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Yield of Cucumbers in Multiple-harvest Trials with Dissimilar Genotypes in Border Rows

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Abstract. **Cultigens frequently are tested for eventual monoculture production conditions in trials with different cultigens in adjacent rows. We determined the effect of using different cultigens of pickling and fresh-market cucumber (*Cucumis sativus* L.) in bordered (three-row) and unbordered (1-row) plots. Cultigens contrasted in characteristics important in competitive effects: plant architecture (tall vs. dwarf), anthracnose resistance (susceptible vs. resistant), and sex expression (monoecious vs. gynoecious). In all four test years, there was no significant interaction of border with center row in unbordered vs. bordered plots, with three exceptions: there was a significant reduction in yield of M 21 in 1982 when bordered by 'Calypso' (a large-vined genotype), and a reduction in yield of 'Southern Belle' in 1984 when bordered by 'Calypso' or SMR 58. In most cases, there was an increase in yield if the border genotype had short vines. We concluded that, in most cases, trials can be run using unbordered plots without significant effect on yield.**

Plant breeders usually test new breeding lines for several years in replicated, multiple-harvest trials to determine whether the lines should be released. However, because of limitations of space or the number of seeds available for each experimental line, trials are often planted with unbordered plots (one row instead of three- or four-row plots). Thus, the lines are not being tested in monoculture, but, rather, in mixed plantings with different lines in adjacent plots.

Competition between different genotypes causes bias in yield trials of some crops, such as soybean [*Glycine max* (L.) Merr.] (Schutz and Brim, 1967). Unbordered plots of soybean are acceptable for trials in the northern United States, but not in the southern, where more foliage growth occurs (Hanson et al., 1961). Several technical aspects of cucumber yield trials have been investigated, including the most stable method of yield measurement for once-over harvest (Ells and McSay, 1981), the optimum plot size for single- and multiple-harvest trials (Smith and Lower, 1978; Swallow and Wehner, 1986), the optimum time to harvest plots once-over (Miller and Hughes, 1969), and the most efficient method for running trials to estimate yield in multiple-harvest trials (Wehner, 1986; Wehner and Miller, 1984). Although guard rows should be used around the outside of the trial to provide competition for the plots on the edges of the experiment, it is unclear whether bordered plots are required to obtain proper estimates of cucumber yield for monoculture conditions.

The objective of this experiment was to determine whether trials consisting of diverse genotypes of cucumbers may be run safely using unbordered plots. The approach taken was to measure whether there was significant interaction between genotype and plot side-borders in pickling and fresh-market cucumber yield trials.

All experiments were run at the Horticultural Crops Research Station, Clinton, N.C., using recommended horticultural practices (Hughes et al., 1983). Fertilizer was incorporated before planting at a rate of 90N–39P–74K ($kg\cdot ha^{-1}$) with an additional 34 kg N/ha applied at vine tip-over stage. Seeds were planted on raised, shaped beds, with rows 1.5 m apart to follow common practice for trials, rather than the closer spacing used by growers. Irrigation was applied when needed to provide plants with a total water allocation of 25 to 40 mm per week. Naptalam (2.2 $kg\cdot ha^{-1}$) and bensulide (4.4 $kg\cdot ha^{-1}$) were applied before planting for weed control.

Cultigens used. Two to four pickling cucumber cultigens, and zero or four fresh-market cucumber cultigens were tested (Table 1) in three-row plots (center plus two border rows) in all combinations of border and center rows. Cultigens were chosen for contrasting characteristics we thought to be most important in competitive effects: plant architecture (dwarf-determinate vs. tall-indeterminate), sex expression (gynoecious vs. monoecious), and anthracnose resistance [caused by *Colletotrichum lagenarium* (Ross) Ellis & Halst]. Anthracnose is the most important disease in the production of cucumbers in North Carolina, and resistance is required for the summer (but not the spring) crop.

The pickling cultigens were M 21 (a resistant, monoecious inbred with 610-mm vine length), 'Southern Belle' (resistant, gynoecious hybrid with 800-mm vine length), 'Calypso' (resistant, gynoecious hybrid with 900-mm vine length), and SMR 58 (a susceptible, monoecious inbred with 920-mm vine length). The fresh-market cultigens were 'Bush Champion' (a susceptible, monoecious inbred with 480-mm vine length), 'Marketmore 76' (a susceptible, monoecious inbred with 810-mm vine length), 'Poinsett 76' (a resistant, monoecious inbred with 860-

Table 1. Cultigens tested, number of replications and harvests used, plot length, plant density, and dates of planting and harvesting for the 4 years of testing of border effect in multiple-harvested cucumbers.

Year	Cultigens tested	No. replications	No. harvests	Plot length (m)	Plant density (thousands/ha)	Dates[z]
1981	M 21 Southern Belle Calypso	6	7	6.1	62	8 July 13 Aug. 3 Sept.
1982	M 21 Southern Belle Calypso	6	6	6.1	74	17 May 24 June 12 July
1983	Calypso SMR 58	6	6	7.7	60	3 May 20 June 8 July
1984	M 21 Southern Belle Calypso SMR 58	4	8	3.0	84	8 May 21 June 16 July
	Bush Champion Marketmore 76 Poinsett 76 Sprint 440	4	7	3.0	84	8 May 25 June 16 July

[z]Date of planting, first harvest, and last harvest for each crop and year.

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Table 2. Yield (fruit value and weight) of pickling cucumber cultigens tested in bordered and unbordered plots in multiple-harvest trials run 1981 through 1983.

Cultigen		Total yield	
Center	Border	Value ($/ha)	Weight ($Mg\cdot ha^{-1}$)
	1981 test (seven harvests)		
M 21	M 21	1161^{b}	9.1^{b}
	Southern Belle	978^{NS}	7.0^{NS}
	Calypso	1031^{NS}	7.5^{NS}
Southern Belle	M 21	1357^{NS}	12.4^{NS}
	Southern Belle	1409^{b}	13.9^{b}
	Calypso	1157^{NS}	12.1^{NS}
Calypso	M 21	1442^{NS}	12.5^{NS}
	Southern Belle	1611^{NS}	14.9^{NS}
	Calypso	1185^{b}	11.7^{b}
	F (border × center)	0.7^{NS}	0.8^{NS}
	LSD (5%)	441	3.9
	1982 test (six harvests)		
M 21	M 21	2511^{b}	43.5^{b}
	Southern Belle	2192*	39.2^{NS}
	Calypso	1999*	35.3*
Southern Belle	M 21	2161^{NS}	49.5^{NS}
	Southern Belle	2054^{b}	46.3^{b}
	Calypso	2118^{NS}	50.6^{NS}
Calypso	M 21	2014^{NS}	49.2^{NS}
	Southern Belle	1935^{NS}	48.1^{NS}
	Calypso	1954^{b}	47.5^{b}
	F (border × center)	1.9^{NS}	1.0^{NS}
	LSD (5%)	231	5.9
	1983 test (six harvests)		
Calypso	Calypso	3791^{b}	43.6^{b}
	SMR 58	3288^{NS}	39.3^{NS}
SMR 58	Calypso	2031^{NS}	31.3^{NS}
	SMR 58	1717^{b}	28.9^{b}
	F (border × center)	7.6*	2.8^{NS}
	LSD (5%)	1088	12.2

^{NS,*}Not significant or significantly different at $P = 0.05$, respectively, from the bordered (^{b}) plot.

Table 3. Yield (fruit value and weight) of pickling cucumber cultigens in bordered and unbordered plots in multiple-harvest trials.

Cultigen		Total yield	
Center	Border	Value ($/ha)	Weight ($Mg\cdot ha^{-1}$)
	1984 test (eight harvests)		
M 21	M 21	6070^{b}	50.0^{b}
	Southern Belle	5982^{NS}	52.5^{NS}
	Calypso	5639^{NS}	43.0^{NS}
	SMR 58	5432^{NS}	40.5^{NS}
Southern Belle	M 21	6680^{NS}	67.8^{NS}
	Southern Belle	6463^{b}	71.1^{b}
	Calypso	5744^{NS}	59.6*
	SMR 58	5630^{NS}	59.5*
Calypso	M 21	6218^{NS}	75.4^{NS}
	Southern Belle	6465^{NS}	70.8^{NS}
	Calypso	5918^{b}	68.5^{b}
	SMR 58	5482^{NS}	62.4^{NS}
SMR 58	M 21	3242^{NS}	43.4^{NS}
	Southern Belle	3234^{NS}	46.8^{NS}
	Calypso	2553^{NS}	33.2^{NS}
	SMR 58	2569^{b}	37.5^{b}
	F (border × center)	0.2^{NS}	0.4^{NS}
	LSD (5%)	903	10.8

^{NS,*}Not significant or significantly different at $P = 0.05$, respectively, from the bordered (^{b}) plot.

mm vine length), and 'Sprint 440' (a resistant, gynoecious hybrid with 1000-mm vine length).

Experimental design. The experiment was a factorial treatment arrangement in a randomized complete-block design with four to six replications (Table 1). The factorial was the two to four (depending on year) cultigens used as center rows in all combinations with two to four cultigens used as border rows. In all cases, the two border rows were planted with the same cultigen. Monoculture was simulated by planting center and border rows to the same cultigen, and mixed culture by planting a cultigen in the center row different from the one in the borders.

Plots were overplanted and thinned to a uniform stand, using densities of 60,000 to 84,000 plants/ha and 3.0- to 7.7-m-long plots over the 4 years (Table 1). We used shorter plots and higher densities in the last 2 years, since they were found to be optimum in another study run simultaneously (Swallow and Wehner, 1986). Use of different trialing methods also allowed us to test the effect of mixed culture in a wider array of systems. Plots were harvested Mondays and Thursdays by hand for six to eight harvests total. Harvest was begun when the earliest cultigen was ready, and continued for as long as the vines remained productive.

Traits measured. Vine length was measured on three randomly chosen plants from each plot center the day before harvest was begun. Yield was measured according to commercial practice. For the pickling cucumbers, fruits were machine sorted into the four North Carolina size grades: 0 to 27 mm, 28 to 38 mm, 39 to 51 mm, and >51 mm in diameter for grades 1, 2, 3, and 4, respectively. Fruits were then weighed (data presented in Mg), and dollar value ($/ha) was calculated as (Mg 1 × $309) + (Mg 2×$143)+ (Mg 3×$88) + (Mg 4×$0). The grade 4 cucumbers are considered oversized, and are often not sold.

Fresh-market cucumbers were hand-sorted into the USDA quality grades, then counted and weighed. The grades are Fancy, No. 1, No. 2, and cull. Marketable yield was calculated as number (thousands/ha) or weight ($Mg\cdot ha^{-1}$) of Fancy, No. 1, and No. 2 fruits. Quality yield was Fancy + No. 1 fruit.

Yield data were summed over all harvests. Correlations were run for all pairs of yield data (fruit weight, value, and number). Plot means were then subjected to analysis of variance (ANOVA). Attention was paid to cultigen × side-border effects, since that is a measure of whether cultigen yields were the same in mixed as in monoculture plantings. Orthogonal contrasts were not helpful because the border rows caused either increased or decreased competition for the center rows, depending on cultigen used, with an average effect near zero.

Yield. Year effects on yield of pickling cucumbers were large. Yields in 1981 and 1984 were lowest and highest, respectively; yields in 1982 and 1983 were intermediate. Differences were probably due to planting date and environment. The 1981 trial was planted late on light, sandy soil (Wagram loamy sand), and grown during a hot, dry season. The 1982 and 1983 trials were grown during average seasons. The 1984 trial was planted early on a dark loam soil (Rains fine sandy loam), and grown during a warm, rainy season.

The main effect for cultigen yield was significant in all trials (data not shown), and the differences were consistent; SMR 58 and

Table 4. Yield (marketable fruit weight and number) of fresh-market cucumber cultigens in bordered and unbordered plots in multiple-harvest trials.

Cultigen		Total yield	
Center	Border	Weight (Mg·ha⁻¹)	Number (thousands/ha)
	1984 test (seven harvests)		
Bush Champion	Bush Champion	51.1[b]	141[b]
	Marketmore 76	46.9[NS]	133[NS]
	Poinsett 76	42.7[NS]	114[NS]
	Sprint 440	46.8[NS]	134[NS]
Marketmore 76	Bush Champion	48.3[NS]	148[NS]
	Marketmore 76	38.7[b]	114[b]
	Poinsett 76	35.5[NS]	108[NS]
	Sprint 440	42.5[NS]	127[NS]
Poinsett 76	Bush Champion	64.2[NS]	204[NS]
	Marketmore 76	58.0[NS]	189[NS]
	Poinsett 76	57.4[b]	199[b]
	Sprint 440	63.2[NS]	211[NS]
Sprint 440	Bush Champion	82.7[NS]	274[NS]
	Marketmore 76	73.3[NS]	224[NS]
	Poinsett 76	73.2[NS]	236[NS]
	Sprint 440	74.2[b]	222[b]
	F (border × center)	0.2[NS]	0.8[NS]
	LSD (5%)	12.0	39

[NS],*Not significant or significantly different at $P = 0.05$, respectively, from the bordered ([b]) plot.

M 21 were the lowest, and 'Southern Belle' and 'Calypso' were the highest-yielding (Tables 2–4).

Correlations among the yield traits indicated that fruit value, number, and weight all produced the same results for comparison among cultigens (data not shown). The data were, therefore, summarized as fruit weight and value for pickling cucumbers, and marketable fruit weight and number for fresh-market cucumbers. For fresh-market cucumbers, quality yield (Fancy + No. 1) and marketable yield (Fancy + No. 1 + No. 2) were affected similarly by changes in border cultigen.

Border effect. In general, there was no significant effect of border row on the yield of the center row of a three-row plot (Tables 2–4). There was a tendency for long-vined cultigens grown in the border rows to reduce the yield of the cultigen in the center row compared to the monoculture condition. However, that effect was not significant, except in a few cases. For example, M 21 had reduced yield (fruit weight) when bordered with 'Calypso' in 1982, and 'Southern Bell' had reduced yield when bordered with 'Calypso' or SMR 58 in 1984.

The most important indicator in this analysis of cultigen yield trials was the variance due to border × center row interaction. With a few exceptions, the ANOVA indicated no significant F ratio in any of the years for either pickling or fresh-market cucumbers (Tables 2–4), suggesting that the yield of the cultigens was affected by adjacent cultigens by about the same amount. One exception was the significant interaction for fruit value (but not weight) in 1983, where susceptible, large-vined SMR 58 was planted next to resistant, smaller-vined 'Calypso' (Table 2). In a year with heavy disease, there may be problems with trials having mixed plots where resistant and susceptible cultigens are adjacent. In general, however, that did not occur, and mixed (unbordered) plots would be fine.

An experimenter could decrease the error variance by adding plot borders (using more field space and seeds per cultigen) or replications (making more work in planting and harvesting). Use of three-row instead of one-row plots would triple the required field space and seeds per cultigen. Increasing the number of replications from three to four would use one-third more field space and seeds per cultigen. However, the additional rows of a bordered-plot trial would not be handled during harvest, whereas the additional (fourth in this example) replication would add to the harvest labor. Although it is not possible to determine the most effective procedure from these experiments, we believe that adding a replication in the initial stages of testing and using bordered plots in the final stages would be efficacious.

Conclusions. When cultigens of different types were planted in adjacent field plots, yield was not significantly affected relative to the bordered plot (monoculture control) in most cases. That was true even when mixing tall with dwarf, or resistant with susceptible cultigens. In most cases, multiple-harvest trials may be run using one-row plots (mixed-cultigen plantings) without concern of significant changes relative to the bordered-plot trial in the ranking of the cultigens tested. Although the cultigens evaluated in this study represent a significant range of diversity, and data were collected over 4 years, only a total of one location and eight cultigens was evaluated. Caution should be exercised when extrapolating to other trials, especially in locations where vines grow more before harvest.

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