TITLE

Grafted Watermelon: Evaluation of Planting Density for High Yield, 2008 Results

PERSONNEL

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INTRODUCTION / PREVIOUS RESEARCH

Watermelon (*Citrullus lanatus* (Thunb.) Matsum. & Nakai) is a major vegetable crop in the U.S., and increasing in popularity. Total area has changed from 189 thousand hectare in 1998 to 154 hectare in 2006 (U.S. Department of Agriculture, 2007). Production has increased from 37 million cwt in 1998 to 42 million cwt in 2006 (U.S. Department of Agriculture, 2007). At present, total value of watermelon production is $435 million. It is clear that though area has decreased over the years, there is increase in the yield that might be attributed to improved varieties and cultural practices. Still, watermelon is always under threat from diseases like *Fusarium* wilt and *Phytophthora*. In recent years, losses caused by these diseases were as high as 100%. There is growing demand of firm fresh-cut watermelon in the United States and fresh-cut watermelon can quickly become mushy. Core (2005) reported that fruits harvested from grafted plants are 25 to 30% firmer and have the advantage of resistance to many soil borne diseases including *Fusarium* wilt.

High yield is one of the major traits growers must have to maximize profits. Successful breeding efforts have increased yield and quality of watermelon over the past several decades. There are cultivars available that are resistant to diseases. Other techniques can be used to improve yield; such as following good management practices and perhaps grafted watermelon. Cohen et al. (2007) have reported several advantages of using grafting watermelons with interspecific squash and *Lagenaria* rootstocks. Pulgar et al. (2000) confirmed higher N uptake by grafted plants which otherwise remain unused in the soil. Water logging is another problem in watermelon cultivars. Water logging leads to anaerobic conditions in field which can kill the plants. Studies have shown that water logging tolerance is also increased in grafted plants (Yetisir and Sari, 2003).

The use of grafted watermelons is not common in the United States and is likely attributed to the high cost of grafting and loss of grafted plants due to high wind conditions (King and Davis, 2006). There are some key advantages in using grafted watermelon transplants. Use of rootstocks has been successful in enhancing the vigor of the scion by imparting resistance to soil borne pathogens (*Fusarium* and *Phytophthora*), low temperature, salinity, and increased uptake of nutrients (Lee and Oda, 2003; Ruiz *et al*., 1997; Miguel *et al*., 2004; Boughalleb *et al*. 2007). Use of rootstocks can minimize cost of production because growers may not have to buy as many pesticides and fungicides. Taylor et al. (2006) reported from Lane, Oklahoma, that use of grafted watermelon can double the yield as compared to nongrafted watermelon in a field infested with Fusarium wilt. Commonly used rootstocks for watermelon are ‘Strongtosa’ (interspecific hybrid between *Cucurbita maxima* and *Cucurbita moschata*), ‘Destiny III’ (*Cucurbita pepo*), ‘Red Kuri’ (*Cucurbita maxima*), ‘Long Island Cheese’ (*Cucurbita moschata*), ‘Birdhouse’, and ‘Emphasis’ (*Lagenaria* sp.)(King and Davis, 2006). Hassell also reported that mini watermelon yields were increased a fruit or two per plant with grafted versus non grafted plants (personal communication).

Water, space, and sunlight are important factors which plants compete for in any plant stand. Increase in plant density in watermelon increased yield and number of fruits per unit area, whereas yield and number of fruits per plant decreased (Sanders et al., 1999; Goreta et al., 2005). They also reported that higher density significantly decreased fruit size. So, optimizing plant density is important in maximizing yields and quality in watermelon. Currently, commercial triploid watermelon eg Tri-X-313, is planted at 8 feet by 3 feet (2.4m x0.9m) or 25 square feet per plant (2.2 m^2) commercially. There is need to optimize plant density in watermelon production, especially when propagule cost is high for grafted watermelon. The current cost of a grafted plant is approximately $1.25 compared with 10 cents for a triploid seed plus transplant production costs (about 40 cents total). Taylor et al., (2006) reported that certain rootstocks produce a more vigorous and productive plant. Reduction in costs per hectare might be achieved with grafted plants if one could reduce plant populations yet attain similar yields compared to when a nongrafted watermelon seedling was planted at a traditional planting density. A reduction in planting density may make the use of grafted plants more economically feasible.

Triploid watermelon is in greatest demand by consumers versus diploid watermelons. Triploid watermelon accounted for 78% of watermelon sold in United States in 2006. In addition to the fruit being seedless due to polyploidy, it produces other advantages due to heterosis of the F1 hybrid. These major benefits of triploid watermelons are better fruit quality in terms of sugar content, vigorous plants, and better shipping quality, resulting in better economic returns (Sun and Luo, 2006).

OBJECTIVES

The objectives of this research were to study the effects four plant densities had on yield and quality of watermelon with grafted versus nongrafted watermelon.

METHODS

Locations

The study was conducted across four southeastern locations; Coastal Research & Education Center, Charleston, South Carolina; North Florida Research and Education Center Quincy, Florida; University of Georgia, Tifton, Georgia; and Cunningham Research Station, Kinston, North Carolina. The experiment was conducted during the summer season of 2008.

Rootstocks

Seedless watermelon cultivar Tri-X-313 was grafted on to 'Shintosa Camel', a squash inter-specific hybrid. The hybrid was supplied by the Coastal Research & Education Center, Charleston, South Carolina.'Tri-X-313' (nongrafted) was used as the control. The one cotyledon procedure was used for grafting.

Densities

Grafted watermelon plants and Tri-X-313 (non-grafted) plants were planted at four plant densities.

8' x 1.0' (6 ft long plots; 8 ft^2/plant)
8' x 3.0' (18 ft long plots; 24 ft^2/plant)
8' x 5.0' (30 ft long plots; 40 ft^2/plant)
8' x 7.0' (42 ft long plots; 56 ft^2/plant)

There were 8 total treatments planted in each experimental location and each treatment was replicated four times. There were 3-row plots. The central row was the treatment row and border rows were planted with 'Tri-X-Palomer'. Each plot consisted of 6 plants with 14' border between plots. Rows middles were separated by 8'. 'SP-4' was used as pollenizer and was placed between 3rd and 4th plant within each plot.

Data collected

Data were recorded for yield and quality traits in grafted watermelon. Each fruit was harvested and weighed. Five randomly selected fruit from each plot were taken for quality measurements on the second harvest. Total yield (cwt/acre), total number (thousand per acre), weight per fruit (lb), fruit weight per plant (lb), and fruit number per plant were recorded as yield traits. Total soluble solids (^{o}brix), hollow heart, fruit shape (length(L), diameter(D) and LD ratio) and hard seeds were recorded as quality traits. Hollow heart was rated on a 0-4 scale with 0 as no hollow heart and 4 with severe hollow heart in which the flesh was separated such that it exposed the rind when the fruit was cut open. Hard seeds were rated on a 0-3 scale with 0 equating to no hard seeds. Total soluble solids (^{o}brix) were recorded using a digital hand refractometer by taking a flesh sample from the middle of the fruit.

Cultural practices

All grafted plants were provided by Dr. Richard L. Hassell, Clemson University CREC, Charleston, SC. The graft type used was the one cotyledon procedure. At each of the five locations plots were set up on black plastic drip irrigation, eight foot centers, three feet between plants, six plants per plot. 'SP-4' was used as a pollenizer and placed between the grafted plants. Recommended cultural practices were followed according to each states' recommendations. Fruit were harvested four times at weekly intervals. The first harvest was considered the early harvest while the main harvest consisted of the other three harvests.

Data for given traits were analyzed using the MEANS, CORR, and GLM procedures of SAS (SAS Institute, Inc., Cary, NC). Data are means of five locations and four replications summed over four harvests.

RESULTS

Data were analyzed and the main effects between rootstock and spacing were made. Where appropriate, the interactions between rootstock and spacing were made. There were total 4 harvests. Harvest 1 was considered an early harvest whereas harvests 2, 3, 4 were treated as the main harvest. Sum of early and main harvest was total harvest (harvests 1 through 4).

Early harvest

Use of rootstock 'Shintosa Camel' significantly increased fruit number (2.7 Th/A) and fruit weight (483.8 cwt/A) compared with nongrafted Tri-X-313 on a per acre basis (Table 1). Weight per fruit, fruit weight per plant, and fruit number per plant were not affected by use of rootstock. Plant spacing had a significant effect on yield traits (Table 2). Closer spacing (8' x 1') resulted in higher fruit numbers (4.9 Th/A) and fruit weight (843.7 cwt/A) than the other spacing treatments. Yield reduction leveled off at the 8' x 5' spacing. However, when considering yields on a per plant basis, wider spacing (8' x 7' and 8' x 5') resulted in significantly higher fruit weights and fruit numbers per plant than the closer in-row spacings. The closest spacing had lowest fruit numbers and weights on per plant basis.

Plants grafted with 'Shintosa Camel' when planted at the 8' x 1' spacing yielded the most fruit weight (971 cwt/A) and fruit number (5.6 th/A) on per acre basis followed by non-grafted plants (716.3 cwt/A and 4.2 th/A, respectively) at same density (Table 3). Wider spacing led to significantly lower fruit yields with both grafted and non-grafted plants. Grafted versus nongrafted plants did not show a significant difference in fruit yields on a per acre basis at the same spacings (except for 8'x 1'). Plants grafted on 'Shintosa Camel' and planted at wider spacings (8' x 7' and 8' x 5') produced significantly higher fruit weight (29.7 lb and 25.3 lb, respectively) and fruit number (1.5 and 1.4, respectively) on a per plant basis than several of the other treatment combinations. Weight per fruit was not affected by any of the treatments. These data suggest that use of rootstock has significant influence in increasing the fruit number and fruit yield on per acre during early harvest.

Main harvest

Use of grafted plants did not show significant increase in fruit weight and fruit number both on a per plant and per acre basis (Table 1). However, fruit size was larger for plants grafted with 'Shintosa Camel'. This was not the case in early harvest. Like early harvest, plant spacing had a significant influence on fruit weight and fruit number (Table 2). Closest spacing (8' x 1') produced significantly higher fruit yields (370.7 cwt/A) and fruit number (2.4 Th/A) than the wider spacing treatments. Yields were similar across the other spacings, the exception being more fruit weight per acre produced at the 8' x 3' spacing than with the widest spacing. Fruit yield and fruit number on a per plant basis, average fruit weight were significantly greater for in-row spacings 3 ft or more compared with the closest spacing (8' x 1').

Plants grafted with 'Shintosa Camel' when planted at 8' x 1' spacing yielded highest fruit weight (421 cwt/A) and fruit number (2.7 th/A) on per acre basis followed by non-grafted plants (320.2 cwt/A and 2.1 th/A, respectively) at same density (Table 3). This indicates that very close in-row spacing has more yields on per acre basis than traditionally used (3 ft) or wider in-row spacings. Use of rootstock did not show any distinct advantage at any of the comparable plant spacings. Fruit size was high at the wide spacing. Fruit weight per plant was significantly higher for plants spaced at the widest plant spacing versus the closest plant spacing. A similar result generally occurred for fruit number per plant.

Total harvest

Yield traits were summed over early and main harvests to obtain total harvest yield. Use of 'Shintosa Camel' significantly produced higher fruit weight per acre, fruit number per acre, and weight per fruit than the nongrafted 'Tri-X-313'(Table 1). However, fruit weight per plant and fruit number per plant was similar regardless as to whether one used grafted or nongrafted plants. Plants established using closer spacing (8' x 1') yielded significantly higher fruit weight per acre (1214.4 cwt/A) and fruit number (7.3 Th/A) followed by 8' x 3' (645.3 cwt/ A and 3.6 th/A, respectively) (Table 2). Wider spacing had even lower yields. Weight per fruit, fruit weight per plant, and fruit number per plant was typically highest at 8' x 7' spacing.

Grafted plants spaced 8' x 1' produced significant higher total fruit weight and number per acre than any other treatment (Table 3). The next highest yields were obtained with nongrafted plants spaced at same density. Wider spacings with or without grafted plants produced lower yields than the 8' x 1' spacing and had similar yields at each respective spacing. Grafted plants did not respond at any of the wider plant spacings. Fruit size was not significantly influenced by any treatment; however, there was a general trend towards increased fruit size as spacing between plants increased. Like early and main harvests, total harvest had high fruit weight per plant and fruit number per plant at wider spacings irrespective of whether rootstock was used or not.

Fruit quality

Grafted plants showed significant effects for fruit shape. Fruits from grafted plants were more round in shape (Table 4). Grafted plants did not affect total soluble solids (TSS), incidence of hollow heart, and presence of hard seeds. Again, all these quality parameters were found to be non-significant at all spacings and combinations of rootstock with spacing treatments (Tables 5 & 6).

Conclusion

Irregardless of spacing, the use of grafted plants significantly increased fruit weight per acre, fruit number per acre, and weight per fruit when compared with nongrafted plants. Grafting did not affect the quality of watermelon fruits we measured in these tests. However, it is well documented that grafting often leads to improved flesh firmness. Close plant spacing produced more yield on a per area basis for both grafted and nongrafted plants without affecting the fruit quality. Wider spacing produced more fruit yield per plant with or without use of rootstock. We did not find compensatory yields when spacing grafted plants further apart compared with nongrafted plants. It would appear as though grafted plants in this test yield similarly as nongrafted plants when planting density is adjusted. Therefore, planting density should not be reduced for grafted plants of 'Shintosa Camel' or significant yield reductions will likely occur.

Table 1. Effect of rootstock on fruit yield of watermelon*

		Early harvest			
Rootstock	Fruit number	Fruit wt.	Wt. per fruit	Fruit wt per plant	Fruit number per plant
	(th/ A)	(cwt/A)	(lb)	(lb)	
Tri-X-313	2.1	377.1	18.0	19.4	1.1
Shintosa Camel	2.7	483.8	18.5	24.5	1.3
LSD (α=0.05)	0.4	65.9	ns	ns	ns
		Main harvest			
Tri-X-313	1.1	171.9	14.0	9.2	0.6
Shintosa Camel	1.3	221.5	15.5	11.2	0.7
LSD (α=0.05)	ns	ns	0.4	ns	ns
		Total harvest			
Tri-X-313	3.2	549.0	16.0	28.6	1.6
Shintosa Camel	4.0	705.2	17.0	35.7	2.0
LSD (α=0.05)	0.7	146.1	0.8	ns	ns

*Early harvest: Ist harvest, Main harvest: 2nd, 3rd, and 4th harvest,
Total harvest: Early harvest + main harvest

Table 2. Effect of spacing on fruit yield of watermelon*

		Early harvest			
Spacing (ft)	Fruit number	Fruit wt.	Wt. per fruit.	Fruit wt per plant	Fruit number per plant
	(th/ A)	(cwt/A)	(lb)	(lb)	
1	4.9	843.7	17.5	15.5	0.9
3	2.3	437.2	17.9	24.1	1.3
5	1.3	228.6	18.5	21.0	1.2
7	1.1	212.3	18.9	27.3	1.4
LSD (α=0.05)	1.5	252.2	ns	10.9	0.5
		Main harvest			
1	2.4	370.7	12.6	6.8	0.4
3	1.2	208.1	15.3	11.5	0.7
5	0.7	109.0	15.4	10.0	0.6
7	0.6	98.8	15.5	12.7	0.8
LSD (α=0.05)	0.6	103.1	2.2	2.8	0.2
		Total harvest			
1	7.3	1214.4	15.1	22.3	1.3
3	3.6	645.3	16.7	35.6	2.0
5	1.9	337.6	16.9	31.0	1.8
7	1.7	311.1	17.2	40.0	2.2
LSD (α=0.05)	1.2	240.6	1.0	12.3	0.6

*Early harvest: Ist harvest, Main harvest: 2nd, 3rd, and 4th harvest,
Total harvest: Early harvest + main harvest

Table 3. Fruit yield in watermelon as affected by treatment combination of rootstock with spacing

			Early harvest			
Rootstock	Spacing (ft)	Fruit number	Fruit wt.	Wt. per fruit	Fruit wt per plant	Fruit number per plant
		(th/ A)	(cwt/A)	(lb)	(lb)	
Tri-X-313	1	4.2	716.3	17.6	13.2	0.8
Tri-X-313	3	2.2	416.7	17.4	23.0	1.2
Tri-X-313	5	1.0	181.8	18.3	16.7	0.9
Tri-X-313	7	1.0	193.7	18.5	24.9	1.3
Shintosa Camel	1	5.6	971.0	17.5	17.8	1.0
Shintosa Camel	3	2.4	457.7	18.4	25.2	1.3
Shintosa Camel	5	1.5	275.3	18.8	25.3	1.4
Shintosa Camel	7	1.2	230.9	19.3	29.7	1.5
LSD (α=0.05)		1.4	234.2	NS	10.7	0.5
			Main harvest			
Tri-X-313	1	2.1	320.2	12.3	5.9	0.4
Tri-X-313	3	1.1	168.6	14.2	9.3	0.6
Tri-X-313	5	0.6	105.2	15.1	9.7	0.6
Tri-X-313	7	0.6	93.6	14.5	12.0	0.7
Shintosa Camel	1	2.7	421.2	12.9	7.7	0.5
Shintosa Camel	3	1.4	247.7	17.0	13.6	0.8
Shintosa Camel	5	0.7	112.8	15.5	10.4	0.6
Shintosa Camel	7	0.6	104.1	16.4	13.4	0.8
LSD (α=0.05)		0.6	104.2	2.9	3.6	0.2
			Total harvest			
Tri-X-313	1	6.3	1036.6	15.0	19.0	1.2
Tri-X-313	3	3.3	585.2	15.8	32.2	1.8
Tri-X-313	5	1.7	287.1	16.7	26.4	1.5
Tri-X-313	7	1.6	287.3	16.5	36.9	2.0
Shintosa Camel	1	8.3	1392.2	15.2	25.6	1.5
Shintosa Camel	3	3.8	705.4	17.7	38.9	2.1
Shintosa Camel	5	2.2	388.1	17.2	35.6	2.0
Shintosa Camel	7	1.8	335.0	17.6	43.1	2.3
LSD (α=0.05)		1.2	229.0	NS	12.6	0.6

*Early harvest: Ist harvest, Main harvest: 2^{nd}, 3^{rd}, and 4^{th} harvest,
Total harvest: Early harvest + main harvest

Table 4. Effect of rootstock on fruit quality of watermelon

	TSS	Hollow heart	Hard seed	Fruit shape
Tri-X-313	12.29	0.91	0.19	1.26
Shintosa Camel	12.11	0.98	0.23	1.24
LSD (α=0.05)	ns	ns	ns	0.95

Table 5. Effect of spacing on fruit quality of watermelon

Spacing (ft)	TSS	Hollow heart	Hard seed	Fruit shape
1	12.2	0.9	0.2	1.2
3	12.2	0.8	0.2	1.2
5	12.1	0.9	0.2	1.3
7	12.4	1.2	0.2	1.3
LSD (α=0.05)	ns	ns	ns	ns

Table 6. Fruit quality in watermelon as affected by treatment combination of rootstock with spacing

Rootstock	Spacing (ft)	TSS	Hollow heart	Hard seed	Fruit shape
Tri-X-313	1	12.12	0.63	0.23	1.23
Tri-X-313	3	12.18	0.86	0.18	1.25
Tri-X-313	5	12.41	0.94	0.18	1.25
Tri-X-313	7	12.46	1.20	0.18	1.29
Shintosa Camel	1	12.23	1.16	0.15	1.21
Shintosa Camel	3	12.19	0.80	0.20	1.23
Shintosa Camel	5	11.78	0.85	0.28	1.26
Shintosa Camel	7	12.26	1.12	0.29	1.26
LSD (α=0.05)		ns	ns	ns	ns