Plant Spacing Influences Watermelon Yield and Yield Components

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Abstract. Watermelon [*Citrullus lanatus* (Thunb.) Matsum & Nakai] cultivars StarBrite and Crimson Sweet were grown during 1991 and 1992 in rows 1.5 m apart at plant spacings of 0.9, 1.5, or 2.2 m. Total fruit yield, marketable fruit yield, fruit-weight distribution, and estimated gross returns were determined for each spacing treatment. Total and marketable fruit yields were greater overall for 'StarBrite' than for 'Crimson Sweet'. Except for 1991 'Crimson Sweet' yields, marketable fruit yields per unit land area increased 29% to 34% as plant spacing decreased from 2.2 to 0.9 m. The yield component contributing the most to increased yields with high-density plantings was increased fruit count per unit land area. Average fruit weight responded only slightly to decreased plant spacing. Fruit-weight distribution on a relative frequency scale was stable regardless of plant spacing or production year. The potential for increasing gross returns per unit land area exists by increasing watermelon plant populations beyond the current Georgia recommendation of 2500 to 3000 plants/ha.

There are many reports and reviews on the theoretical aspects of the relationship between crop yield and plant population density (Pant, 1979; Stang et al., 1979; Thomley, 1983; Willey and Heath, 1969). In general, increasing a plant population produces a greater biological yield per unit land area for most crops up to some upper limit or threshold density for the species, after which further increases in plant density either maintain the same yield or cause yield decline (Weiner, 1990; Willey and Heath, 1969). However, the effect of plant population on economic yield is not as straightforward. To achieve the highest yield of economic product per unit land area, crops should intercept solar radiation fully during the growth stage, when photosynthesis contributes carbohydrates to the economic product (Hall, 1990). The threshold plant population beyond which yield does not increase depends on environmental factors (Dweikat and Kostewicz, 1989; Thomley, 1983; Weiner, 1990). Also, plant population can influence crop × pest interactions. For instance, a closer plant spacing may

give crops a competitive advantage over weeds or provide ecological weed control (Auld et al., 1987; Weiner, 1990; Zimdahl, 1980). Increased plant density may discourage colo-

nization by certain insects or reduce the percentage of insect-damaged plants (Power and Kareiva, 1990). In terms of disease pressure, high-density plantings may cause more rapid dissemination of certain pathogens, or, as with insect damage, there may be a reduced percentage of the population that is infected by certain other diseases (Mundt, 1990). Additionally, C partitioning is not constant as planting density changes; thus, an optimum density for vegetative growth is not necessarily the optimum density for fruit yield (Harper, 1977).

For fresh vegetable crops, product quality must be considered when examining the effects of plant population on yield. Several investigations have revealed increased marketable vegetable crop yields per unit land area as plant population increases (Cantliffe and Phatak, 1975; Knavel, 1991; Stoffella and Bryan, 1988; Stoffella et al., 1988; Widders and Price, 1989). However, there is a paucity of information concerning the influence of plant population on watermelon yield and yield components, particularly for some of the new hybrid cultivars that are available to growers (Brinen et al., 1979). The recommended plant population density for Georgia watermelons is 2500 to 3000 plants/ha (Granberry et al., 1986). This density is less than that reported to have increased marketable watermelon yields else-

Table 1. Total and marketable fruit count, fruit weight, and average individual fruit weight of 'StarBrite' and 'Crimson Sweet' watermelons grown at three plant spacings during 1991 and 1992.

Plant spacing (m)	StarBrite		Crimson Sweet	
	1991	1992	1991	1992
<i>Fruit/ha (1000s)</i>				
0.9	10.75	19.07	5.75	17.57
1.5	8.62	14.17	4.00	12.42
2.2	6.50	13.00	3.75	10.75
Linear significance	*	*	NS	**
<i>Total fruit wt (t·ha⁻¹)</i>				
0.9	69.7	154	27.0	125
1.5	59.9	109	20.1	86.8
2.2	46.6	111	22.7	79.2
Linear significance	*	*	NS	**
<i>Average fruit wt (kg/fruit)</i>				
0.9	7.4	8.0	5.3	7.1
1.5	7.1	7.7	5.7	7.0
2.2	7.8	8.5	7.0	7.4
Linear significance	NS	NS	**	NS
<i>Marketable fruit wt (t·ha⁻¹)</i>				
0.9	49.7	125	12.3	88.2
1.5	42.8	84.1	11.3	60.5
2.2	37.2	96.9	14.6	65.6
Linear significance	*	*	NS	*
<i>Marketable fruit/ha (1000s)</i>				
0.9	5.64	12.56	1.54	9.23
1.5	4.61	8.72	1.28	6.92
2.2	4.10	9.49	1.54	7.18
Linear significance	*	*	NS	*

NS,*,**Nonsignificant or significant at $P \leq 0.05$ or 0.01, respectively.

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where (Brinen et al., 1979). The objective of this research was to examine the influence of plant spacing on yield and yield components using a traditional open-pollinated watermelon cultivar (Crimson Sweet) and a new hybrid cultivar (StarBrite).

Experiments were conducted at Griffin, Ga., during 1991 and 1992 on a Cecil sandy clay loam (clayey, kaolinitic, thermic Typic Hapludult). On 31 May 1991 (day of year: 151) and 12 May 1992 (day of year: 133), 4-week-old 'StarBrite' and 'Crimson Sweet' watermelon transplants were planted in the field at several plant spacings. A 2×3 factorial arrangement of treatments within a randomized complete block with three replications was used. Rows were 1.5 m apart for each plot, and in-row plant spacings were 0.9, 1.5, or 2.2 m, a configuration resulting in plant populations of 7410, 4444, and 3030 plants/ha, respectively. Plots were six rows wide by 13 m long during 1991 and four rows wide by 13 m long during 1992. Transplants were hand-planted and watered. Before transplanting them, a 10N-4.4P-8.3K fertilizer was incorporated at 560 kg/ha. An additional 78 kg N (as ammonium nitrate)/ha was surface-sidedressed weeks after transplanting. Weeds were controlled using a combination of recommended herbicides and hand weeding. Recommended insect and disease control measures also were used. Overhead-sprinkler irrigation was used to supplement rainfall. A hive of bees was located near the research plots each year.

A once-over harvest was made for the two experiments on 20 Aug. 1991 (day of year: 232) and 29 July 1992 (day of year: 211) to determine the distribution of fruit weights, independent of time. Watermelons were harvested from the two center rows of each plot in a total harvest area of 39 m². All fruit in the harvest area were picked and weighed individually. Soluble solids concentration (SSC) was measured in all fruit in 1991 and in a subsample in 1992. These data revealed that, in general, fruit weighing >5 kg had an SSC >9%, a result indicating a sweetness level between "good" and "very good" (Hurst, 1988). Fruit weighing ≥ 6.8 kg were considered marketable. Data were tested using analysis of variance to determine the significance of cultivar and spacing main effects and their interaction on various yield components. Regression was performed for each cultivar to determine the effects of plant spacing on crop attributes of interest. Gross returns were calculated using a regression equation obtained for marketable yield to predict yield for a particular plant spacing and by multiplying this yield by the 5-year average price of \$0.13/kg fruit weight (Mizelle, 1990). Additionally, fruit-weight class intervals of 2 kg were constructed for the individual fruit-weight data. The relative frequency in each class interval, based on fruit count, was calculated. These data were plotted as cumulative relative frequency of the fruit count for individual fruit-weight classes.

Cultivars differed ($P \leq 0.05$) in fruit count, total fruit weight, and average fruit weight during both years, but there were no signifi-

cant cultivar $\times$ spacing interactions. 'Crimson Sweet' yielded less than 'StarBrite' during both years (Table 1). The cultivar difference likely was due to overall increased plant vigor and more uniform growth and fruit set of 'StarBrite' compared to those of 'Crimson Sweet' (Granberry, 1988).

Yields during 1991 were substantially lower than during 1992. The major yield component contributing to the yield differences between years was greater fruit counts during 1992, although average fruit weights were slightly higher during 1992. The 1991 crop was planted later in the growing season than the 1992 crop (day of year 151 vs. 133), and there may have been some decrease in fruit set due to higher temperatures (data not presented) during the early part of the growing season. Night temperatures were higher the first 20 to 25 days after transplanting for the 1991 crop than for the 1992 crop. Rainfall distribution was not a problem, as supplemental irrigation was used during both years. Therefore, the reason for such a vast difference between years is not clear.

Total and marketable yields (Table 1) increased as plant spacing decreased from 2.2 to 0.9 m. The yield component that contributed most to greater yields under high-density plantings was increased fruit count per unit land area. Average fruit weight decreased some as plant spacing decreased, but the magnitude of difference was inconsequential, except for the 1991 'Crimson Sweet' crop. Hence, 7410 plants/ha did not produce substantially smaller

fruit than 3030 plants/ha. These results are consistent with previously reported plant-spacing responses of 'Charleston Gray' watermelon by Brinen et al. (1979), who reported a 13% to 14% reduction in average marketable fruit weight and a total marketable yield increase per unit land area of 37% to 48% when plant spacing was reduced from 2.4 to 0.6 m.

Information concerning total and marketable yields traditionally is reported for many watermelon experiments. However, these data alone do not adequately describe fruit-weight distribution. Cumulative relative frequencies of watermelon fruit count over various fruit-weight class intervals indicated that fruit-weight distribution for a particular cultivar was similar, regardless of spacing or year (Fig. 1). One first-order logistic function was fitted to all distribution data for each cultivar. Data farthest from the average cumulative distribution line are the extremes of the experiment (i.e., the 0.9-m plant spacing in 1991 vs. the 2.2-m plant spacing in 1992).

The closer plant spacings reduced total fruit weight and count per plant under some conditions (Table 2), as reported previously for watermelon and other vegetable crops (Brinen et al., 1979; Knavel, 1991; Staub et al., 1992; Stoffella and Bryan, 1988; Widders and Price, 1989). However, producers are not concerned with an individual plant's performance. Instead, their goal is to increase total marketable yield per unit land area in an economically efficient manner to boost gross returns. Gross returns for watermelon derived from

Fig. 1. Cumulative relative frequency of fruit count in various weight classes for 'StarBrite' and 'Crimson Sweet' watermelons grown in 1.5-m-wide rows with plant spacings of 0.9, 1.5, or 2.2 m during 1991 and 1992. The solid line is a fitted, first-order logistic function for all data points for a particular cultivar.

Table 2. Fruit count and fruit weight per plant for 'StarBrite' and 'Crimson Sweet' watermelons-grown-at three plant spacings during 1991 and 1992.

Plant spacing (m)	StarBrite		Crimson Sweet	
	1991	1992	1991	1992
<i>Fruit/plant</i>				
0.9	1.5	2.7	0.8	2.5
1.5	2.0	3.3	0.9	2.9
2.2	2.1	4.3	1.2	3.6
Linear significance	NS	**	NS	***
<i>Fruit wt (kg/plant)</i>				
0.9	9.9	21.9	3.8	17.9
1.5	14.1	25.7	4.7	20.4
2.2	15.2	37.0	7.6	18.1
Linear significance	NS	**	*	NS

ns,*,**,**Nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively.

Table 3. Gross returns for 'StarBrite' and 'Crimson Sweet' watermelons grown at three plant spacings during 1991 and 1992.

Plant spacing (m)	StarBrite		Crimson Sweet	
	1991	1992	1991 ²	1992
<i>\$/ha (1000s)</i>				
0.9	6.5	15.2	---	10.8
1.5	5.7	13.6	---	9.5
2.2	4.9	11.7	---	8.0

²Yield and dollar values did not respond to plant spacing for this cultivar in 1991.

yields estimated by regression, like those for cucumber derived by Cantliffe and Phatak (1975), indicate that returns increased with high-density plant populations (Table 3). The most significant additional input per unit land area for the grower is increased transplant or seed cost.

Additional research is needed to determine the carrying capacity or upper limit of yield response to plant population increases for 'Crimson Sweet', 'StarBrite', and other watermelon cultivars. However, these results indicate that, in terms of marketable yield and gross returns, a grower's advantage would reside in increasing plant populations if the current population being used is within 2500 to 3000 plants/ha. A grower may not want to increase plant population on a fixed acreage, however, since the market is finite. Instead, a grower may reduce acreage and use high-density plantings to achieve similar production from fewer acres, a strategy resulting in savings on fertilizer, pesticides, machinery, and irrigation. Also, there would be less envi-

ronmental exposure to chemicals and less total water used to grow the crop.

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