

# Gardner's Grid System and Plant Selection Efficiency in Cotton<sup>1</sup>

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## ABSTRACT

Gardner's grid system was investigated relative to plant selection efficiency within an upland cotton (*Gossypium hirsutum* L.) cultivar known to be genetically variable for fiber length. A relatively small area, planted to 'Westburn,' was arbitrarily subdivided into three equal-sized grids prior to harvest. One hundred individual plant selections were made in each grid on the basis of boll type and apparent yield. Then, based on fiber length, the upper and lower 10% of the plants were selected within each grid and over the area as a whole. Progeny row performances of the selected plants were obtained for fiber length in two environments. Phenotypic variances, selection differentials, selection responses, and heritabilities under the two procedures (grids vs. no grids) were then compared at the 5 and 10% levels of selection intensity.

In this experiment, the grid method reduced phenotypic variation by 22%; lowered selection differentials by 11 to 14%; produced 20 to 35% greater selection responses; and estimated "realized" (i.e., narrow-sense) heritabilities 41 to 52% higher than did the identical selection procedure without grids.

Based on the results of this and other experiments and on the logic underlying the method, use of grids should increase the effectiveness of plant selection regardless of crop, quantitative trait, or breeding method employed, provided there is genetic and environmental variability in the material. The method appears particularly useful when the breeder attempts to discriminate among small, inconsistent differences (i.e., when heritability is low). Use of the technique was considered for areas larger or smaller than those utilized herein, as well as for selection among progeny rows.

**Additional index words:** *Gossypium hirsutum* L., Fiber length, Two-way selection, Selection differential, Selection response, Heritability.

IN 1961 Gardner (2) reported yield increases in maize (*Zea mays* L.) of 3.9%/cycle over four generations using a modified form of mass selection. The modification concerned the method by which individual plants were chosen before the seed from those selected plants were bulked to produce the next generation. Gardner's innovation entailed the stratification of a selection block into a number of equal-sized grids and

the selection of a constant percentage of the higher yielding plants in each grid (rather than the usual procedure of selecting that percentage over the block as a whole). This modification was reasoned to reduce environmental variation among plants being compared—thereby, increasing the effectiveness of selection. By the thirteenth generation (3), a total gain of 38% (or 2.9%/selection cycle) was attained in his material.

Successful use of the method has also been reported in maize by Covarrubias [cited by Lonnquist, Cota, and Gardner (8)] and Johnson (6). Hallauer and Sears (4) were less successful in their maize selections, but several factors (particularly small total genetic variance, low selection intensity, and high planting rate) could have contributed to the lack of response in their experiment. Judging from the published literature, Gardner's selection method has been purposely employed only in maize (2, 3, 4, 6, 8); and even there, it has not been practiced by many breeders.

In cotton (*Gossypium hirsutum* L.), Meredith and Bridge (9) recently reported on the relationship between  $F_2$  vs. selected  $F_3$  progeny performance. As part of their study, 10  $F_2$  progenies were included in a randomized, complete-block design with eight replications. They visually selected the highest yielding plant in each plot excluding the first plant in each row. Lint yield was increased 5.7% in the  $F_3$  by making selections in this manner. Thus, if each plot in each replication is considered as being a grid, a serendipitous side effect of their work is that it provides confirmation for the effectiveness of Gardner's system in increasing the yield of a crop other than maize.

One of the purposes for the present study was to investigate the effectiveness of Gardner's grid system of plant selection in a crop other than maize (i.e., cotton) for a trait other than yield (fiber length). Another aim was to increase plant breeders' awareness of Gardner's grid system and of the method's possible utility in their breeding programs.

## MATERIALS AND METHODS

In 1967 a block of 'Westburn' cotton was grown at Hollis, Okla., on a sandy soil severely infested with the fusarium wilt [*Fusarium oxysporum* Schlecht. f. *vasinfectum* (Atk.) Snyder and Hansen] and root-knot nematode [*Meloidogyne incognita* (Kofoid and White) Chitwood (*M. incognita acrita*)] complex to which the cultivar is resistant (7, 10). The block was 60 × 60-m

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square (i.e., approximately 0.36 ha) and was bordered by Westburn on three sides and by Westburn and 'Lankburn' on the other. Lankburn is also resistant to the wilt-nematode complex (7). Rows were spaced 1.02 m apart, and plants within rows were 15 to 20 cm apart. No attempt was made to ensure self-pollination of individual plants, but insecticides were used periodically throughout the season. As a result, cross-pollination was probably not excessive. Irrigation was practiced; but water is limited at that location, and some drouth stress did occur.

After frost, the block was arbitrarily subdivided into three  $20 \times 60$ -m grids. However, no apparent differences in yield, earliness, or plant height were visually detected among the grids. One hundred individual plant selections/grid were made on the basis of boll type and apparent yield (i.e., plants with storm-proof or storm-resistant bolls and high lint production were chosen). Plants bordering skips in the same row or in adjacent rows were excluded from consideration. Except for the grids, this is the usual procedure followed in selecting plants within our breeding materials. The seed cotton from each plant was saw-ginned, and the 300 fiber samples were submitted to the fiber laboratory at Okla. State Univ. for length determinations. Fiber length was measured on the digital fibrograph as 2.5% span length in inches.

On the basis of fiber length, the upper and lower 10% of the plants were selected in each grid and over the block, ignoring grids. Eighty-five selections resulted; 35 of the 60 selected over the experiment as a whole were also chosen as within-grid selections.

Seed of the 85 selections were then randomly assigned to single progeny rows 7.6-m long at Perkins, Okla., under irrigation in 1968 and 9.1-m long at Chickasha, Okla., on dryland in 1968 and 1969. Rows and plants within rows were spaced as previously described. The rows at Chickasha in 1968 were planted late because of excessive rainfall before planting, exhibited poor stands at least partly because of additional rains before emergence, and were subjected to an unusually early frost in the fall. As a result, those data are not reported herein. Seed-cotton samples were collected from each row at Perkins in 1968 and at Chickasha in 1969. They were taken from the central portions of all plants in the row except those bordering alleys or skips. Samples were ginned, and fiber length was measured as previously described.

To avoid duplication, further details on the methods employed are described in the next section.

## RESULTS AND DISCUSSION

The 30 long and 30 short-fibered plant selections chosen within grids (10 of each/grid) did not correspond one-to-one with those made over grids. The distribution by grids of the long-fibered selections made over the experiment as a whole was 22, 5, and 3 from Grids I, II, and III, respectively, while the distribution of the short-fibered selections was 1, 6, and 23, in that order. Since the upper (and lower) 10% selections include among them the upper (and lower) 5%, comparisons in distribution between the two selection methods could also be made at the higher level of selection intensity. Selections in the upper 5% over grids were 11, 3, and 1 from Grids I, II, and III, respectively, while those in the lower 5% were 1, 2, and 12. The distribution was skewed in favor of Grid I for the long-fibered selections and toward Grid III for the short-fibered. Grid II had a more even balance of high vs. low selections over grids, but it had less than its proportionate share in each category. Thirty-five (58%) of the plants chosen over grids at the 10% selection intensity were also chosen in the within-grid selections; 25 (42%) were not. At the 5% selection intensity, 17 (57%) were chosen regardless of selection method; but 13 (43%) differed.

Had the two selection procedures (grids vs. no grids) resulted in the same plants being chosen, effectiveness of the two methods would have been identical; and as

Table 1. Partition of total variance into its between and within-grid components.

Source	df	Mean square		Estimates of variance components
		Calculated	Expected	
Between grids	2	0.033257**	$\sigma_W^2 + n\sigma_B^2$	0.001131 + 100(0.000321)
Within grids	297	0.001131	$\sigma_W^2$	0.001131

\*, \*\* Significant at the 0.05 and 0.01 levels of probability, respectively.

a consequence, selections ignoring grids would be simpler and more convenient to make. Since the same plants were not chosen by the two methods, one procedure should be superior to the other.

Among the reasons advanced by Gardner (2) to explain his success using the grid method, the primary one (in our estimation) was that environmental variation among plants was smaller in the subdivisions of a block (i.e., grids) than over the block as a whole. To determine if such was the case in this study, a between and within-grid analysis of variance was conducted on the fiber data from Hollis (Table 1). The between-grid MS was significant at the 0.01 probability level. The expected MS and variance component estimates are also shown in that table. The between-grid component was 22% [i.e.,  $0.000321/(0.001131 + 0.000321)$ ] of the phenotypic variation for the experiment as a whole ignoring grids. The above situation is similar to within-family selection, except that there is no family structure; and as a result, the genetic relationship among individuals within subgroups (relative to the base population) is zero.

The within-grid MS contains both genetic and environmental variation. The fact that Westburn varies genetically for fiber length is known because 'Westburn 70' was developed from that cultivar. Westburn 70 has a fiber approximately 1/32 in. longer than that of Westburn (13).

The between-grids component is environmental (or predominantly so); therefore, if phenotypic variance was 22% smaller utilizing grids in this experiment, selections should have been more effective where grids were employed. This difference would be reflected in greater selection response and higher heritabilities. Table 2 provides such evidence at the 5 and 10% levels of selection intensity. "Selection differentials" were calculated for each selection unit by subtracting the means of the lower from the higher selected groups and were based on the original plant selections made at Hollis in 1967. "Selection responses" were calculated in the same manner based on the performance of the progeny rows at Perkins and Chickasha. Both differentials and responses were based on two-way selections; and in using this technique, the assumption is made that response in one direction is roughly equivalent to that in the other. For only one selection cycle, this does not seem to be a drastic assumption. In the two-way selection experiments familiar to the authors, limits which natural selection places in the path of artificial selection in one or both directions are not usually reached until after a number of selection cycles have been completed. However, most breeders do select in one direction rather than two. To derive estimates for unidirectional selection, the selection differential and response values in the table should be halved. The heritabilities therein remain unchanged

Table 2. Two-way selection estimates of selection differentials vs. responses and of heritabilities derived using two methods of selection.

Selection method	10% level of selection intensity					5% level of selection intensity				
	Selection, in.		Realized heritability			Selection, in.		Realized heritability		
	Differential	Response		Perkins	Chickasha	Differential	Response		Perkins	Chickasha
Within grids										
Grid I	0.112	0.054	0.055	0.482	0.491	0.129	0.068	0.052	0.527	0.403
Grid II	0.104	0.061	0.045	0.587	0.433	0.121	0.062	0.096	0.512	0.793
Grid III	0.130	0.043	0.062	0.331	0.477	0.140	0.076	0.052	0.543	0.371
Over grids	0.130	0.041	0.040	0.315†	0.308*	0.152	0.057	0.056	0.375*	0.368‡

\*, †, ‡ Significantly less than the corresponding within-grid heritability estimates at the 0.01, 0.10 and 0.20 levels of probability, respectively.

Table 3. Response of one-way selections not in common between the two methods of selection.

Location	Direction of selection	Level of selection intensity, %	Selection method means, in.		df	Calculated t-values
			Within grids	Over grids		
Perkins	Upper	10	1.033	1.027	21	0.405
		5	1.065	1.032	9	2.943*
	Lower	10	0.990	1.010	20	-1.295†
		5	0.996	0.992	10	0.290
Chickasha	Upper	10	0.979	0.965	21	0.800‡
		5	0.981	0.987	9	-0.228
	Lower	10	0.939	0.955	20	-1.251†
		5	0.924	0.953	10	-1.036‡

\*, †, ‡ Significant at the 0.01, 0.15, 0.20, and 0.25 levels of probability, respectively.

regardless of whether selections are made in one or two directions.

Since total variance within grids was smaller than total variance ignoring grids, selection differentials should be smaller within grids. The data in Table 2 confirm that expectation. Five of six selection differential estimates were less within grids than over grids. The sixth was equal to its corresponding over-grid estimate. The mean within-grid estimates were 11 to 14% less than the over-grid estimate in the same set of data. Ten of 12 estimates for selection response were greater within grids than over grids, while the other two were only 0.004 in. less than the corresponding over-grid estimate. The difference between mean within-grid vs. corresponding over-grid estimates ranged from 20 to 35%. This type of situation is potentially discouraging to breeders that select in the normal manner without grids, because they would expect greater progress but actually receive less than if they had selected within smaller areas.

Hanson (5) has considered heritability and selection advance as complementary concepts. That is certainly the case here because of the method by which heritability was calculated (i.e., selection response/selection differential). Therefore, the heritabilities in Table 2 are "realized" estimates (1) and tend toward being narrow-sense, rather than broad-sense heritabilities.

The heritabilities estimated within grids were larger in every case than the corresponding estimates over grids. The mean within-grid estimates ranged from 41 to 52% greater than the over-grid estimate in the same data set. Tests of significance were conducted within each data set between the within-grid heritability estimates vs. the over-grid estimate. The reasoning behind this test followed that of Nelder (11) in that a mean estimate was obtained over the three within-grid estimates and the variation of the individual estimates around that overall mean was used to derive a SE of the mean.

The SE was then used to conduct one-tailed t-tests to determine whether the heritabilities within grids were significantly higher than the corresponding esti-

mate over grids. In two sets of data (i.e., the 10% selection intensity at Chickasha and the 5% intensity at Perkins), the heritabilities within grids were significantly greater than the corresponding over-grid estimates at the 0.01 level of probability. This trend was significant at the 0.10 probability level at Perkins (10% selection intensity) and at the 0.20 probability level at Chickasha (5% intensity).

Two possible criticisms of the above comparisons come to mind. One, selection in the upper direction is confounded with selection in the lower; and two, the selections which were made regardless of selection method were included in the within vs. over-grid comparisons. To remedy those situations, data for the selections not in common between the two methods and separated by direction of selection were calculated for the two methods (Table 3).

Mean fiber length should have been greater in the upper direction within grids and less in the lower. That expectation was fulfilled in six of eight comparisons. In the two instances (Perkins, lower 5%; Chickasha, upper 5%) where it did not occur, significant differences between selection methods were not obtained even at the 0.25 probability level. Five of the six remaining comparisons were significant at the 0.25 or higher level of probability. One (Perkins, upper 5%) was significant at the 0.01 level. Individually, the comparisons in Table 3 are not totally conclusive; collectively, they tend to be so.

The foregoing results in this and other experiments and the logic on which Gardner's grid system is based suggest that use of grids would increase the effectiveness of plant selection regardless of crop, quantitative trait, or breeding method used, provided there is genetic and environmental variability in the material. It would appear particularly useful when the breeder attempts to discriminate among small, inconsistent differences (i.e., when heritability is low).

Several additional points seem worthy of comment at this time. One, this experiment was conducted on an area considerably smaller than the usual cotton breeding nursery. Most nurseries probably range in

size from 1 to 3 ha. If the grid method was this effective on an area of only 0.36 ha where the grids were judged visually indistinguishable, one can only speculate how much more effective the method would be in the larger nurseries, especially where differences in plant response between various sections of those nurseries are obvious. Where considerable dissimilarities are noted between areas, it becomes all the more important that plants grown in those separate areas should not be compared between areas, but that they should be compared only with those plants in their vicinity. Planting a check cultivar periodically through one's nurseries should be useful in helping define such areas.

Two, it is likely that subdivisions into smaller and smaller grids would, within limits, further increase selection effectiveness. However, a point of diminishing returns must eventually be reached where further subdivisions would not increase selection gains in proportion to the time and effort expended. What that point is we would not presume to say. However, the plot (i.e., grid) size Meredith and Bridge (9) used in making their plant selections for yield was two rows 16-m long with 1.0 m between rows.

Three, it is also likely that the principle of grids may successfully be extended to selection among progeny rows. However, when comparing rows rather than plants, larger grids could probably be used without substantial loss in efficiency because selection based on rows is not so dependent upon the microenvironment in the immediate vicinity of an individual plant. The pluses and minuses on plant performance provided by such environmental effects would probably tend to cancel each other through the length of a row. Schutz and Cockerham (12) have empirically compared three incomplete block designs in terms of expected gain from selection; and they demonstrated that, in general, the proper weighting of block information in all three resulted in increased gain from selection over that obtained without blocking.

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