Strawberry Cultivar Evaluation on Farms Utilizing Conventional Growing Methods in the Coastal Plain of Virginia

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Summary, In North America strawberries (*Fragaria x* ananassa Duch.) are one of the major high value crops. According to the national agriculture census data, in 2012 there were 313 farms growing strawberries on 290 acres in Virginia (USDA, 2012). In this study we tested ten commercially available June-bearing cultivars ('Benicia', 'Camarosa', 'Camino Real', 'Chandler', 'Festival', 'Flavorfest', 'Radiance', 'Treasure', 'Sweet Charlie', and 'Winterstar') and two day-neutral cultivars ('Albion' and 'San Andreas') for their suitability in Virginia production systems at three on-farm locations for yield performance, fruit quality, sweetness, vegetative growth, and fruit size. The highest total yields averaged across all three locations were 'Benicia', 'Camino Real', 'Chandler', and 'Camarosa'. 'San Andreas' yields for the year may have exceeded the June bearing cultivars if it had been allowed to be carried over into fall season. 'Flavorfest', followed by 'Sweet Charlie', and 'Albion' produced the sweetest berries tested. In Westmoreland 'Benicia', 'Camino Real', 'San Andreas' and 'Flavorfest' were the cultivars with the largest average berry size. Based on this 1-year study 'Camino Real', 'Benicia', 'Chandler', and 'Camarosa' are the recommended June-bearing cultivars and 'San Andreas' the recommended day-neutral cultivar.

The strawberry production acreage in Virginia is predominantly Pick-your-own, where the consumers come directly to the farm and harvest the berries themselves. Similar to the other Mid-Atlantic states of Delaware, Maryland, New Jersey, and West Virginia, the plasticulture strawberry growers in Virginia currently grow three main cultivars; 'Chandler' and 'Camarosa', developed in the University of California (UC), Davis, program and 'Sweet Charlie', developed in the University of Florida program (Hokanson and Finn 2000). These three cultivars were bred for the commercial pre-pick and shipping markets for their intended geographic locations, but have been adapted for you-pick/ direct to consumer markets in the Mid-Atlantic and the southern region of the United States. The majority of the strawberry acreage in Virginia is grown using the annual plasticulture production system, where plug plants are transplanted in the fall for harvest in the spring.

The performance of specific cultivars is sometimes correlated greatly to the use of fumigation and further to microclimatic conditions present at the farm in which they are being grown. Studies at University of California at Davis showed significant variations in plant diameter and fruit yield due to the interaction of cultivar selected and horticultural system utilized (Shaw and Larson 2008).

After the phase-out of methyl bromide use as a fumigant there has been a shift towards a production system without preplant fumigation for pest control on some farms. In Florida total marketable yield (417g/plant fumigated vs. 227g/plant non-fumigated) and average fruit weight (17.4g fumigated vs. 15.6g un-fumigated) was reduced significantly when grown in un-fumigated soil (Chandler et al. 1998). In contrast to these findings in Florida it was shown in Virginia during crop years 2013-14 and 2014-15 that yields across the non-treated control, the

fumigated plot, and some soil solarization treatments were not different in a new strawberry production site (Samtani et al. 2017).

Cultivar evaluations are important for determining cultivar suitability for a region. Cultivar adoption by growers is currently driven by factors such as processing and marketing practices, resistance to insect pests and disease, larger and higher-quality fruit, and private sector breeding programs (Shaw and Larson 2008). When modern cultivars were compared to cultivars released from UC Davis between 1945-1966, values for fruit yield, fruit size, appearance, and firmness, across all management systems showed 47-140% greater values for the modern cultivars with the largest increase coming in fruit yield (Shaw and Larson 2008; Hokanson and Finn 2000). Each commercially available variety brings its own advantages and disadvantages. In other trials (Lawson, 2008; Maine, 2009; Molinar, 2001; O'Malley, 2001, 2003; Roegge, 2013), the newer varieties of both day neutral and June bearing strawberries showed merit and warranted trialing in Virginia.

For Virginia growers, finding cultivars best-adapted to our environment among those developed for other regions has become a more important and relevant consideration. Significant genotype x environment interaction (GEI) can be seen with modifications of planting date, plant density, environment, and genotype selections (Lopez-Medina et al. 2001). Each grower has adapted and modified systems that work for them, in their environment and under site specific conditions. Factors such as row and plant spacing, bed dimensions, and preplant pest treatments will influence crop yield. In three different environments across California, in 47 strawberry cultivars significant genetic differences to powdery mildew were demonstrated (Nelson et al. 1996) Potato (*Solanum tuberosum)* production across four environments in Kenya

was greatly influenced by environmental factors such as rainfall and temperature, leading to the presence of pathogenic pests (Muthoni et al. 2015). In tomatoes it was found that the GEI varied significantly when data on the marketable yield were analyzed (Panthee et al. 2013). Environmental factors such as soil pH, available potassium, and phosphorus fertility accounted for a large amount of the genotype x environment interaction (Ortiz et al. 2007).

The objective of this study was to show growers in Virginia what commercially available strawberry cultivars existed as well as show them the disease tendencies, yield potential, and fruit characteristics of those cultivars grown at different geographic locations and under different management techniques.

Materials and Methods

On farm studies were initiated in fall of 2013 to evaluate commercially available strawberry cultivars 'Albion', 'Benicia', 'Camarosa', 'Camino Real', 'Chandler', 'Festival', 'Flavorfest', 'Radiance', 'San Andreas', 'Sweet Charlie', 'Treasure', and 'Winterstar' (See Table 1 for details on cultivars). Strawberry plug plant material was supplied by the North Carolina State University plant nursery with the exception of 'Flavorfest' provided by Kube-Pak (Allentown, New Jersey), and 'Camarosa' and 'Chandler' from Aarons Creek Nursery (Buffalo Junction, Virginia). Studies were established at three locations in the coastal plain of Virginia: in the City of Chesapeake (36.836045, -76.398461, USDA Hardiness Zone 7b), in the City of Virginia Beach (36.714832, -76.016372, USDA Hardiness Zone 8a), and in Westmoreland County (38.130043, -77.047534, USDA Hardiness Zone 7a). All three locations provided preplant soil amendments, frost protection, spring fertility, and pest control on an as needed basis. Soil samples from each location were submitted to the Virginia Tech Soils Testing

Laboratory and lime and fertilizer were applied as per the recommendations prior to the study being established in August of 2013. Additional background information about each location can be found in Tables 2 and 3.

Plant stand count and visual plant health ratings were taken on a monthly basis beginning on 6 November 2013 in Chesapeake, 30 October 2013 in Virginia Beach, and on 28 October 2013 in Westmoreland. The plant health visual ratings were evaluated using a scale of 0 = dead plant to 10 = very vigorous. Leaf canopy diameter readings were taken on 20 March 2014 in the Cities of Chesapeake and Virginia Beach and on 11 March 2014 in Westmoreland County.

Harvest began as soon as ripe fruit was present in the spring and ended when all June bearing varieties had no marketable fruit left on the plant. The plots were harvested two to three times per week during the harvest period. In Chesapeake harvest began on 1 May 2014 and ended on 6 June 2014; in Virginia Beach the harvest period was from 2 May 2014-12 June 2014; in; and in Westmoreland County harvest began on May 8 and ended on 2 June 2014. Total yield, marketable yield, nonmarketable yield, average fruit size, and average fruit weight were calculated over the whole season. Fruits were separated into categories of marketable and nonmarketable in the field. Any incidences of disease were noted on our data collection sheets used during harvest. Unmarketable fruit comprised of small, misshapen, diseased, or deformed fruits and fruits less than 10 g in weight. They were then weighed to determine marketable, unmarketable, and total yields, divided by the number of plants per plot and then expressed as yield per plant. Fruit size was measured using a digital Vernier caliper (Neiko, Taiwan) at the widest point on the berry, which was usually just below the proximal end. After measuring fruit size, berry calyces were removed, placed in labeled, polythene freezer bags for each plot, transported in coolers with freezer packs and placed in freezer at -14.5^{o}C (5.8^{o}F). After the

harvest season, berries were thawed, crushed, and sieved to separate the juice from the pulp. Samples of five berries per plot per week were frozen for testing total soluble solids (TSS) with refractometer (-MA 871, Milwaukee, WI) at 21^{o}C after harvest season ended. Two separate taste tests were conducted on farm in Virginia Beach and at the Hampton Roads AREC. The participants tasted berries from numbered containers not knowing the cultivars that they were tasting. Participants were asked to provide ratings on flavor, firmness, sweetness and attractiveness of fruit. The ratings were from 1 = no flavor, not firm, not sweet, and not attractive to 5 = very flavorful, quite firm, exceptionally sweet, and most appealing.

Data analysis. Prior to running the analysis of variance (ANOVA), data were checked for normality of residuals. A two-way analysis of location by cultivar was done using JMP Pro (version 13: SAS Institute Inc., Cary, NC) for each of the dependent factors including plant health ratings, plant canopy diameter, crop yields, fruit size, and TSS. For canopy readings, averages of the subsamples were calculated and the average values were analyzed (Purdue University, 2016). If the location by cultivar interaction was significant for a dependent factor at alpha = 0.05, data were analyzed separately by location. If interaction was not significant, data were pooled to evaluate for the significant main effects. Mean separation was done using Tukey's Honest significant differences test.

Results and Discussion

YIELD. There was a significant location by cultivar interaction when analyzing marketable yield, and the main effects of location and cultivar were significant for total yield. Significant differences among cultivars were observed in Virginia Beach, but not Chesapeake and only limited differences in Westmoreland (Table 4). In the City of Virginia Beach, the highest yielding cultivars were 'Camino Real', 'Chandler' and 'Camarosa' followed by

156 'Benicia'. At the other two locations, due to smaller differences of greater variability the mean
157 separation did not clearly distinguish the lowest and highest yielding cultivars. Main effect for
158 the location and cultivar were significant for the cumulative total yield. When total yields were
159 observed, the top four cultivars were 'Benicia', 'Camino Real', 'Chandler', and 'Camarosa'.
160 'San Andreas' total yield was comparable to the top four cultivars with highest total yield (Table
161 5). 'Albion'; 'Sweet Charlie'; and 'Radiance' were the cultivars yielding the lowest total yields
162 (Table 5). Results from a strawberry cultivar trial in Blackstone Virginia showed the marketable
163 yield of 'Camino Real' being higher than 18 other cultivars, second only to 'Chandler', and
164 having the highest average fruit weight overall (Pattison, 2008). Our trial showed that 'Benicia'
165 and 'Camino Real' can yield as well or better over different geographic locations and soil types
166 in eastern Virginia than the 'Chandler' and 'Camarosa' cultivars currently being grown on most
167 strawberry farms in Virginia. Two of the most abundantly grown cultivars in Virginia
168 'Chandler' and 'Camarosa' yielded as well or better than all other varieties grown in this trial
169 across all locations, so growers should feel confident that they are growing two of the top four
170 yielding cultivars. In the future we hope growers will consider trying a few plants of the
171 'Benicia' or 'Camino Real' on their farms. 'Radiance' was the lowest yielding cultivars at the
172 City of Virginia Beach location. Trials in two locations of North Carolina during the 2014-2015
173 growing season showed that when analyzed for total yield 'Benicia' and 'Camino Real' out
174 yielded 'Camarosa' but fell short of 'Chandler' total yield (NCCE, 2015). As with any crop,
175 micro climates, soil taxonomy, individual management techniques, among many other factors
176 can lead to differences in performance by cultivars.

177 **Fruit Characteristics and Taste Test.** The hypothesis that the highest
178 yielding cultivars might lend themselves to having the largest average fruit size, was partially

correct. Larger average fruit size of ‘Benicia’ and ‘Camino Real’ contributed to higher total yield biomass compared to other cultivars with smaller fruit size (Table 6). At the Chesapeake location there was very little separation when it came to fruit size, but at Virginia Beach ‘Albion’, ‘Camino Real’, and ‘Benicia” led the other nine cultivars (Table 7). At Westmoreland ‘Benicia’, ‘Camino Real’, San Andreas’, and ‘Flavorfest’ had the largest fruits.

TSS (Total soluble solids) readings varied widely during the harvest season. Based on the ^{o}Brix readings cultivars ‘Flavorfest’, ‘Sweet Charlie’, and ‘Albion’ had the sweetest berries overall across all three locations presented in Table 8. During the harvest season we held two separate taste tests, one was on farm in Virginia Beach, the other was held at the HRAREC. Total participants at both locations was 25. With an overwhelming majority, 42% of all taste testers chose ‘Flavorfest’ as the berry they most liked, followed by ‘Camarosa’ at 15%, and ‘Albion’ at 10%. Based on the taste test results the sweetest berries were ‘Flavorfest’, ‘Camarosa’, ‘Chandler’ and ‘Albion’ tied, then ‘Sweet Charlie’, with all others not chosen by any participants (data not shown).

Vegetative Growth. When analyzed with Tukey’s honest significant difference test, the Chesapeake location had the greatest canopy diameters, followed by the location in Westmoreland County, and finally the location in Virginia Beach which had our highest total yields, had the smallest canopy (Table 9 and 10).

Plant Health. Fruit rot caused by Botrytis (*Botrytis cinerea)* and anthracnose (*Colletotrichum acutatum*), as well as sun scald were the primary biotic and abiotic problems limiting marketable yield at all locations. By the second week of harvest at all locations, some level of botrytis fruit rot lead to increased nonmarketable yield. Harvest in week 3 and 4 at all locations brought infections from anthracnose fruit rot, with the heaviest infections on ‘San

Andreas' and 'Benicia' in the City of Chesapeake Throughout the harvest period at all locations some sun scald was found on all, with the heaviest damage on 'San Andreas' fruits at all three locations.

Interest in cultivars to either replace or complement the three main cultivars ('Camarosa', 'Chandler', and 'Sweet Charlie') being grown in Virginia's plasticulture industry is increasing among local producers in Virginia. This evaluation showed that 'Camino Real' and 'Benicia" have the potential for high yields and produce berries of large size. For a day neutral option 'San Andreas' is a promising cultivar. 'Flavorfest', 'Sweet Charlie', and 'Albion' produce berries with high TSS for additional marketing opportunities. Since findings from the 2013-2014 Virginia trials have been disseminated at preplant meetings in Virginia and the southeast strawberry expo in North Carolina in 2014, there has been strong interest in 'Camino Real' in the Mid-Atlantic region to the point that some major plug propagators and suppliers have made 'Camino Real' available beginning in 2016.

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Table 1. Information about the breeding programs and history of the 12 cultivars that were planted in the 2013-14 on-farm variety trials at three locations in the coastal plain of Virginia

Cultivar	Origin	Pedigree	Year of release
Albion[Z]	University of California	Diamante x Cal 94.16-1	2006
Benicia	University of California	Palomar x Cal 0.18-601	2006
Camarosa	University of California	Douglas x Cal 85.218-605	1992
Camino Real	University of California	Cal 89.230-7 x Cal 90.253-3	2002
Chandler	University of California	Douglas x Cal 72.361-105	1983
Festival	Florida Foundation Seed Producers	Rosa Linda x Oso Grande	2000
Flavorfest	USDA Beltsville, MD	B759 X B786	2012
Radiance	University of Florida	Winter Dawn x FL99-35	2008
San Andreas[z]	University of California	Albion x Cal 97.86-1	2009
Sweet Charlie	University of Florida	FL80-456 x Pajaro	1994
Treasure	J & P Research Inc., P. Chang, Florida	A3 x Oso Grande	2000
Winterstar	University of Florida	Florida Radiance x Earlibrite	2011

[z] Day neutral cultivar- for purposes of this evaluation, all cultivars were harvested on a June-bearing cultivar time frame

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Table 2. Planting date, plant spacing and frost protection strategies for 3 locations in the Coastal Plain of Virginia during the 2013-2014 growing season

Location	Planting Date	Plant Spacing	Row Spacing	Frost Protection Strategy
City of Chesapeake	3 October 2013	12 inches between plants 12 inches between rows on bed	5 feet apart measured to the center of the bed	Overhead irrigation, 3,498 gallons per hour per acre
City of Virginia Beach	29 September 2013	16 inches between plants 14 inches between rows on bed	6 feet apart measured to the center of the bed	1.2 ounce row cover (Dupont, Walker Brothers Supply Co., Lancaster, PA 17603)
Westmoreland County	27 September 2013	14 inches between plants 12 inches between rows on bed	5 feet apart measured to the center of the bed	1.2 ounce row cover (Atmore Industries, Atmore, AL 36502
Row orientation at all locations was from east to west				

Table 3. Location specific fumigation or preplant herbicide treatment, application date, rate, and equipment utilized in preparation for 2013-14 on-farm cultivar trials at three conventionally managed strawberry farms in the Cities of Chesapeake and Virginia Beach and Westmoreland County Virginia.

Location	Treatment	Treatment Date	Treatment Rate	Treatment Equipment	Predominant Soil Type	Plot Size
City of Chesapeake	Telone C-35 (63.4% 1,3-dichloropropene + 34.7% chloropicrin; TriEst Ag Group, Inc., Greenville, NC 27835)	24 August 2013	135 lbs./ acre	3 knives system on a Reddick mulch layer (TriEst Ag Group, Inc., Greenville, NC 27835)	Bojac fine sandy loam (coarse-loamy, very deep, well drained, parent material: loamy and sandy fluvial and marine sediments), normally found in 0-10% slope.	20 plants per cultivar *
City of Virginia Beach	1,3-D + Pic (39% 1,3-dichloropropene + 59.6% chloropicrin; TriEst Ag Group, Inc., Greenville, NC 27835)	1 September 2013	120 lbs./ acre	2 knives system on a Reddick mulch layer (TriEst Ag Group, Inc., Greenville, NC 27835)	State loam (fine-loamy, very deep, well drained, parent material: Alluvium), normally found in 0-10% slope	30 plants per cultivar **
Westmoreland County	Devrinol 50-DF (United Phosphorus, Inc., King of Prussia, PA 19406)	24 September 2013	8 lbs./ acre	Bed top application with a Rain Flo mulch layer (Rain-Flo Irrigation, East Earl, PA 17519)	Pamunkey fine sandy loam (fine-loamy, deep, well drained, parent material: weathered igneous and metamorphic rocks), normally found in 0-15% slope	20 plants per cultivar ***

Experimental design RCBD = randomized complete block design, 3 replications
All locations used 1.25 Mil black embossed VIF (virtually impermeable film) and Chapin 10 Mil .5 gallon per hour with 12 inch emitter spaced dripline placed .5 inch below soil line at top of bed
All locations had bed dimensions of 30 inches wide by 8 inches high
*Exception being Flavorfest- established at 15 plants per plot
**Exception being Flavorfest- established at 20 plants per plot
***Exception being Benicia and Flavorfest- reduced due to plant health issues

Table 4. Average marketable yield results in g per plant of 12 commercially available, conventionally managed strawberry cultivars during the 2013-14 season in the Cities of Chesapeake and Virginia Beach and Westmoreland County separated by least square mean.

	Location Least Square Mean [z]		
Cultivar	City of Virginia Beach	City of Chesapeake	Westmoreland County
Albion	467.4 cdef	218.9 a	145.8 b
Benicia	572.1 bcd	313.6 a	420.6 a
Camarosa	648.0 abc	318.6 a	333.6 ab
Camino Real	839.2 a	363.0 a	383.6 ab
Chandler	753.5 ab	339.4 a	284.2 ab
Festival	479.7 cde	218.9 a	237.4 ab
Flavorfest	513.0 cde	251.5 a	219.9 ab
Radiance	257.6 f	156.7 a	229.8 ab
San Andreas	467.4 cdef	222.0 a	274.0 ab
Sweet Charlie	417.9 def	301.5 a	141.4 b
Treasure	470.6 cde	239.3 a	284.1 ab
Winterstar	341.1 ef	185.9 a	180.7 ab
P value	0.0009		

[z]Means within a column followed by the same letter are not significantly different using Tukey's honest significant difference test $P \leq 0.05$.

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Table 5. Total yield by variety averaged across three locations in the coastal plain of Virginia during the 2014 harvest season expressed as g per plant [z]

Cultivar	Total Yield g/ plant
Benicia	656.7 a
Camino Real	641.1 a
Chandler	626.2 a
Camarosa	571.9 a
San Andreas	556.6 ab
Treasure	489.2 abc
Flavorfest	480.6 abc
Festival	388.4 bc
Winterstar	386.8 bc
Radiance	355.7 c
Sweet Charlie	354.5 c
Albion	347.5 c
P value	<0.0001

[z]Means within a column followed by the same letter are not significantly different using Tukey's honest significant difference test $P \leq 0.05$.

Table 6.Total yield (computed from average total yield per plant multiplied by 15,000 plants per acre) average berry size, and harvest days computed from averages of all 12 commercially available cultivars from all three locations throughout the coastal plain of Virginia trialed in 2013-14 growing season.

Cultivar	Total yield, pounds per acre	Average berry size (mm)	Harvest season (days)
Benicia	21,716.6 a	37.3 a	33.7
Camino Real	21,200.8 a	36.2 b	35.3
Chandler	20,708.0 a	33.2 cde	35.3
Camarosa	18,912.4 a	33.1 cde	34.0
San Andreas	18,406.4 ab	34.5 bcd	34.0
Treasure	16,177.5 abc	32.5 def	35.3
Flavorfest	15,893.1 abc	33.9 cde	31.0
Festival	12,844.1 bc	30.5 f	35.3
Winterstar	12,791.2 bc	32.3 ef	34.0
Radiance	11,762.8 c	33.7 cde	35.3
Sweet Charlie	11,723.1 c	32.4 def	35.3
Albion	11,491.6 c	35.1 abc	35.3
P value	<0.0001	0.007	

[z]Means within a column followed by the same letter are not significantly different using Tukey's honest significant difference test $P \leq 0.05$.

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Table 7. Fruit Size readings (mm) of 12 commercially available strawberry cultivars grown on farm in 3 locations in the Coastal Plain of Virginia			
	Location		
Cultivar	City of Chesapeake	City of Virginia Beach	Westmoreland County
Albion	33.3 ab	38.3 a	33.6 bcd
Benicia	36.2 a	36.5 abc	39.2 a
Camarosa	32.0 ab	33.4 de	33.8 bcd
Camino Real	35.3 a	37.2 ab	36.1 ab
Chandler	31.4 ab	34.0 de	34.1 bc
Festival	29.6 b	31.9 e	29.9 d
Flavorfest	31.2 ab	35.2 bcd	35.2 abc
Radiance	33.6 ab	34.3 d	33.1 bcd
San Andreas	33.4 ab	34.9 cd	35.3 abc
Sweet Charlie	31.9 ab	34.1 de	31.2 cd
Treasure	32.4 ab	33.3 de	31.7 cd
Winterstar	29.7 b	34.9 cd	32.2 bcd
P value	0.007		
[z]Means within a column followed by the same letter are not significantly different using Tukey's honest significant difference test $P \leq 0.05$.			

Table 8. Season long averages of total soluble solids content of 12 conventionally managed strawberry cultivars grown in three locations throughout the coastal plain of Virginia during the 2014 harvest season	
Cultivar	Average Refractometer Readings separated with l east square mean[z]
Flavorfest	8.3 a
Sweet Charlie	8.2 ab
Albion	7.9 abc
Festival	7.5 bcd
Chandler	7.5 bcd
Camarosa	7.4 cde
Camino Real	6.8 def
Treasure	6.7 ef
Winterstar	6.6 f
San Andreas	6.4 f
Benicia	6.3 f
Radiance	6.1 f
P value	<0.0001
[z]Means within a column followed by the same letter are not significantly different using Tukey's honest significant difference test $P \leq 0.05$.	

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Table 9. Average canopy readings per location taken in spring of 2013-14 growing season across all plots of the 12 strawberry cultivars

Location	Canopy Diamter [z]
City of Chesapeake	25.5 a
Westmoreland County	22.4 b
City of Virginia Beach	15.0 c
P value	<0.0001

[z]Means within a column followed by the same letter are not significantly different using Tukey's honest significant difference test $P \leq 0.05$.

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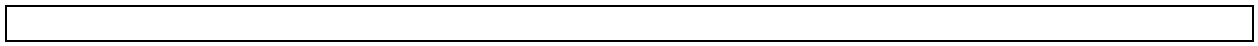
Table 10. Average canopy readings of 12 conventionally managed strawberry cultivars grown in three locations throughout the coastal plain of Virginia during the 2014 harvest season

Cultivar	Average Canopy Diameter Readings with LS Means Differences[z]
Sweet Charlie	22.7 a
Benicia	22.6 a
Radiance	21.8 ab
Treasure	21.6 ab
Camarosa	21.6 ab
Chandler	21.5 ab
Winterstar	21.3 ab
San Andreas	21.0 ab
Festival	20.6 ab
Camino Real	20.4 ab
Flavorfest	19.2 bc
Albion	17.2 c
P value	<0.0001

[z]Means within a column followed by the same letter are not significantly different using Tukey's honest significant difference test $P \leq 0.05$.



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