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Inter-row Competitive Effects Among Four Cotton Cultivars[1]

Cesar A. Moran-Val and P. A. Miller[2]

ABSTRACT

Inter-row competition among cotton (*Gossypium hirsutum* L.) genotypes may cause major biases in the estimation of cultivar performance. The objective of the present study was to evaluate the nature and importance of such effects among four cotton cultivars and relate the results to field evaluation techniques.

Four cultivars, representing the extremes of vegetative growth habit among the strains currently being tested in North Carolina, were grown. Inter-row competition was measured using each cultivar as a test cultivar subjected to all possible pair wise combinations of the same four entries as competitors. Thus, there were 10 competitor combinations for each test cultivar, for a total of 40 treatments. A randomized block design of six replicates was grown at each of three locations in North Carolina. Six traits were measured including seed cotton yield, lint yield, lint percent, boll weight, plant height, and plant width.

The four cultivars differed significantly in competitive ability. Although effects on all traits were noted, fiber and seed cotton were the only traits which were modified sufficiently to be of major concern in an evaluation program. Both additive (average) and specific inter-row competitive effects were observed for yield. Mean squares for average effects were consistently larger than those for specific effects. Averaged over the three locations, biases expected from the use of nonbordered single-row plots ranged up to 13.2% for lint yield. Competition effects of this magnitude suggest the need to use bordered plots for measuring yield, at least in advanced trials.

Additional index words: Gossypium hirsutum L., Cultivar testing techniques.

COMPETITION between individual plants and between rows is usually encountered in genetic and plant breeding experiments. Plant breeders are concerned about inter-row competition among cotton (*Gossypium hirsutum* L.) genotypes since competition may cause biases in evaluation trials.

Results reported on the importance of inter-row competition in cotton are inconsistent. Christidis (1935) evaluated nine cultivars in three-row plots and measured competition by comparing the yield of the middle row with the two border rows. He observed variations in yield due to competition effects which ranged from 0 to 6% of the mean performance. Later, Christidis and Harrison (1955) reported deviations as large as 17% due to inter-row competitive effects.

Quinby, Killough, and Stansel (1937) harvested each of the rows of four-row plots separately. Data on 19 comparisons over a 3-year period did not detect significant competitive effects, and they concluded that single-row plots would be satisfactory for yield tests. Hancock (1936) studied inter-row competition using two cultivars of unlike vegetative growth habit. Although he detected a significant competition effect on the yield of one of the cultivars, the magnitude of the effect was small; nevertheless, he suggested that two-row plots be used for evaluation trials. Richmond (1943) studied competition between two early and two late cultivars. He observed that even though competititive effects may be statistically significant, magnitudes were not great enough to alter the ranking of the cultivars for yield. Thus, he concluded that single-row plots would be the most practical except in tests where the cultivars might show extreme differences in yield and plant type, or for tests grown on high-fertility soils. Green (1956) grew four cultivars with a wide range of maturity. Results varied from test to test, and he concluded that it was not possible from his data to predict conditions under which border rows were necessary. He suggested that more precise experimental techniques were needed to study this problem more critically.

Hanson, Brim, and Hinson (1961) presented a diallel-type design and analysis for measuring inter-row competition effects under field conditions. A description of this analysis in terms of certain model restrictions has recently been given by Rawlings (1974). The present study utilizes these techniques to measure inter-row competition effects among four cotton cultivars.

MATERIALS AND METHODS

Four cultivars of varying growth habit were used in this study: 'Dixie King,' 'Carolina Queen,' 'Auburn M,' and 'Gregg.' The first two cultivars are relatively tall and vigorous, while the latter are shorter with less vegetative growth. These cultivars were selected to represent the extremes of vegetative growth habit among cultivars, which were currently being tested in North Carolina and thus might be the most likely ones to show intervarietal competitive effects.

Inter-row competition was measured using each of the $p = 4$ cultivars as the test cultivar subjected to all possible pair-wise combinations of the same four cultivars as competitors. Thus, there were $p(p + 1)/2$ or 10 competitor combinations for each test cultivar so that the test involved 40 treatments. It was assumed that inter-row competition results only from the cultivars in the two rows adjacent to the test cultivar and that cultivar sequences such as 1, 1, 2 would be equivalent to 2, 1, 1 as measured by the test cultivar 1. Treatments were obtained from the sequential arrangement of cultivars in the field, and arrangement such as . . . 3 1 1 4 1 2 . . . gives estimates of cultivar 1 bordered by 3 and 1; cultivar 1 bordered by 1 and 4; cultivar 4 bordered on both sides by 1, etc. The randomization procedure consisted of first randomly assigning the three-row check plots of a test cultivar to a position within a replication and then randomly assigning the cultivars in sequence until all treatment combinations were obtained (disregarding order or sequence). For treatments which occurred more than once within a replication, the plot value to be used in the analysis was randomly selected.

A randomized block design of six replicates was grown at three locations: Rocky Mount, Lewiston, and Salisbury, N. C.

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[2] Formerly graduate student (present address, Univ. Nacional Agraria, La Molina, Lima, Peru) and professor of crop science, N. C. State Univ., Raleigh, NC 27607.

(designated as locations 1, 2, and 3, respectively). All plots were 7-m long with 1 m between rows at locations 1 and 3 and 91 cm between rows at location 2. Plants averaged 10 cm apart within the row. Data were recorded from each plot for seed cotton yield (q/ha), lint yield (q/ha), lint percentage, boll weight (g of seed cotton/boll), and plant height (cm) and width (cm) at maturity.

The competitor combinations are the same as the mating combinations used in the partial diallel mating design with the parents included (see Griffing, method 2, 1956). The analysis used for the current experiments are based upon Griffing's analysis with the model restrictions and modifications described by Rawlings (1974). Let the average performance of test cultivar i grown in competition with cultivars j and k in the two adjacent rows be $Y_{i(jk)}$, where the average is over r replicates. The linear model for the results of the ith test cultivar can be written as

$$Y_{i(jk)} = \mu_i + c_{i(j)} + c_{i(k)} + s_{i(jk)} + \bar{e}_{i(jk)}$$

where: μ_i = mean performance of cultivar i over all competitor combinations, i = 1, . . . , m; $c_{i(j)}$ = average competitive effect of cultivar j, j = 1, ... , p, on the performance of test cultivar i; $s_{i(jk)}$ = competitive interaction effect specific to competitor combination jk on performance of cultivar i; and $\bar{e}_{i(jk)}$ = average experimental error over r replicates assumed to be normally distributed with mean zero and variance σ^2/r.

Model II, as denoted by Rawlings (1974) with the imposed restriction that $\sum_{k=1}^{p} s_{i(jk)} = 0$ for all j, was deemed the more appropriate analysis for estimating average and specific competitive effects. An additional parameter designated as competitive bias (Δ) was estimated as described by Rawlings (1974) to measure the average difference in performance between single-row nonbordered and bordered plots, ignoring specific competitive effects and not permitting the test cultivar to be a potential competitor. The latter restriction would more nearly simulate results from a testing program using a randomized, complete block design, although a small chance exists that a cultivar in one block by virtue of falling on the boundary is competing against the same variety in another block. Cultivars are regarded as fixed entities and the competition effects measured are specific to that situation. Location effects are treated as random.

Table 1. Cultivar responses averaged over all competiting conditions at each location and combined over locations.

Cultivar*	Seed cotton yield	Lint yield	Lint	Boll wt	Plant ht	Plant width
	q/ha	q/ha	%	g	cm	cm
			Location 1			
DK	27.2	11.0	40.6	8.1	86	83
CQ	30.8	12.6	41.0	7.1	85	84
Auburn M	29.7	11.6	39.1	7.4	75	78
Gregg	30.4	11.2	36.8	6.9	76	79
Mean	29.53	11.6	39.4	7.4	81	81
			Location 2			
DK	36.8	14.1	38.4	8.2	70	66
CQ	39.8	15.2	38.3	7.1	71	68
Auburn M	36.6	13.1	35.9	7.5	59	61
Gregg	28.0	9.4	33.6	6.9	59	61
Mean	35.3	13.0	36.6	7.4	65	64
			Location 3			
DK	39.4	15.7	39.8	8.1	109	91
CQ	44.0	17.4	39.6	6.9	109	91
Auburn M	37.7	14.0	37.2	7.1	94	88
Gregg	29.7	10.3	34.7	6.7	93	89
Mean	37.7	14.4	37.8	7.2	101	90
			Combined over locations			
DK	34.5	13.6	39.6	8.1	89	81
CQ	38.2	15.1	39.7	7.1	89	82
Auburn M	34.7	12.9	37.4	7.4	77	76
Gregg	29.4	10.3	35.0	6.8	77	77
Mean	34.2	13.0	37.9	7.4	83	79

* DK = Dixie King and CQ Carolina Queen.

RESULTS

Cultivar responses averaged over all competing conditions at each location and combined over locations are presented in Table 1. The season was favorable for cotton production, and yields were relatively high at all locations. There were marked differences in vegetative growth as measured by plant height and width at the three locations with luxurious growth at location 3, intermediate growth at location 1, and reduced growth at location 2. Carolina Queen, the highest yielding cultivar, averaged 30% more seed cotton over the three locations than low yielding Gregg.

Average competitive effects (Table 2) are of relatively large magnitude and statistically significant for seed cotton yield, lint yield, and plant height at all three locations. They also are important for lint percentage and plant width at location 3. Specific competitive effects were significant for seed cotton yield at location 1 and for lint yield at locations 1 and 3. Interactions of both average and specific competitive effects with cultivars were usually not statistically significant, indicating that the competitive effects of the cultivars are similar when measured by the performance of the four different test entries.

Table 2. Mean squares for average competitive effects (ACE) and specific competitive effects (SCE) pooled across the four cultivars for each location and combined over locations.

Source†	df	Loc. 1	Loc. 2	Loc. 3	Combined	Loc. 1	Loc. 2	Loc. 3	Combined	Loc. 1	Loc. 2	Loc. 3	Combined
		Seed cotton yield, q/ha				Lint yield, q/ha				Lint, %			
ACE	3	121.4**	78.0*	239.2**	394.1**	20.9*	12.1**	38.4**	65.0**	1.22	1.53	2.96**	3.13
ACE × cult.	9	5.6	12.1	19.5	19.6	0.6	2.4	3.5	3.2	0.44	1.66*	0.11	0.54
ACE × loc.	6	--	--	--	22.3	--	--	--	3.2	--	--	--	1.29*
ACE × cult. × loc.	18	--	--	--	8.8	--	--	--	1.5	--	--	--	0.83
SCE	6	52.9**	34.7	26.1	173.0**	8.1**	5.4	9.2**	17.4**	0.58	0.85	0.82*	0.98
SCE × cult.	18	8.7	27.9	14.2	28.3**	1.7	4.5	2.2	4.8**	0.57	0.82	0.23	0.63
SCE × loc.	12	--	--	--	14.9	--	--	--	2.6	--	--	--	0.63
SCE × cult. × loc.	36	--	--	--	11.3	--	--	--	1.7	--	--	--	0.49
Error	195‡	9.7	20.9	17.4	16.0	1.6	3.1	2.5	2.4	0.50	0.76	0.34	0.53
		Boll wt, g				Plant ht, cm				Plant width, cm			
ACE	3	0.07	0.22	0.10	0.22	94.7*	169.9**	361.9**	504.7*	15.9	60.6	44.3**	86.4*
ACE × cult.	9	0.07	0.18	0.93**	0.10	64.7*	38.3	48.9	81.9	25.4	27.0	11.5	17.3
ACE × loc.	6	--	--	--	0.08	--	--	--	60.9	--	--	--	17.2
ACE × cult. × loc.	18	--	--	--	0.12	--	--	--	35.0	--	--	--	8.9
SCE	6	0.04	0.16	0.03	0.03	21.1	55.8	29.0	45.5	10.2	12.7	9.2	4.4
SCE × cult.	18	0.05	0.22	0.04	0.14	26.1	34.8	45.2	29.7	13.8	26.6	9.9	11.4
SCE × loc.	12	--	--	--	0.10	--	--	--	30.3	--	--	--	13.9
SCE × cult. × loc.	36	--	--	--	0.09	--	--	--	30.2	--	--	--	36.9**
Error	195‡	0.08	0.16	0.07	0.10	29.0	29.0	38.9	32.5	16.2	23.4	9.8	16.0

*, ** Significantly different from zero at the 0.05 and 0.01 probability levels, respectively. † Cult. = cultivar and loc. = location. ‡ Error df 585 for combined data.

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Both average and specific competitive effects are highly significant for lint and seed cotton yield (Table 2). Average competitive effects also are of importance for plant height and width. Interactions of specific competitive effects with the test cultivars are significant for yield, although the magnitude of the mean squares is substantially smaller than those for the corresponding main competition effect. Competition effects were generally consistent over locations as indicated by the small and nonsignificant interactions of competitive effects with locations.

The average seed cotton yield (Table 3) of the four test cultivars was decreased by 1.42 q/ha when Carolina Queen was one of the two competing cultivars. Carolina Queen is a strong competitor with respect to yield. Gregg is a very weak competitor; yields of cultivars were enhanced when Gregg was one of the competing cultivars. Dixie King and Auburn M in general have only minor competitive effects for yield and might be designated as "neutral." Considering the data combined over locations, it is noted that all four cultivars, as competitors, significantly modified the average plant height of the test cultivars. When the two taller cultivars (Dixie King and Carolina Queen) were competing rows, the average plant height of the test cultivars was increased. The converse was observed when the two shorter cultivars were competitors. Some small effects were also noted for lint percentage, but generally yield was the only trait modified sufficiently to be of concern in a cultivar evaluation program.

Average expected yield biases which estimate the differences in yield between bordered and nonbordered single-row plots are given in Table 4. A plus bias indicates that a cultivar would yield more when nonbordered and, thus, in competition with other cultivars than when bordered by itself. A negative bias indicated the opposite response. If the four cultivars were evaluated in a single-row nonbordered plots in a randomized block design, the yield of Carolina Queen would have been biased upward by a substantial amount as compared with its expected performance when bordered by itself. Averaged over locations, the expected upward bias was 13.2% for lint yield of Carolina Queen. Lint yields of Gregg, on the other hand, would have been consistently underestimated with an expected bias of −11.1% for mean performance over the three locations. Biases for lint percentage and boll weight were generally small and would be of little practical importance in cultivar evaluation. Several significant biases were noted for plant height and width, but the magnitude of these biases are such that they would not be of concern in a testing program.

DISCUSSION

Data show that these four cultivars differ in competitive ability. It should be emphasized that the estimates presented apply only to the defined competing system. Although competitive effects modified the response of the test cultivars for all traits measured in certain treatment combinations at specific locations, yield was the only trait which was modified sufficiently to be of major concern in a cultivar evaluation program. Both additive (average) and specific inter-row competitive effects were observed for yield. Mean squares for average effects were consistently larger than those for specific effects.

Competitive effects for yield are not directly related to vegetative growth habit. Dixie King and Carolina Queen are very similar in plant height and width, but Carolina Queen is a much stronger competitor for yield. Likewise, Auburn M and Gregg are similar in vegetative growth habit, but Gregg is a much weaker competitor.

Although the relative competitive effects of the four cultivars were reasonably consistent over the three locations, the magnitude of the effects as related to the type of growth observed. Competitive effects for yield were larger at location 3 (where plant growth was the most luxuriant), intermediate at location 1 (medium vegetative growth), and smallest at location 2 (least vegetative growth).

For cultivar testing, it is obvious that the use of nonbordered plots could result in significant biases

Table 3. Average increase or decrease of the four test cultivars when bordered by the designated competitor.

Competitor cultivar	Seed cotton yield	Lint yield	Lint	Boll wt	Plant ht	Plant width
	q/ha	q/ha	%	g	cm	cm
			Location 1			
DK	-0.04	-0.04	-0.08	0.02	1.0**	0.3
CQ	-1.30**	-0.54**	-0.09	-0.04	-0.1	0.2
Auburn M	0.32	0.15	0.08	0.02	-1.0**	-0.3
Gregg	1.02**	0.42**	0.09	0.01	0.1	-0.2
			Location 2			
DK	-0.06	0.01	0.01	0.00	1.0**	0.6
CQ	-0.99**	-0.38**	0.08	-0.06	0.9*	0.6
Auburn M	0.12	0.00	-0.18**	0.02	-0.7*	-0.4
Gregg	0.92*	0.37**	0.10	0.03	-1.3**	-0.8
			Location 3			
DK	0.86*	0.24	-0.16**	0.04	1.6**	0.8
CQ	-2.08**	-0.79**	-0.11*	-0.01	1.2*	-0.2
Auburn M	0.19	0.10	0.10*	-0.03	-1.4**	-0.0
Gregg	1.04**	0.44**	0.16**	0.00	-1.4**	-0.5*
			Combined over locations			
DK	0.24	0.07	-0.07*	0.02	1.2**	0.6**
CQ	-1.42**	-0.57**	-0.07*	-0.04*	0.8**	0.2
Auburn M	0.20	0.08	0.01	0.00	-1.1**	-0.3
Gregg	0.98**	0.41**	0.13**	0.01	-0.8**	-0.5*

*, ** Significantly different from zero at the 0.05 and 0.01 levels of probability, respectively.

Table 4. Average expected differences (Δ) between bordered and nonbordered single-row plots.

Cultivar	Seed cotton yield	Lint yield	Lint	Boll wt	Plant ht	Plant width
	q/ha	q/ha	%	g	cm	cm
			Location 1			
DK	-0.11	0.04	0.27	0.11	-4.3*	-3.5*
CQ	3.40**	1.38*	-0.03	0.00	3.2	0.6
Auburn M	-2.49*	-1.04*	-0.24	0.00	1.8	0.4
Gregg	-3.36*	-1.35*	-0.43	-0.08	1.6	0.8
			Location 2			
DK	-0.66	-0.29	0.08	0.13	-2.4	0.6
CQ	3.32	1.56*	-0.35	0.00	-3.3	-1.5
Auburn M	-1.42	-0.68	-0.48	-0.11	-2.2	3.0
Gregg	-3.30	-1.11	-0.11	0.08	1.9	1.6
			Location 3			
DK	-1.54	-0.35	0.27	0.21	-9.4**	-3.9**
CQ	6.16	2.52**	0.21	0.05	0.5	1.5
Auburn M	-1.22	-0.57	-0.32	0.08	3.0	0.6
Gregg	-2.91*	-1.17*	-0.24	0.19	4.9*	3.2**
			Combined over locations			
DK	-0.65	-0.20	0.21	0.00	-5.1**	-2.4*
CQ	4.30**	1.82**	0.32	0.03	0.3	0.4
Auburn M	-1.71	-0.76*	-0.35*	0.00	1.8	1.3
Gregg	-3.19**	-1.21**	-0.27	0.08	1.8	1.9

*, ** Significantly different from zero at the 0.05 and 0.01 levels of probability, respectively.

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in the estimation of pure stand yield. On the other hand, the extra land required for bordered plots would most likely result in an increase in both the cost of conducting a trial and in the variability due to a larger block size. The use of two-row nonbordered plots, one-half as long would be expected to decrease the competition effects to about one-half of that found in a single-row nonbordered plots. Perhaps, in the preliminary stage of cultivar evaluation, single-row plots (nonbordered) could be used for screening purposes to eliminate the poorest lines, particularly for traits other than yield. For the next stage of testing, the use of two-row nonbordered plots might be sufficient. If competitive effects of the magnitude observed in this study are generally present in yield trials, however, fully bordered plots would be indicated for the final stages of testing where precise information is needed on the performance of the cultivars.

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