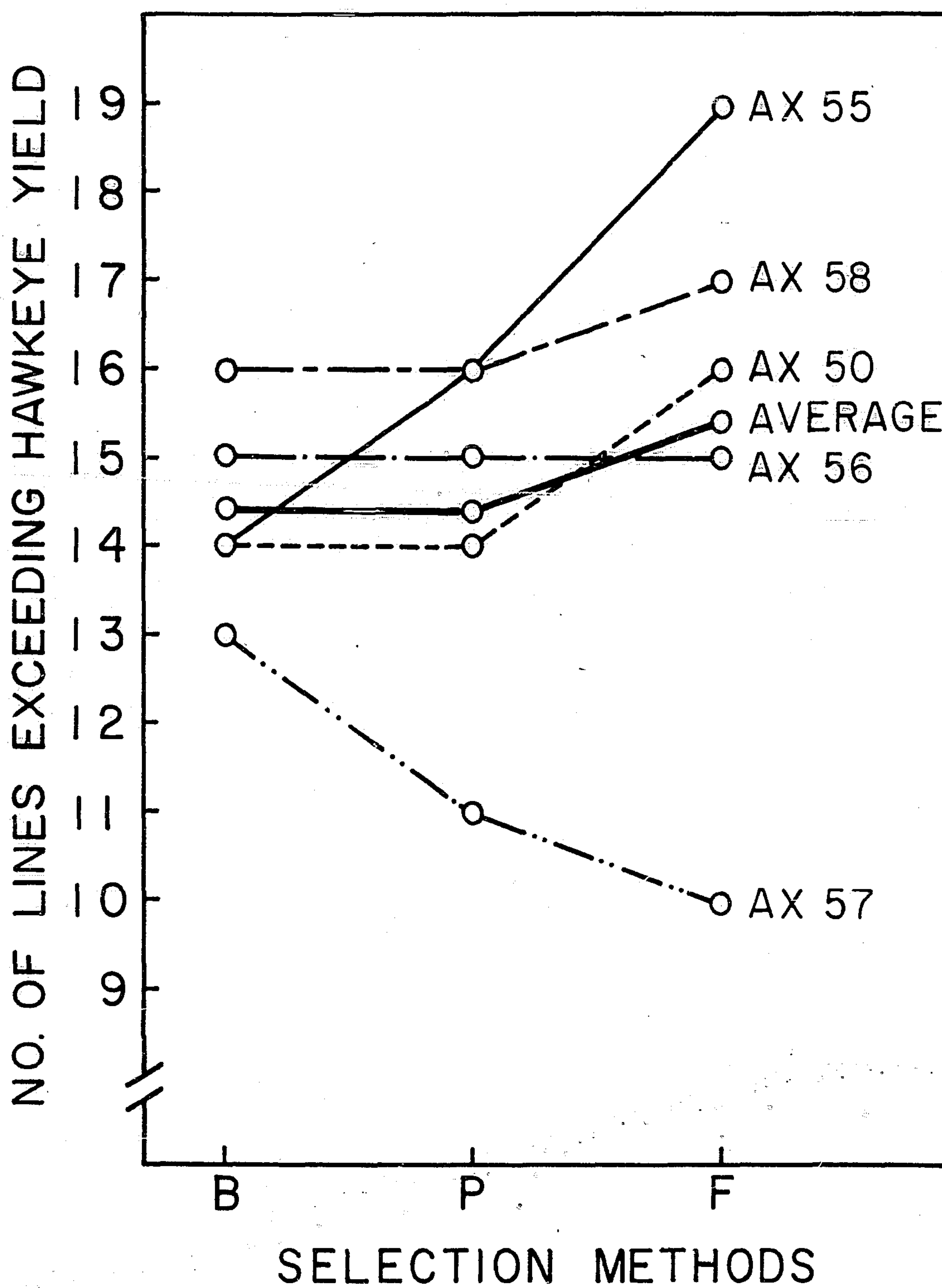
in Table 9. Method F had the largest number of lines, with nearly the highest average yield, exceeding the five percent level of probability above cross mean yields and the smallest number of lines, with the highest average yield, below cross mean yields. Method F gave the shortest height and lowest lodging score for lines exceeding the five percent probability level both above and below the cross mean yields.

A graphical presentation for the number of lines per cross within methods exceeding the yield of Hawkeye is shown in Figure 1. The average number of lines per method from all crosses yielding above Hawkeye was the same for methods B and P. Method F averaged one more line per cross than methods B or P even with the poor performance of AX57. Method F gave the best line performance in AX50, AX55, and AX58, the poorest in AX57, and was equal to methods B and P in AX56. The range in number of lines per cross above Hawkeye yield was from 10 for lines from AX57 to 19 out of 20 from AX55. Ax57 produced the least number of lines above Hawkeye yield for all methods.

Table 9. Number of lines in each selection method deviating at the 5% level of probability above and below their respective cross mean yield together with their mean agronomic performance

	Method	Number of lines	Mean of the character for number of lines indicated			
			Yield	Maturity	Height	Lodging
5% level of probability above cross mean yield	B	5	50.6	26.8	41.7	2.9
	P	5	51.4	27.8	42.5	2.6
	F	7	51.3	29.5	40.0	2.5
5% level of probability below cross mean yield	B	6	36.5	24.6	41.2	3.3
	P	8	35.4	21.7	39.9	2.7
	F	3	37.8	22.6	39.9	2.0

Figure 1. Number of lines per cross in selection methods exceeding Hawkeye mean yield in F_5 test in 1958


NO. OF LINES EXCEEDING HAWKEYE YIELD
19
18
17
16
15
14
13
12
11
10
9
AX 55
AX 58
AX 50
AVERAGE
AX 56
AX 57
B
P
F
SELECTION METHODS

Using line means, correlation of yield with maturity was indicated in only one or two crosses per method. A regression was computed from line mean yields on their maturities within methods in crosses, and the method mean yields within crosses corrected according to their deviation in maturity from the cross mean. This yield correction for maturity neither materially changed the mean yield of methods nor the original ranking of methods for yield performance.

Correlation coefficients for the 1957 parent row with the 1958 progeny mean were computed for all characters of method F lines and all but yield of method P lines. The correlations for method F are given in Table 10 and for method P in Table 11. In both methods P and F, no one character showed a high correlation in all crosses for the 1957 parent row with the 1958 progeny mean. Lodging showed near the lowest correlation for any character in both methods. Combined crosses for seed yield of method F gave a significant but low correlation of data for 1957 and 1958. Method F gave a higher correlation than method P for maturity, height, and lodging of combined crosses.

Table 10. Correlation coefficients for agronomic characters in method F in 1957 and 1958

Character	Cross					Combined crosses
	AX50	AX55	AX56	AX57	AX58	
Yield	.200	-.143	.182	.455*	.067	.258**
Maturity	.250	.477*	.479*	.577**	.401	.405**
Height	.776**	.169	.275	.691**	.486*	.662**
Lodging	.422	-.348	.279	.487*	.188	.169
Degrees of freedom	18	18	18	18	18	98

*Correlation coefficient exceeds 5% level.

**Correlation coefficient exceeds 1% level.

Table 11. Correlation coefficients for agronomic characters in method P in 1957 and 1958

Character	Cross					Combined crosses
	AX50	AX55	AX56	AX57	AX58	
Maturity	.512*	.139	.095	-.048	.299	.105
Height	.466*	-.044	.587**	-.112	.013	.243*
Lodging	-.069	.340	.146	.097	.050	.144
Degrees of freedom	18	18	18	18	18	98

*Correlation coefficient exceeds 5% level.

**Correlation coefficient exceeds 1% level.

DISCUSSION

The procedures used permitted each breeding method to operate on comparable germ plasm originating from the same F_2 plants. Thus, it was theoretically possible for one high yielding selection by each method to trace to the same F_2 plant. Such a procedure would afford an equal chance to select by all three methods a line from a particular F_2 genetic recombination. This should have the tendency to maximize genetic differences resulting from methods of selection and minimize variation due to other than genetic causes.

It is recognized that the bulk population would actually be a "selected bulk" to the extent of selection in the F_2 generation for maturity and height, but a minimum of selection pressure for lodging and yield would be expected from phenotypically selecting on a plant basis. The method B F_4 populations were thinned at flowering time by removing only those plants too early or too late from Hawkeye for date of first flower. The dual purpose of increasing the concentration of plants with desirable maturities and increasing seed set on these plants was accomplished since there is a high correlation of date of first flower with maturity (10,16). The selection pressures applied to method B in the F_2 generation and at flowering time in the F_4 generation, tended to concentrate plants of desirable maturity and should have given little selection for yield and lodging other than from genetic linkage.

The pedigree system afforded selection pressure through the F_2, F_3, and F_4 generations for maturity, height, and lodging but method B had no selection pressure for any characters in the F_3 generation.

This was reflected in the results which showed method P lines equal to Hawkeye for maturity, height, and lodging while method B lines averaged greater for all these characters. This substantiates the findings in other research (3,6,18) that maturity and height, and to some degree lodging, may be selected for in early generations. Methods P and B lines approximated each other in yield but both were superior to Hawkeye. Consequently, method P was superior to method B for maturity, height, and lodging, but equal for yield, indicating that little progress should be expected from phenotypic selection for seed yield in early generations of a cross.

Weber (15) practiced single plant selection for yield from drilled, four-inch, and eight-inch plant spacings in each of three bulk F_3 and three bulk F_6 hybrid soybean populations. Initial selections were for a constant maturity but phenotypic selections in drilled plantings resulted in slightly later maturity than did selection in wider plant spacings. He found final yield, height, and lodging differences among spacings within crosses to be inconsequential.

In this experiment the F_5 lines were selected from drilled, four-inch, and eight-inch F_4 spacings in methods F, B, and P, respectively. The F_5 maturities of methods F, B, and P ranked from late to early, respectively which is in agreement with Weber (15). Perhaps some of the differences in maturity among methods may be due to F_4 spacing differences for plant selections. The differences among methods F, B, and P for yield, height, and lodging would be due to differences in method performance, assuming there was no influence on these characters by F_4 spacing differences.

The 1957 lodging scores were low and those of 1958 were high. It would appear from these data, as well as from field observation, that much greater differential lodging occurred in 1958 than 1957. This may account for the apparent abnormally low correlation of lodging scores of 1957 with 1958 for both methods P and F. The correlations were computed on 1957 F_4 single row data and the 1958 F_5 mean of three replications for maturity, height, and lodging of methods F and P. The only difference was that the 1957 F_4 drilled rows for observation were eight and four feet long for methods F and P, respectively. The only difference in selection pressure for maturity, height, and lodging between methods F and P was the length of the F_4 row used for observation. The lower average lodging score of method F might suggest that the four foot observation row for method P was below minimum length for most accurate evaluation for lodging under the existing environmental conditions. The larger correlation coefficients of method F over method P for maturity and height might also suggest the eight foot row was superior to the four foot drilled rows of method P for maturity and height estimates.

In selecting 20 F_3 families per cross from the F_4 method F test, four crosses (AX50, AX55, AX56, and AX58) produced 20 lines satisfactory for maturity from the top 23 to 28 families ranked by yield. AX57 produced 20 lines satisfactory for maturity from the top 50 out of 60 F_3 families ranked by yield. Thus, a considerable number of AX57 lines were selected from families ranking well below the Hawkeye mean yield. This uneven selection of lines was reflected in the 1958 results for AX57 which gave the lowest number of lines from method F exceeding the Hawkeye mean yield.

The five highest yielding F_5 lines suitable in maturity were selected within each method and cross for further evaluation of selection methods for yield. These will be tested in a replicated trial in the F_6 in 1959.

SUMMARY AND CONCLUSIONS

1. A form of early generation replicated yield evaluation in the F_4 generation from F_3 families from five soybean crosses produced lines significantly higher in yield in the F_5 generation test compared to previously non-yield tested lines by methods B and P. There was no significant difference between the F_5 mean yields of lines from methods B and P.

2. Method F produced a greater number of lines exceeding the five percent level of probability above the cross mean yields and fewer below than methods B and P.

3. A greater number of lines by method F exceeded the Hawkeye mean yield than by methods B or P. Four of the five soybean crosses used reacted similarly to the three selection methods but method F was least successful in AX57. However, there was no significant yield interaction for selection methods x crosses.

4. There were significant differences among methods for maturity, however, the actual magnitudes of the differences were inconsequential. Lines selected by method P averaged earliest followed by slightly later maturities for lines from methods B and F, respectively.

5. Lines selected by method F were shortest and lodged the least compared with those selected by methods P and B.

6. Method P produced lines more suitable in maturity, height, and lodging than method B but equal in yield.

7. Superior high yielding lines were obtained with suitable maturity, height, and lodging resistance. Further evaluation of the better strains may prove one or more worthy of varietal release.

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