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Interaction of border and center rows of multiple row plots in watermelon yield trials

Grant P. Neppl, Todd C. Wehner & Jonathan R. Schultheis[1]
Department of Horticultural Science, North Carolina State University, Raleigh, NC 27695-7609, U.S.A.; [1]*Graduate research assistant and professors, respectively*

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Summary

Abstract Researchers interested in evaluating watermelon (*Citrullus lanatus* (Thunb.) Matsum. & Nakai) cultivars for yield often use multiple-row plots to simulate the monoculture system growers use or single-row plots to save on land, labor, and seeds. An important question is whether there is significant interaction of border rows with center rows when diverse cultivars are planted in adjacent rows. Based on recommendations from watermelon researchers in the U.S., 'Charleston Gray', 'Crimson Sweet', and 'Sugar Baby' were chosen to represent long, medium, and short-vined cultivars, respectively. Cultivars were planted in three-row plots with all nine combinations of the three represented in border and center rows. The experiment was a randomized complete block with the nine border by center plot combinations, two locations (Kinston, Clinton), and three replications at each location. Vine length was measured during the season, and fruit from four harvests were graded (marketable and cull), counted and weighed. Results showed that 'Charleston Gray' had the longest vines, followed by 'Crimson Sweet' and 'Sugar Baby'. In the analysis of variance, the largest effects (F ratio) on yield were from cultivar, location, and the interaction of the two. The smallest effects were border row and the interaction of center with border row. Center by border interactions were significant (5% level) in some cases, but were usually small and did not involve change in rank. Therefore, researchers interested in running trials with many cultivars and small seed quantities can obtain good data using single-row plots. However, there is a small (but significant) interaction of center with border rows in some cases, so testing at the final stage should be with trials having multiple-row plots or with cultivars grouped by vine length. Additional research is needed to determine the effect of cultivars having extreme plant types, for example dwarf cultivars in bordering rows with long-vined cultivars.

Introduction

Watermelon (*Citrullus lanatus* (Thunb.) Matsum & Nakai) is the primary edible and cultivated species of *Citrullus*, a genus that consists of five species. Watermelon breeding programs often expend a large amount of their resources on field testing new experimental lines and hybrids in the locations of interest. Therefore, breeders are interested in optimizing their field testing methods to provide the most information for the lowest cost. Multiple-row plots provide conditions similar to the monoculture production system that growers will use. On the other hand, single-row plots permit more experimental cultigens to be tested alone or with more replications, while requiring fewer seeds per plot. Since seed supply, land, labor, and funding are limiting, breeders are interested to know whether multiple-row plots are necessary for proper testing of experimental cultigens.

One potential biasing effect on yields of single-row plots is the competition between plants of adjacent plots. Arny (1922) showed that border rows could be harvested along with the center rows of the plot in small grains if the alleys between plots were planted with winter wheat sown in the spring. Cropped alleys provided competition to the plants at each end of the plot, eliminating the yield inflation that normally occurred. Christidis (1931) noted that competition between plants existed in some cases; the effects (when present) were limited to one row on either side of a plot, and competition effects were negligible when cultivars similar in growth habit and morphology were grown in adjacent plots.

If there were no border competition, single-row plots would be the most efficient trialing method. Regardless of whether single-row plots are used, the entire experiment should be surrounded by guard rows and end plots to provide competition to the outside plots (Wehner, 1987). Should significant border competition exist, steps should be taken to eliminate the effects from the trials. Two methods have been proposed to reduce or eliminate border effects. The first, proposed by David et al. (1996), is to allocate cultivars in field layouts so plots are grouped to include cultivars having similar competition effects. This allows for competition effects on yield to be effectively ignored in later statistical analysis. A second method allows competition to occur, but compensates for biased yield effects through the use of designated border rows, which are not included in the measurement of plot yield.

The use of border rows is recommended for crops such as sugarbeet (*Beta vulgaris*) (Deming & Brewbaker, 1934), rice (*Oryza sativa*) (Zimmermann 1980), field bean (*Vicia faba*) (Costa & Zimmermann, 1998; Kempton & Lockwood, 1984), soybean (*Glycine max*) (Evans & Lewin, 1986; Gedge et al., 1977; Monzon et al., 1972; Probst, 1943), red clover (*Trifolium pratense*), alfalfa (*Medicago sativa*) (Hollowell & Heusinkveld, 1933), and the small grains oat (*Avena sativa*), barley (*Hordeum vulgare*), winter and spring wheat (*Triticum aestivum*) (Hulbert & Remsberg, 1927; Down, 1942). Studies of border competition in wheat and barley have shown mixed results on whether border row use is warranted due to the existence of border effects and the lack of the effect being significant in altering plot yields in some cases (Kramer et al., 1982; Romani et al., 1993; Stringfield, 1927). Maize (*Zea mays*) studies have also shown a lack of significance in border row effects (Bowman, 1989; Silva et al., 1991). Significant change in yield due to competition has been noted in field bean (Kempton & Lockwood, 1984), potato (*Solanum tuberosum*) (Thornton, 1987), triticale (*Triticosecale 'Lasko'*) (Kempton et al., 1986), and wheat (Austin & Blackwell, 1980; Clarke et al., 1998; Fasoula, 1990; May & Morrison, 1986). The biasing effect on yield due to different competing abilities of adjacent cultivars can be associated with plant architecture. In wheat, yields are reduced 0.34% for every centimeter increase in height of adjacent plots (Clarke et al., 1998).

No studies to date have evaluated border effects in watermelon. Research on another cucurbit, cucumber, indicated that multiple-row plots were not needed due to non-significant interaction of center row with border rows of a different genotype (Wehner, 1984; Wehner, 1988; Wehner & Miller, 1990).

The objective of this study was to determine whether watermelon yield was affected by border cultivar in field trials using three cultivars differing in vine length. We also measured vine length and canopy size of the cultivars to verify that the ones chosen were actually different. We were primarily interested in whether there was a significant interaction of border and center row cultivars for yield, and whether the interaction involved changes in cultivar rank.

Materials and Methods

The experiment was conducted during the summer season of 2000 at the Cunningham Research Station in Kinston and the Horticultural Crops Research Station in Clinton, North Carolina. Hereafter, locations will be referred to as Kinston and Clinton, respectively.

Experiment design

The experiment was a randomized complete block design with two locations, three replications at each location, and nine border-center row combinations of the three cultivars. Location was the whole plot and border-center treatment was the sub-plot. Replication (block) was nested within location. Each plot (treatment combination) consisted of three rows such that all possible combinations of center row with left and right border rows (of the same cultivar but not necessarily the same as the center row) could be obtained. Data were analyzed using the ANOVA, correlation and means procedures of SAS (SAS Institute, Cary, NC).

Weak plants were replaced with additional transplants 4 to 14 days after transplanting to assure that all plots had 12 plants. At harvest, all plots had the required 12 plants. Rows were covered with black plastic mulch and irrigated using plastic drip tape. Plastic mulch was 0.03 mm at Kinston and 0.04 mm at Clinton. Drip tape was 0.2 mm manufactured by Roberts Irrigation Products Inc. (San Marcos, California) at Kinston and 0.2 mm Streamline 80 manufactured by Netafim (Fresno, California) at Clinton.

Individual rows of each plot were 7.3 m long, on 3.0 m centers with 0.6 m between hills, and 2.4 m alleys at each end of the plot.

Cultivars used

Three cultivars were evaluated based on recommended extremes of vine length gathered from a survey of public and private breeders in the U.S. Cultivars used included 'Charleston Gray' (long vine), 'Crimson Sweet' (medium-length vine) and 'Sugar Baby' (short vine). Seeds of 'Sugar Baby' were obtained from N.C. State University seed increase lots, 'Crimson Sweet' from Hollar and Co. (Rocky Ford, Colo.), and 'Charleston Gray' from Willhite Seed Inc. (Poolville, Texas). Seeds of all cultivars (except 'Sugar Baby', which were fermented after increase at N.C. State Univ.) were acid washed prior to planting to eliminate bacterial fruit blotch causing organisms. Fermenting of seeds will also eliminate the bacteria. Acid treatment consisted of placing seeds into 1% hydrochloric acid (HCl) for 15 minutes. Seeds were then rinsed in tap water for six minutes and dried.

Flats were seeded on 21 and 28 March to be transplanted at Kinston and Clinton experiment stations, respectively. A third set of transplants was seeded on 4 April as insurance for loss of a previous set, but was not used in the experiment. All transplants were grown in the research greenhouses at N.C. State University. Transplants were taken to cold frames for seven days before transplanting on 17 and 24 April for Kinston and Clinton, respectively.

Scotts Professional® water soluble 20–16.6–8.8 (N-P-K) fertilizer was applied to transplants in the greenhouse and under cold frames at a concentration of 28.35 g of fertilizer per 3.79 L of concentrate. Fertilizer was applied once per week using a brass siphon mixer (Miracle-Gro Siphonex, Scotts Miracle-Gro Products Inc., Port Washington, NY 11050) generating a dilution rate of 16:1. Hand brushing was used three times per day while transplants were in the greenhouse to limit stem elongation. For each brushing, the flattened palm of the hand was lightly moved across the tops of the transplants in a random manner across each flat so that plants were brushed approximately three times per brushing. Seedlings were transplanted at Kinston on 25 April and at Clinton on 1 May.

Cultural practices

The experiment was conducted using recommended horticultural practices (Sanders, 1999). Plots were on raised plastic mulch beds. Soil at Kinston was a Norfolk sandy loam (Fine-loamy, kaolinitic, thermic Typic Kandiudults). Soil at Clinton was Orangeburg loamy sand (Fine-loamy, kaolinitic, thermic Typic Kandiudults).

Kinston field preparation included soil incorporation of a 10–16.6–8.8 (N-P-K) fertilizer applied at 336 $kg \cdot ha^{-1}$ and the fumigant Telone C-17 (1,3-Dichloropropene + chloropicrin) applied at a rate of 60 $L \cdot ha^{-1}$ on 6 April. At transplanting completion on 27 April, 20–16.6–8.8 (N-P-K) fertilizer and 30 ml of Diazinon (Diethyl 2- Isopropyl-4-Methyl-6-Pyrimidyl Thionophosphate) were applied per 189 L of transplant water after transplanting. Application rates were less than 5.6 $kg \cdot ha^{-1}$ or a water diluted equivalent of a 1–0.83–0.44 (N-P-K) fertilizer. Fungicide, insecticide and herbicide applications were made as needed throughout the growing season. Fertilizers applied after planting were injected into the irrigation system.

Field preparation at Clinton included the soil incorporation of a 10–8.3–4.4 (N-P-K) fertilizer applied at 561 $kg \cdot ha^{-1}$ and Telone C-35 (1,3-Dichloropropene + chloropicrin) fumigant applied at 168 $kg \cdot ha^{-1}$ on 29 March. Fertilizer application for the remainder of the growing season consisted of 224 $kg \cdot ha^{-1}$ of 13.5–0–19.8 (N-P-K) and 112 $kg \cdot ha^{-1}$ of calcium along with 15.5–0–0 (N-P-K) applied on 22 May, 30 May, and 7 June. Only 13.5–0–19.8 (N-P-K) was applied on 14 June and 23 June. Gramoxone (1,1'-Dimethyl-4,4'-bipyridinium dichloride) was applied to plastic mulch edges on 23 May using a backpack sprayer. Fungicide, insecticide and herbicide applications were made as needed throughout the growing season. Fertilizers applied after planting were injected into the irrigation system.

Data collection and analysis

Plots at each location were harvested weekly for a total of four harvests beginning 27 June at Kinston and 6 July at Clinton. Each location was harvested once per week on non-overlapping days. Vine tracing was used when the plot of origin for a fruit was in question. Data were taken from the center row of each three-row plot, using the border rows of the plot only for competitive effects. Fruit were determined as ripe after checking fruit in the border rows for sugar content, a dried tendril nearest that fruit, light colored ground spot, and the sound of the fruit when thumped. Individual cull and marketable fruit were weighed to the nearest 0.1 kg for each plot. Numbers of cull and marketable fruit were also recorded. Yield was calculated as total or marketable fruit weight ($Mg{\cdot}ha^{-1}$) or number ($thousands{\cdot}ha^{-1}$) after summing plot yields over the four harvests.

Canopy size, as an indication of row width coverage by canopy, was rated on a scale of 1 to 9, where 1–3 = small vines, 4–6 = medium sized vines, 7–9 = large vines. Ratings were taken based on average canopy of the entire harvested center row of each plot.

Vine Length

Vine length was measured in plots adjacent to the main experiment using the same cultivars. The experiment was a randomized complete block with two locations, three replications per location, and three cultivars, with a total of 18 single-row plots. Location was the whole plot and cultivar was the sub-plot. Replication (block) was nested within location. Plots were planted using the same row spacing as described above for the border competition study. At harvest, all plots had the required 12 plants.

Three measurements of vine length were taken beginning at first fruit set for each location and every other week thereafter. The first vine length was taken on 31 May at Kinston and 8 June at Clinton. Measurements two and three were taken on 12 and 27 June for Kinston, and 22 June and 6 July for Clinton, respectively. First fruit set was when fruit were softball size. Plants three, seven and eleven in a plot were used for measurement. The same vine of each plant was used throughout the experiment unless the growing tip had been damaged. In that event, a neighboring plant within the plot was used. Vine length was measured from the base of each plant to the growing point. A main vine was measured, one of those extending furthest from the crown. Data were analyzed using the ANOVA, Correlation and Means procedures of the Statistical Analysis System (SAS Institute, Cary, NC).

Results

Border competition

Differences between location main effects were significant (at least at the 5% level) for all traits except percentage culls (Table 1). Center row main effects were highly significant (at the 1% level) for all traits, and location × center interactions were highly significant for fruit weight and number. Border row main effects, location × border interactions, and location × center × border interactions were non-significant for all traits. The border × center row interaction was found to be significant for fruit yield (weight and number), but not for weight per fruit or percentage culls.

Total and marketable yield were highly correlated (r = 0.99), so only the total yield data are presented (Table 2). Cultivars yielded nearly twice as much at Kinston than at Clinton where 'Charleston Gray' had a total yield of 108.4 or 52.8 $mg{\cdot}ha^{-1}$, respectively, when planted in both border and center rows, representing monoculture conditions (Table 2).

'Charleston Gray' had the highest yield, but 'Crimson Sweet' was only slightly and not significantly lower. 'Sugar Baby' had the lowest yield (Table 2). The ranking of the three cultivars remained about the same regardless of which of the three cultivars was planted in the plot borders. Percentage culls was low for 'Crimson Sweet' and 'Sugar Baby' (0 to 6%), and significantly higher in 'Charleston Gray' (6 to 30%). There was large variation for percentage culls, and few of the differences for that trait were significant.

Total fruit number was highly correlated (r = 0.80) with total yield ($Mg{\cdot}ha^{-1}$), indicating that weight per fruit did not vary much over treatments (Table 2). Weight per fruit was non-significant for all sources of variation (Table 1). The only exception was for center row cultivar, since 'Charleston Gray' (9.0 kg/fruit) and 'Crimson Sweet' (9.6 kg/fruit) were large-fruited, and 'Sugar Baby' (4.8 kg/fruit) was small-fruited (Table 2).

Vine length / canopy size

Vine length of the three cultivars chosen from an initial survey of watermelon breeders was verified using the length of the main stem and a subjective rating of canopy size (Table 3). According to analysis of variance, location was highly significant for canopy size and all vine length measurements except the first one. The location × center interaction was significant for vine length at weeks 5 and 9, and for the mean over weeks. Canopy size and vine length at week 7 did not have a significant location × center interaction. Center row cultivar was highly significant for canopy size. Vine length at weeks 7 and 9, and for the mean over weeks had significant center row effects. Vine length at week 5 had no significant effect for center row cultivar.

Table 1. Analysis of variance for total yield for watermelon trials using three-row plots tested at two locations (Kinston and Clinton, NC)

Source of variation	Degrees of freedom	Mean squares for total yield: Fruit wt. ($Mg \cdot ha^{-1}$)	Fruit no. ($th \cdot ha^{-1}$)	Wt./fruit (kg)	Culls (%)
Location (L)	1	12962.939**	90.588**	23.066*	9.386
Replication/L	4	102.381	0.912	2.746	122.942
Center (C)	2	11706.020**	13.628**	119.114**	828.293**
Border (B)	2	38.156	1.210	0.401	91.586
B × C	4	207.619*	2.985**	0.517	90.851
L × C	2	2099.583**	11.290**	3.757	79.802
L × B	2	87.657	0.279	0.601	119.155
L × C × B	4	75.317	1.385	0.517	48.077
Error	32	72.742	0.715	1.144	58.131

**, * = F ratio significant at 1 and 5% levels, respectively.

Canopy size rating at Kinston ranged from 5.3 for ‘Sugar Baby’ to 8.4 for ‘Charleston Gray’ (Table 3). At Clinton, canopy size ranged from 3.1 for ‘Sugar Baby’ to 6.9 for ‘Charleston Gray’. Location by cultivar interaction was not significant for canopy size.

Between locations tested, ‘Crimson Sweet’ vines were significantly longer at Clinton while vines of ‘Sugar Baby’ were longer at Kinston after five weeks of growth (Table 3). From seven weeks of growth until the last vine length measurement, vine length differences stabilized with ‘Charleston Gray’ and ‘Sugar Baby’ vines being significantly longer at Kinston. ‘Crimson Sweet’ vine length showed no difference between location after seven and nine weeks of growth. Vine length rankings also varied between locations with ‘Charleston Gray’ the longest vined cultivar at Kinston while ‘Crimson Sweet’ and ‘Charleston Gray’ were both long vined at Clinton.

‘Charleston Gray’ and ‘Crimson Sweet’ had significantly higher canopy size ratings than ‘Sugar Baby’. Vine lengths averaged over the entire growing season showed a reversed trend, with ‘Charleston Gray’ having a significantly longer vine than either ‘Crimson Sweet’ or ‘Sugar Baby’. For the initial vine length measurement after five weeks of growth, ‘Charleston Gray’ and ‘Sugar Baby’ were significantly longer than ‘Crimson Sweet’. However, from seven weeks of growth onward, only ‘Charleston Gray’ maintained greater vine length than either ‘Crimson Sweet’ or ‘Sugar Baby’.

After five weeks of growth, vine lengths of all three cultivars did not differ (Table 3). Between weeks seven and nine, vine length rankings did not change, with ‘Charleston Gray’ being the longest cultivar and ‘Sugar Baby’ the shortest. At week seven, ‘Charleston Gray’ and ‘Crimson Sweet’ were longer than ‘Sugar Baby’. However, at week nine, only ‘Charleston Gray’ remained longer than ‘Sugar Baby’. Canopy size rating was uncorrelated with vine length at week five, but was positively correlated with vine length at weeks seven and nine (Table 3).

Discussion

Higher total and marketable fruit weight and number were produced at Kinston for ‘Charleston Gray’ and ‘Crimson Sweet’ in every treatment where these cultivars were planted in the center row. Higher yields at Kinston may have been due to more productive soils and better crop maintenance, with fewer weeds, diseases, and insects than at Clinton. In general, the crops at both locations were in good shape, but disease (mostly anthracnose) and insect incidence was lower at Kinston. Plants at Clinton had a low incidence of gummy stem blight, spider mites, thrips and leaf miners.

Border competition in watermelon was found to have a small but significant effect on total and marketable fruit weight and number of adjacent plots in the field as noted by Christidis (1931). Many studies conducted on watermelon have evaluated plant and row spacing, as well as plant density. Generally, researchers have reported that as spacing increased, yields decreased while weight per fruit increased (Bracy & Parish, 1994; Brinen et al., 1979a, 1979b; Elmstrom & Crall, 1985; Gilreath et al., 1987; NeSmith, 1993).

Table 2. Yield of 3 watermelon cultivars as the center row of a 3-row plot having one of three different cultivars in the border rows[z]

Cultivar Center	Border	Total yield ($Mg{\cdot}ha^{-1}$)	Culls (%)	Fruit no. ($th{\cdot}ha^{-1}$)	Wt./Fruit (kg)
Clinton location					
Charleston Gray	Charleston Gray	52.8	17.4	6.0	9.3
	Crimson Sweet	65.4	30.2	7.6	8.6
	Sugar Baby	56.4	6.1	7.0	8.3
Crimson Sweet	Charleston Gray	53.9	5.3	6.1	9.2
	Crimson Sweet	53.3	6.4	6.3	8.8
	Sugar Baby	57.6	1.1	6.7	8.4
Sugar Baby	Charleston Gray	31.6	2.2	6.9	4.8
	Crimson Sweet	37.8	0.0	7.3	5.1
	Sugar Baby	24.4	1.4	6.0	4.3
Mean		*48.1*	*7.8*	*6.7*	*7.1*
LSD (5%)		*14.2*	*12.7*	*1.4*	*2.1*
Kinston location					
Charleston Gray	Charleston Gray	108.4	11.2	11.4	9.9
	Crimson Sweet	103.5	13.7	11.2	10.3
	Sugar Baby	99.3	12.0	10.2	10.6
Crimson Sweet	Charleston Gray	90.0	2.8	8.5	10.8
	Crimson Sweet	90.3	6.4	8.7	10.6
	Sugar Baby	108.2	6.0	10.5	10.6
Sugar Baby	Charleston Gray	37.1	2.8	7.6	4.9
	Crimson Sweet	40.8	2.2	8.4	4.9
	Sugar Baby	34.5	5.6	6.9	5.0
Mean		*79.1*	*7.0*	*9.2*	*8.4*
LSD (5%)		*14.2*	*12.7*	*1.4*	*2.1*
Location mean					
Charleston Gray	Charleston Gray	80.6	14.3	8.7	9.6
	Crimson Sweet	84.5	21.9	9.4	9.5
	Sugar Baby	77.9	9.1	8.6	9.4
Crimson Sweet	Charleston Gray	72.0	4.0	7.3	10.0
	Crimson Sweet	71.8	6.4	7.5	9.7
	Sugar Baby	82.9	3.6	8.6	9.5
Sugar Baby	Charleston Gray	34.3	2.5	7.2	4.9
	Crimson Sweet	39.3	1.1	7.8	5.0
	Sugar Baby	29.4	3.5	6.4	4.7
Mean		*63.6*	*7.4*	*8.0*	*8.0*
LSD (5%)		*10.0*	*9.0*	*1.0*	*1.5*
F ratio (center × border)		*2.8**	*1.6ns*	*4.2***	*0.07ns*
Correlation (total vs. marketable yield as weight in $mg{\cdot}ha^{-1}$) = 0.99**					
Correlation (total fruit weight vs. total fruit number) = 0.80**					

[z] Data are means of 3 replications of 12 plants/plot summed over 4 harvests.
ns, **, * Indicates correlations not significant, or significant at the 1 and 5% levels, respectively.

Table 3. Canopy size (based on canopy ground coverage) and vine length of three watermelon cultivars having no border row[z]

Cultivar	Canopy size (Rating)	Vine length (m) Week 5	Week 7	Week 9	Mean
Clinton location					
Charleston Gray	6.9	2.0	3.0	3.0	2.7
Crimson Sweet	6.4	2.2	3.1	3.3	2.9
Sugar Baby	3.1	1.9	2.3	2.4	2.2
Mean	*5.5*	*2.0*	*2.8*	*2.9*	*2.6*
Kinston location					
Charleston Gray	8.4	2.2	3.8	4.8	3.6
Crimson Sweet	7.3	1.9	3.0	3.4	2.8
Sugar Baby	5.3	2.2	3.0	3.8	3.0
Mean	*7.0*	*2.1*	*3.3*	*4.0*	*3.1*
LSD (5%)	*1.3*	*0.3*	*0.6*	*0.8*	*0.5*
F ratio (Location × Center)	*1.1ns*	*6.7**	*3.8ns*	*6.5**	*7.9**
Location mean					
Charleston Gray	7.7	2.1	3.4	3.9	3.1
Crimson Sweet	6.9	2.0	3.1	3.4	2.8
Sugar Baby	4.2	2.1	2.7	3.1	2.6
Mean	*6.3*	*2.1*	*3.0*	*3.5*	*2.9*
LSD (5%)	*0.9*	*0.2*	*0.4*	*0.6*	*0.3*
F ratio (Center)	*32.7***	*0.6ns*	*8.4**	*4.9**	*6.8**
Correlation (Mean rating vs. week 5) = –0.01ns					
Correlation (Mean rating vs. week 7) = 0.68**					
Correlation (Mean rating vs. week 9) = 0.60**					

[z] Data are means of 3 replications of 3 plants/plot (canopy size rating is also averaged over 3 border row treatments). Canopy size was rated 1 to 9 (1–3 = small vines, 4–6 = medium sized vines, 7–9 = large vines).
ns, **, * Indicates correlations not significant, or significant at the 1 and 5% levels, respectively.

Researchers report that more fruit were produced with closer spacing, although each fruit had less biomass (Duthie et al., 1999a, 1999b; Elmstrom & Crall, 1985; Gilreath et al., 1987; NeSmith, 1993). Increased density and thus competition in another cucurbit, cucumber, resulted in lower mean fruit number per plant. Fruit weight per plant was shown to decrease with increasing density (Bach & Hruska, 1981; Delaney et al., 1983; Schultheis et al., 1997b; Staub et al., 1992; Widders & Price, 1989).

The above effects on fruit yield result from competition from neighboring plants. Since our study made no use of different plot sizes, differences in vine length among the cultivars tested may have resulted in different levels of competition. Long-vined cultivars such as 'Charleston Gray' grow faster and shade adjacent rows more than short-vined cultivars such as 'Sugar Baby'. Since more soil area would be covered by large-vined cultivars, the effects on other cultivars would be similar to increased planting densities or reduced row spacing. The only difference between 'Charleston Gray' and 'Crimson Sweet' was that 'Charleston Gray' had a greater vine size rating at Kinston. This would lead to increased shading of 'Crimson Sweet' borders than with itself as a border. We expected higher total fruit weight for 'Charleston Gray' bordered by either 'Crimson Sweet' or 'Sugar Baby' to result from longer vine lengths and greater canopy, but found no total fruit weight differences between 'Charleston Gray' centers and different borders. Higher total fruit weight for 'Crimson Sweet' centers with 'Sugar Baby' borders at Kinston were likely due to competition effects resulting from canopy differences. Since 'Crimson Sweet' has greater canopy coverage than 'Sugar Baby' (even though average vine length was not different), 'Crimson Sweet' was still able to out-compete 'Sugar Baby' borders, resulting in higher total yields.

Differences in vine traits may also account for yield differences seen in total and marketable fruit number and marketable weight per fruit. When 'Charleston Gray' was grown with 'Crimson Sweet' in the border rows, more total fruit were produced at Clinton, but that was compensated for by a large increase in percentage of culls produced. 'Crimson Sweet' centers and 'Sugar Baby' borders also produced significantly more total and marketable fruit numbers at Kinston than when it was bordered by 'Charleston Gray' or itself. 'Crimson Sweet', like 'Charleston Gray', also had a larger canopy so that it could have obtained more solar energy to produce more fruit weight or number.

Effects of border competition may be due to the shading of adjacent plants by large, competitive neighbors. Large plants may also be competing better for nutrients and water in the soil. A plant having a lower competing ability produces less leaf area per plant or slower fruit development when competition against it is high, such as with high plant densities in cucumber (Schultheis et al., 1997b). This could be a possible explanation for the higher total fruit weights found for 'Crimson Sweet' when grown with 'Sugar Baby' as a border. However, these questions will have to be answered in future studies, since we did not measure leaf area, root size or water and nutrient uptake of plants in the border and center rows in this study.

Not all of our findings can be explained through differences in competing ability. Yield results for treatments having a 'Sugar Baby' center do not fit what would be expected in relation to competing ability. Instead of having the highest total yield when bordered by itself, yields were the lowest. 'Sugar Baby' also produced more total fruit when bordered by 'Crimson Sweet', a cultivar with larger vines.

According to Fasoula (1990), auto-competition occurs when genetically identical genotypes compete equally for environmental resources, as was the case for our treatments where border and center cultivars were the same. Allo-competition occurs when dissimilar genotypes share resources unequally, as was the case for border and center cultivars being different cultivars. Nil-competition is the absence of competition, where every plant can exploit resources according to its genetic potential. In bread wheat, there was a negative correlation between yield and competing ability. 'Sugar Baby' has lower competing ability than either 'Charleston Gray' or 'Crimson Sweet', perhaps because of its smaller vine length and less canopy ground coverage.

Previous research on watermelon showed that pollen production, nectar volume, and sugar content of nectar were important in determining the number of honeybee visits and the resulting fruit yield (Wolf et al., 1999). If more pollen were produced by 'Crimson Sweet' followed by increased bee visitation, more 'Crimson Sweet' pollen would be deposited on female flowers. In the case of 'Sugar Baby' yield, 'Crimson Sweet' pollen from adjacent rows may outcompete 'Sugar Baby' pollen resulting in more successful fruit set. In a study using different pollenizers including 'Crimson Sweet' in the production of seedless watermelon, 'Crimson Sweet' produced greater numbers of large (>7.3 kg) seedless fruit than with the other pollenizers 'Fiesta' and 'Royal Sweet' (Fiacchino & Walters, 2000).

Researchers evaluating the root distribution of watermelon grown either as a direct seeded or transplanted crop found that direct-seeded plants developed vigorous, extended tap roots, while transplants produced more extensive lateral root systems near the soil surface (Elmstrom, 1973). Differences in root competition for nutrients may explain further the small border by center interaction seen in our experiment as well as the yield trend for 'Sugar Baby' when grown with either itself or 'Crimson Sweet' in the border. Additional studies are needed to determine whether watermelon cultivars differ in root size and distribution.

Cucumber is the only cucurbit for which competition and plot borders have been studied extensively. Unbordered plot ends resulted in a yield inflation of 5 to 21%. However, overall rankings of cultivars were not affected, so that unbordered plots could be used for trials where only relative yield performance is desired (Wehner, 1984; Wehner, 1988). Border studies in other crops have resulted in recommendations that plots have some type of end border. Another study specifically on border row effects used contrasting plant architecture of dwarf-determinate vs. tall-indeterminate and gynoecious vs. monoecious to determine border effects. Long-vined cultivars in border rows did have a tendency to reduce center row yields, but the effects were not significant in enough of the treatments to warrant the use of border rows in trialing plots (Wehner & Miller, 1990). Although our experiment showed a small center by border interaction, the overall ranking of cultivars was not affected. Typical high yielding cultivars Charleston Gray and Crimson Sweet had consistently higher total fruit weights compared to 'Sugar Baby' in all center border combinations.

Since center × border interactions were small and involved no changes in rank, it is probably not necessary to control border effects in most watermelon yield trials. However, several options exist for researchers interested in reducing border effects. Multiple-row plots can be used, wide row spacing can be used, or plots may be grouped according to competing ability. When plots consist of multiple rows, two harvesting choices become available. One method would be to harvest only inner rows of a plot so that the yield bias of the outside rows is eliminated. Referred to as the net plot by Kramer et al. (1982), this harvest method has drawbacks limiting its usefulness. When border rows are discarded, trials have a reduced sample area making random effects more important. Net plots have also been shown to result in a higher coefficient of variation (CV) in both proso millet (Nelson, 1981) and spring wheat (Kramer et al., 1982). The same study on wheat suggested that harvesting all rows of multiple row plots is better than harvesting just the center rows. Thus, sampling a larger area reduces the CVs, reduces the border effects, and increases the heritability. Unfortunately, the use of border rows will greatly increase the size of a trial as well as the amount of seeds needed per cultivar.

One method for controlling intergenotypic competition would be to increase the spacing between rows. This would greatly increase the size of the trial. Wider row spacing also has the potential of introducing bias due to different genotypic reactions to increased spacing.

Another method for controlling intergenotypic competition, and the resulting border effects, would be to group cultivars according to competing ability. Cultivars could be divided into groups according to competitive ability (David et al., 1996). Competition effects could then be ignored. Watermelon cultivars could be classified based on vine length. A study conducted on a wide range of watermelon cultivars found standard-type cultivars had vine lengths ranging from 2.8 m to 7.4 m, and dwarf cultivars with vine lengths of 1.2 m to 2.7 m (Neppl & Wehner, 2001). One major concern with the grouping concept is the possible introduction of cultivar estimate bias due to plot heterogeneity which would need to be addressed in the restricted randomization (David et al., 1996).

Commercial watermelon growers are generally not interested in the performance of individual plants. Rather, their goal is to increase marketable yields per unit of land area. Plant breeders are interested in simulating the environment of grower's fields, but are restricted by the need to evaluate as many cultivars as possible while keeping costs low. Single-row plots are sufficient in early trialing stages since there was a small (although significant) center × border interaction, which did not involve change in cultivar rank. Testing at later breeding stages would benefit from conducting trials with multiple row plots or grouping cultivars according to vine length. Cultivars having extreme plant architecture (dwarf vines for example) probably should be tested in separate trials to reduce yield bias due to competition. Further study of border competition using more extremes of plant architecture such as dwarf or citron types may help further refine which cultivars may be grown adjacent to one another without significant yield bias. Inclusion of long-vined cultivars such as Charleston Gray and short-vined cultivars such as Sugar Baby would be useful for comparisons. Additional investigation of pollen transfer, pollen competition, and root distribution may also further explain the anomalous high yields for 'Sugar Baby" when bordered by 'Crimson Sweet'.

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