PROGRESS REPORT
TO
Grower and Industry Cooperators

TITLE: Summer 2017 Tomato Rootstock Variety Trial for Bacterial Wilt Resistance

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DEPARTMENT(S): Plant Pathology and Horticultural Science

REPORT:

Tomato production is limited by a number of serious soilborne pathogens. Major issues in North Carolina include Verticillium wilt (race 2), Fusarium wilt (especially race 3 problems), southern blight, root knot nematodes and bacterial wilt. We have done considerable work across the state addressing issues with each of these pathogens. Our goal is to evaluate all available and emerging tools that will advance integrated management of tomato soilborne pathogens and communicate that to the tomato industry. This report highlights the tomato rootstock variety trial we conducted across NC in the summer of 2017 where we assessed a number of variables including wilt resistance, yield, and fruit size characteristics.

OBJECTIVES:

1) Identify new and emerging tomato rootstocks for bacterial wilt management coming available on the market.

2) Test those rootstocks alongside currently recommended rootstocks in all 3 ecological regions of NC in fields naturally infested with bacterial wilt.
    a. Especially in the Coast Plains.

3) Use locally commercially desirable scions without bacterial wilt resistance at each location as a non-grafted industry standard.

4) Adhere to grower cooperator cultural and management practices.

5) Evaluate bacterial wilt development throughout the season.

6) Evaluate the yield components of fruit size and number for each market class—cull, small, medium, large, extra-large, and jumbo.

DESIGN:

We performed a 5-location grafted variety trial across NC (Figure 1) during the summer of 2017. Table 1 provides a summary of important location, management, and cultural practices that were used at each location. Please note that the Coastal Plains 1 location was the only field that was not fumigated prior to planting.

Figure 1: Variety trial locations--Jackson, Haywood, Rowan, Brunswick, and Pender counties (left to right). The Haywood location was on the Mountain Research Station in Waynesville and was a no disease contrast for the Jackson co. field.

Table 1: Location, field preparation, and cultural practices for each location.

Location:	Coastal Plains 1	Coastal Plains 2	Mountain Research Station	Mountain 1	Piedmont
County:	Pender	Brunswick	Haywood	Jackson	Rowan
Elevation (ft):	41	43	2638	1848	783
Field planted:	5/17/2017	6/14/2017	6/27/2017	6/28/2017	7/20/2017 to 7/27/2017
Observation period:	79	86	78	77	76
Total harvests:	3	4	5	5	2
Days to harvest (type):	65 (Red ripe)	64 (Red ripe)	71 (Red ripe)	71 (Red ripe)	70 Mature green
Local Scion:	Red Morning	Red Morning	Mountain Majesty	Mountain Majesty	Red Mountain
Soil type:	Norfolk loamy fine sand and Goldsboro fine sandy loam	Goldsboro fine sandy loam	Cullowhee-Nikwasi complex, fine sandy loam	Hemphill clay loam	Cecil sandy clay loam to clay
Soil Fumigation:	No	Yes	Yes	Yes	Yes
Plastic:	Black	Silver reflective on white	Black	White	White on black
Number of rows:	3	5	7	7	4
Row spacing:	~5 feet	~5 feet	~5 feet	~5 feet	~5 feet
Plant spacing	18 inch	22 inch	18 inch	18 inch	22 inch
Total Plots:	44	28	64	68	44
Pruning:	none	2 suckers	2 suckers	2 suckers	2 suckers
Expected wilting (S):	70 to 100%	50 to 100%	0%	70 to 100%	5 to 50%
Plants per acre:	5808	4752	5808	5808	4752

We tested a total of 12 rootstocks from 8 different suppliers/seed sources, including the NC State tomato breeding program (Table 2). These rootstocks were chosen for a variety of reasons, including being currently marketed or developed for NC, and previous use. 6 of the rootstocks were new to us for NC, while 2 others had been examined either only in 1 year previously and/or not in either the Coastal Plains or the Mountain regions by extension specialists. The old rootstocks were selected based on recommendations from our previous work (Kressin, 2014; Rivard et al., 2012; Rivard and Louws, 2008; Silverman, 2015). All of the seed for these experiments were donated by the listed supplier. The NC-based Tri-Hishtil grafting company in Mills River obtain the seed, grew the plants, and grafted all the commercial material, while the NC State grafting team obtained, grew, and grafted all the NCSU-supplied seed and the non-grafted scion standards. All the grafted plants were high quality, standard single leader seedlings—not pinched.

Table 2: Information about the tomato materials used for the experiments.

Rootstock	Interest	Type	Use	Tested[x]	Locations	Supplier
1238-16-F3	New	NCSU breeding line	Rootstock	CG,NG; std	2	NCSU
NC13192-F3	New	NCSU breeding line	Rootstock	CG,NG; std	2	NCSU
NC13194-F3	New	NCSU breeding line	Rootstock	CG,NG; std	2	NCSU
CRA66	Old	Open-pollinated	Rootstock	CG; std	4	NCSU; others
Hawaii 7998	Old	Open-pollinated	Rootstock	CG; std	4	NCSU; others
Armada F1	New	Hybrid	Rootstock	CG; std	5	Takii Seed
BHN 1087 (RT1054)	Old	Hybrid	Rootstock	CG; std	5	BHN Seed
Bowman	New	Hybrid	Rootstock	CG; std	5	Sakata Seed
DR6258TX	New	Hybrid	Rootstock	CG; std	5	Seminis
RST-04-106-T	Old	Hybrid	Rootstock	CG; std	4	DP Seeds
Shield	Newish	Hybrid	Rootstock	CG; std	5	Rijk Zwaan
Shin Cheong Gang	Newish	Hybrid	Rootstock	CG; std, deep	5	Seminis
Mountain Majesty	Local scion	Hybrid	Local scion	NG; std	2	Harris Moran
Red Morning	Local scion	Hybrid	Local scion	NG; std	2	Harris Moran
Red Mountain	Local scion	Hybrid	Local scion	NG; std	1	Harris Moran

x CG: Commercial graft use; NG: Non-grafted; std: recommended planting depth of just coving the root ball with soil; deep: planted deep so that graft union was buried from sight.

The fields were laid out in a randomized complete block design with 4 replications. Each plot had between 8-12 plants depending on the location. A few plots had 1 to 6 plants due to low numbers of plants (Jackson, Haywood, and Brunswick co. tests). Between each plot we planted a non-grafted susceptible guard plant. Out of curiosity, and because we had a surplus of the treatment, we decided to test if burying the graft union on a known highly resistant rootstock treatment (‘Shin Cheong Gang’) would lead to compromised resistance after the scion had rooted. So, we plant two treatments of that rootstock—the recommended shallow depth where the root ball is just barely covered with soil, and where the graft union was purposefully buried below the soil line. All other treatments were planted at the recommended depth.

After planting, we assessed transplant survival after 7-10 days. Transplant success was very good, with no more than a handful of plants requiring replacement at any location. We then began weekly to biweekly ratings for bacterial wilt development. We used our standard 0-5 severity to scale to assess the percentage of canopy wilt, where 0=no wilt and 5=permanent wilting point and drying/decay. We scored every plant in every plot, as well as the susceptible guards, which were used to assess the distribution and uniformity of bacterial wilt development.

When the plots were ready to harvest, we harvested the market type fruits and sorted them according to size. Because we were primarily interested in fruit number and weight, we had a high tolerance for fruit blemishes. In edible fruit were culled, but the rest were considered marketable based on size. Sorting for size was performed using a home-made field sizer system (Table 3, left), which the exception of the Mountain Research Station trial where we used their mechanical sorter machine with the gates set for the same diameters as our bucket system. We used the generally established fruit diameter classes in the staked tomato production guide developed by the USDA and NC State (Ivors and Sanders, 2010; USDA-Agricultural Marketing Service, 1991). We used the USDA maximum sizing scale, with the addition of the NC suggested “jumbo” grade (Table 3, right). Plots were harvested 3 to 5 times, each size class was counted and weighed. The total season average yields per plant were calculated and then multiplied by the plants per acre estimate based on the local field setup (Table 1).

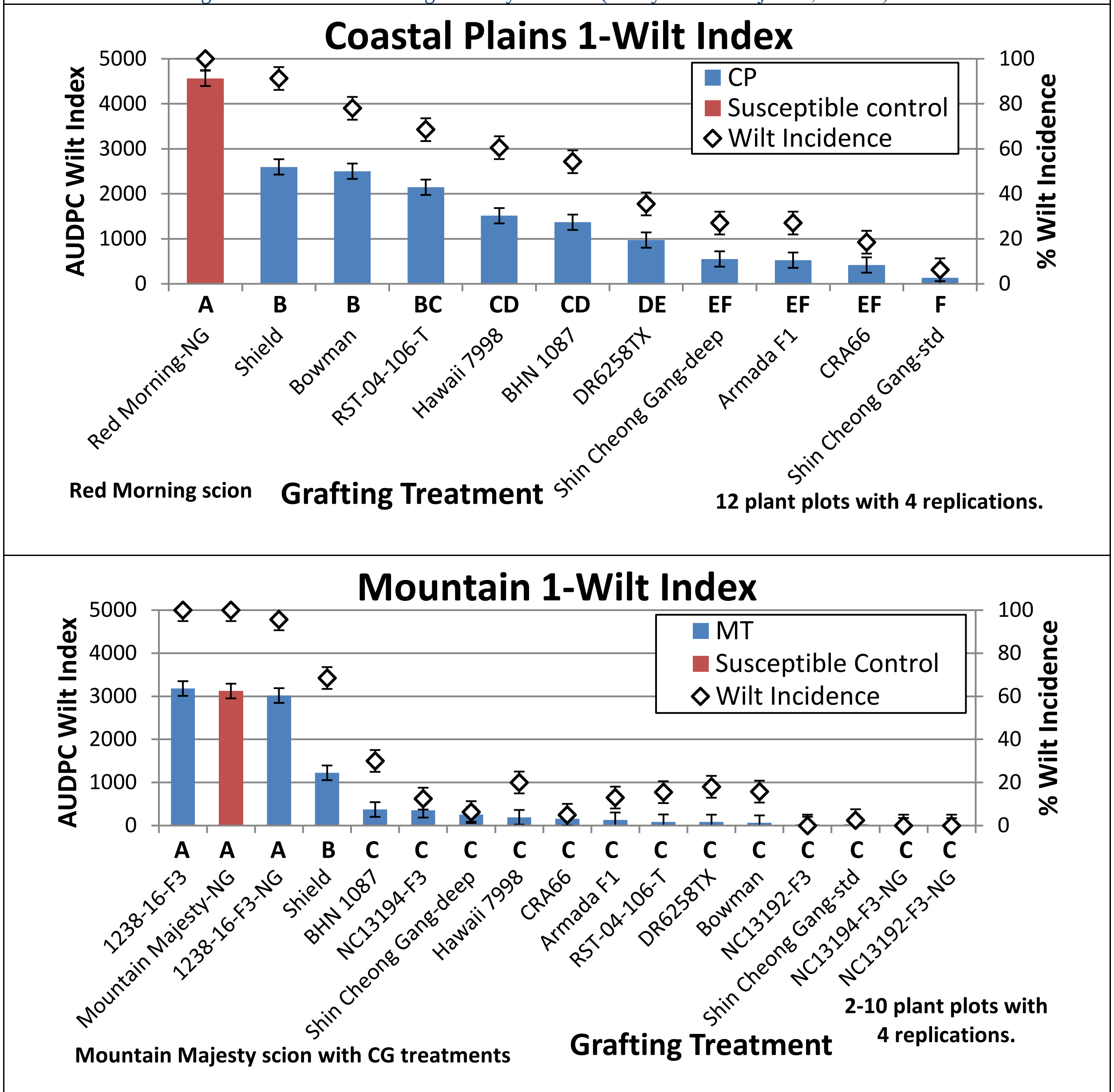
Table 3: Fruit size hand grader system (left) and diameters used to classify each size class (right).

	Maximum diameter	
Class	**in.**	**cm**
Cull	<2-4/32	<5.4
Small	2-9/32	5.8
Medium	2-17/32	6.4
Large	2-25/32	7.1
Extra-large	3-15/32	8.8
Jumbo	>3-16/32	8.9

RESULTS:

Bacterial wilt pressure was very strong in the Pender and Jackson co. locations but was essentially non-existent in the Brunswick and Rowan co. locations, as well as in our no-disease control research station field. In the Pender co. field, first wilt symptoms were observed 15 days after planting, primarily in the susceptible guard plants. In contrast, the first wilt development was observed in the Jackson co. field at 23 days after transplanting. The differences are likely related to the Mountain field being a little cooler and having been fumigated. The overall vigor of the plots in Pender was much lower than the other fields and had the strongest bacterial spot and bacterial wilt pressures. Analyzing the area under the disease progress curve (AUDPC) values for each plot revealed strong differences in rootstock resistance performance. The Pender and Jackson co. locations are detailed in Figure 2.

Figure 2: Analysis of the AUCPD values (bars) and final wilt incidence (diamonds) for each grafting treatment from two locations. Bars sharing the same letter are not significantly different (Tukey-Kramer adjusted; α=0.05).



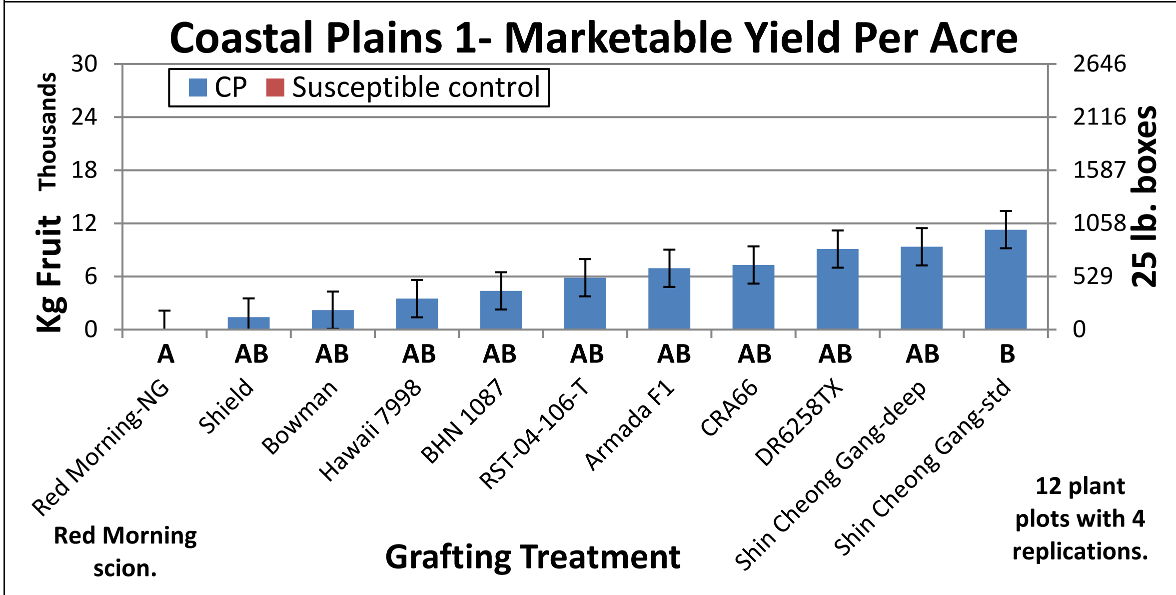
It is clear from the analyses that there are multiple rootstocks with equally high levels of bacterial wilt resistance that work in both the Coastal Plains and the Mountain regions—'Shin Cheong Gang', 'CRA66', 'Armada F1', and DR6258TX (Seminis test name). Additionally, ' BHN 1087', 'RST-04-106-T', and 'Hawaii 7998' performed moderately well, but were significantly higher than in the Mountains. Certainly in the Mountain region, the NC rootstocks 13192 and 13194 (test names), 'Bowman', 'RST-04-106-T', and 'BHN 1087' are additional options for growers consider for rootstock rotation. 'Bowman' may not be a good fit in the Coast Plains, and 'Shield' performed the worst of the commercial rootstocks in both locations and is probably not a good fit for NC.

Curiously, despite having scion rooting, the 'Shin Cheong Gang' treatment where the graft union was buried did not appear to compromise resistance. The plants maintained a healthy, strong appearance all season long despite ample disease pressure around the plots and in the guard plants (Figure 3, left side). While the data is too preliminary (only 1 year) to recommend any changes in planting method, the pattern is very curious. We will continue to investigate that in the future.

We also observed strong differences in yield between the fields and rootstock treatments. Due to the differences in scion variety, management, and cultural practices, we do not recommend much comparison between fields, only within each field. Since we set up the Mountain Research Station location as a no disease control for the Jackson co. test, it is appropriate to make comparisons between those locations. Similarly, the Brunswick co. location can be considered like a no-disease comparison with the Pender co. test. We have analyzed yield in several ways: total yield per acre (weight), average fruit size overall (weight), and average fruit number within each size class. We did see some differences in average fruit weight within some size classes as well, where treatments were heavy on the low or high ends of the diameter range. The yield components are summarized below (Figures 4 through 8).

Figure 3: Contrast of bacterial wilt resistance efficacy between susceptible roots and resistant rootstocks.

Figure 4: Yield parameters at the Pender co. location.



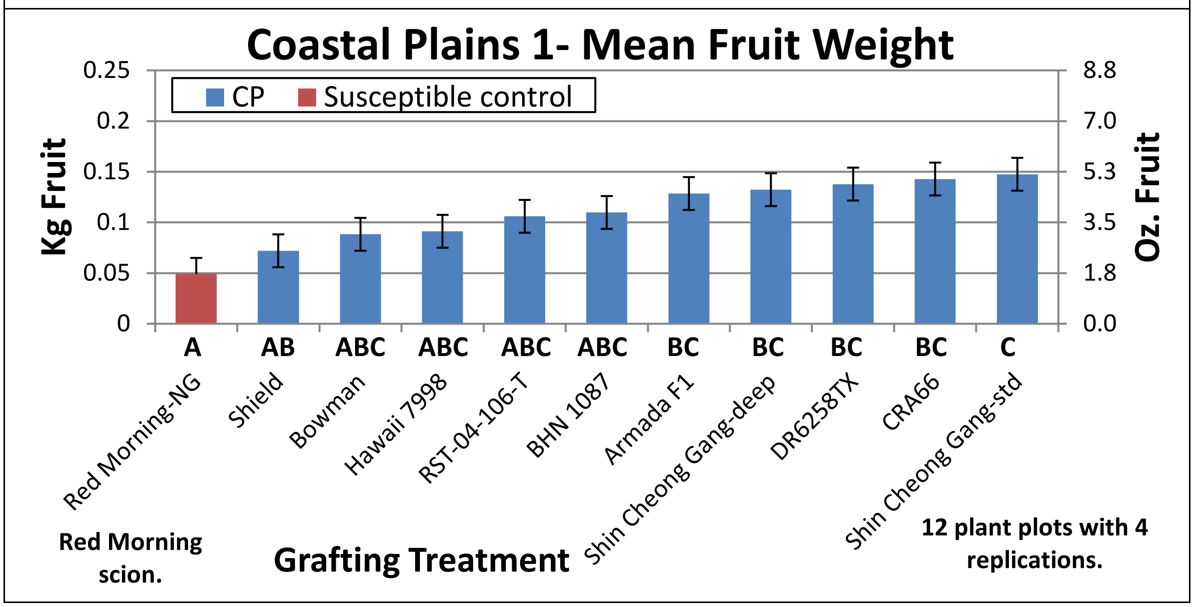
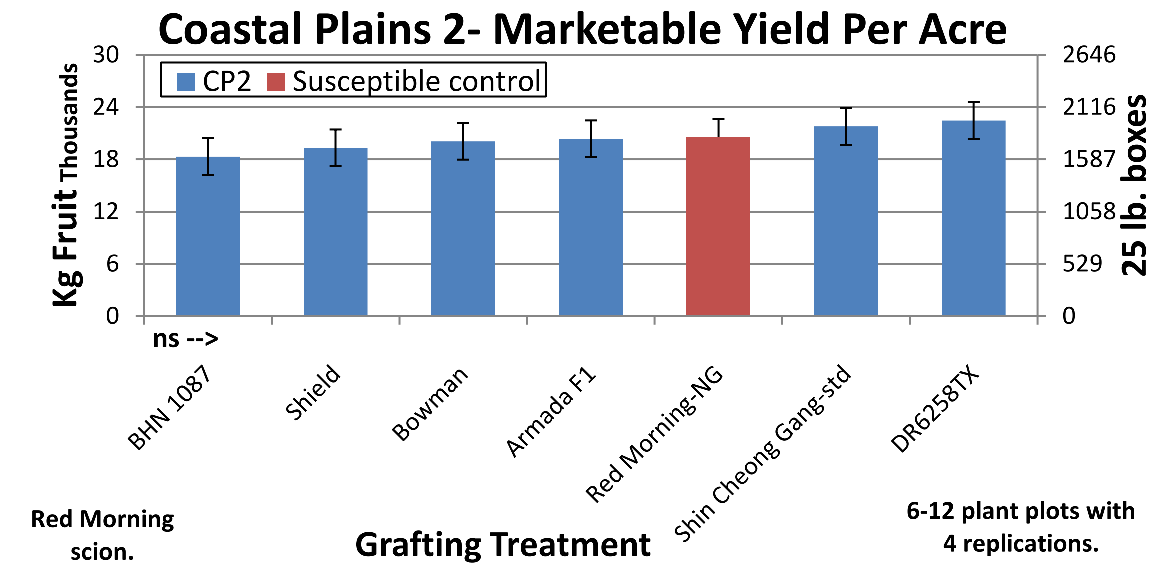


Figure 5: Yield parameters at the Brunswick co. location.



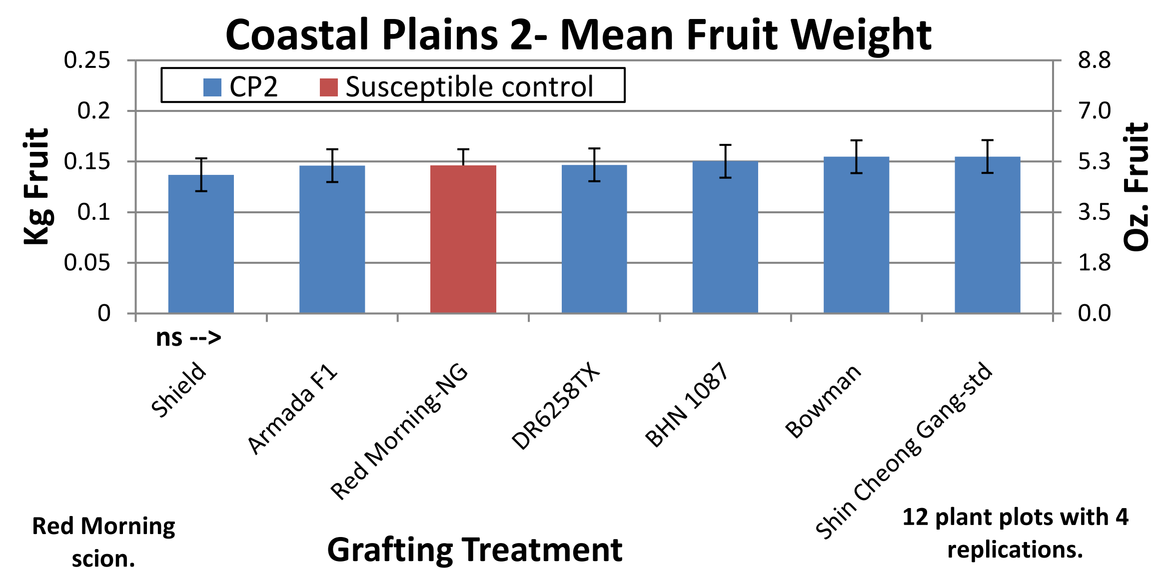
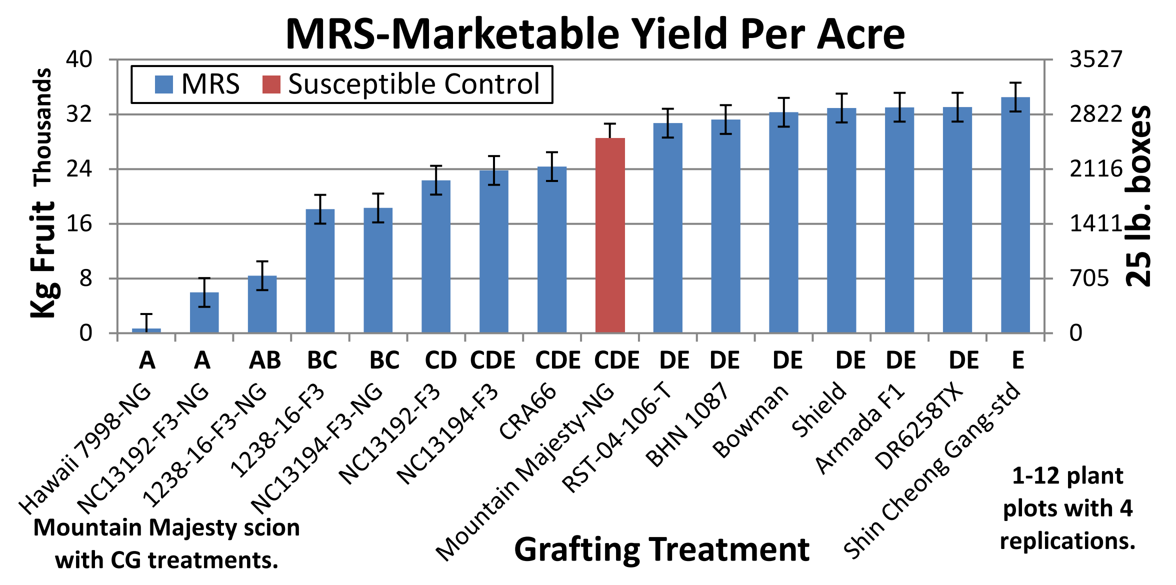


Figure 6: Yield parameters at the Haywood co. location.



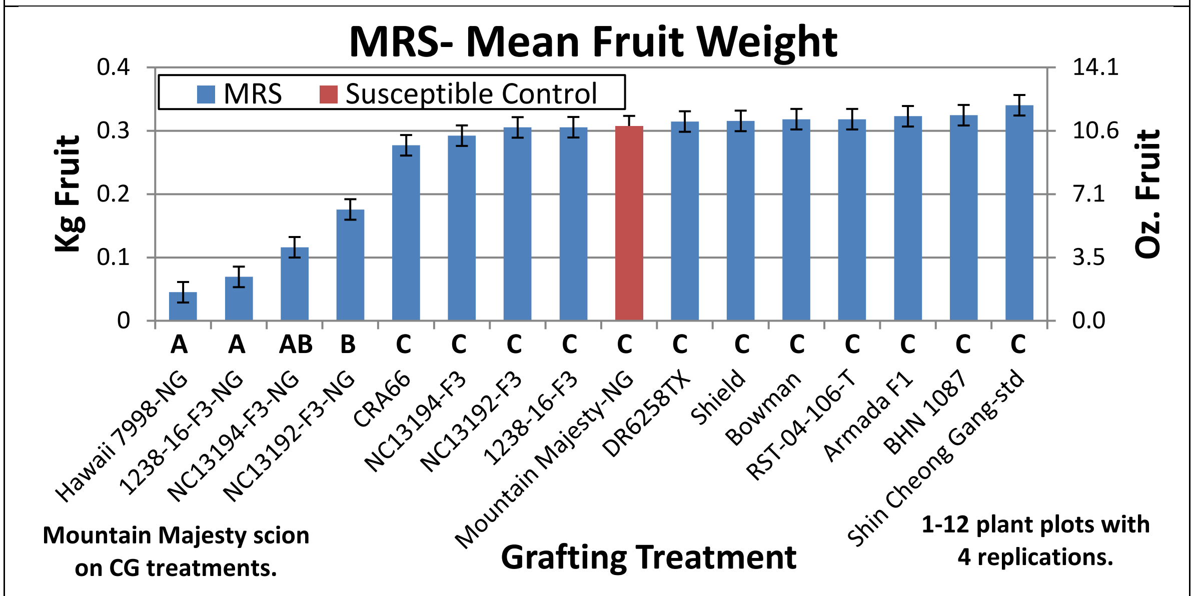
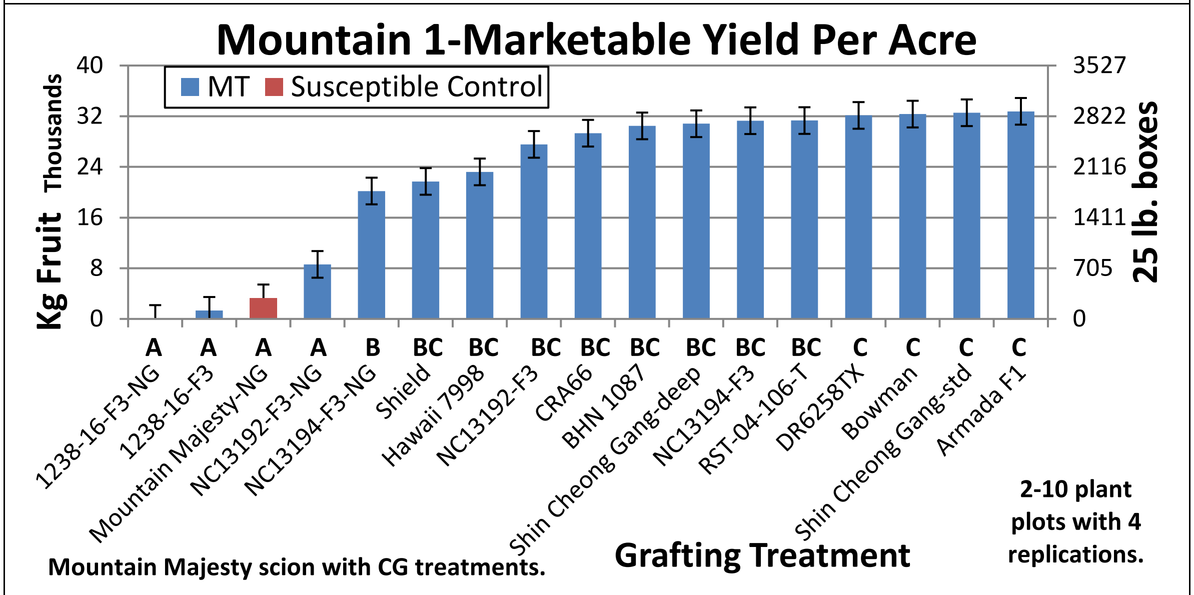


Figure 7: Yield parameters at the Jackson co. location.



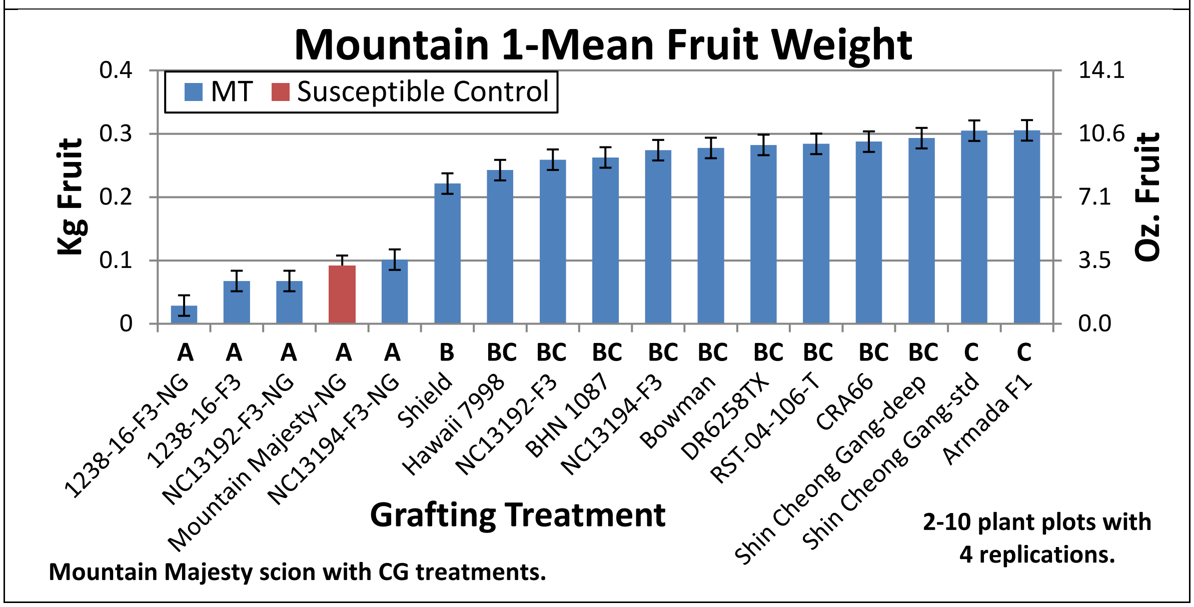


Figure 8: Yield parameters at the Rowan co. location.

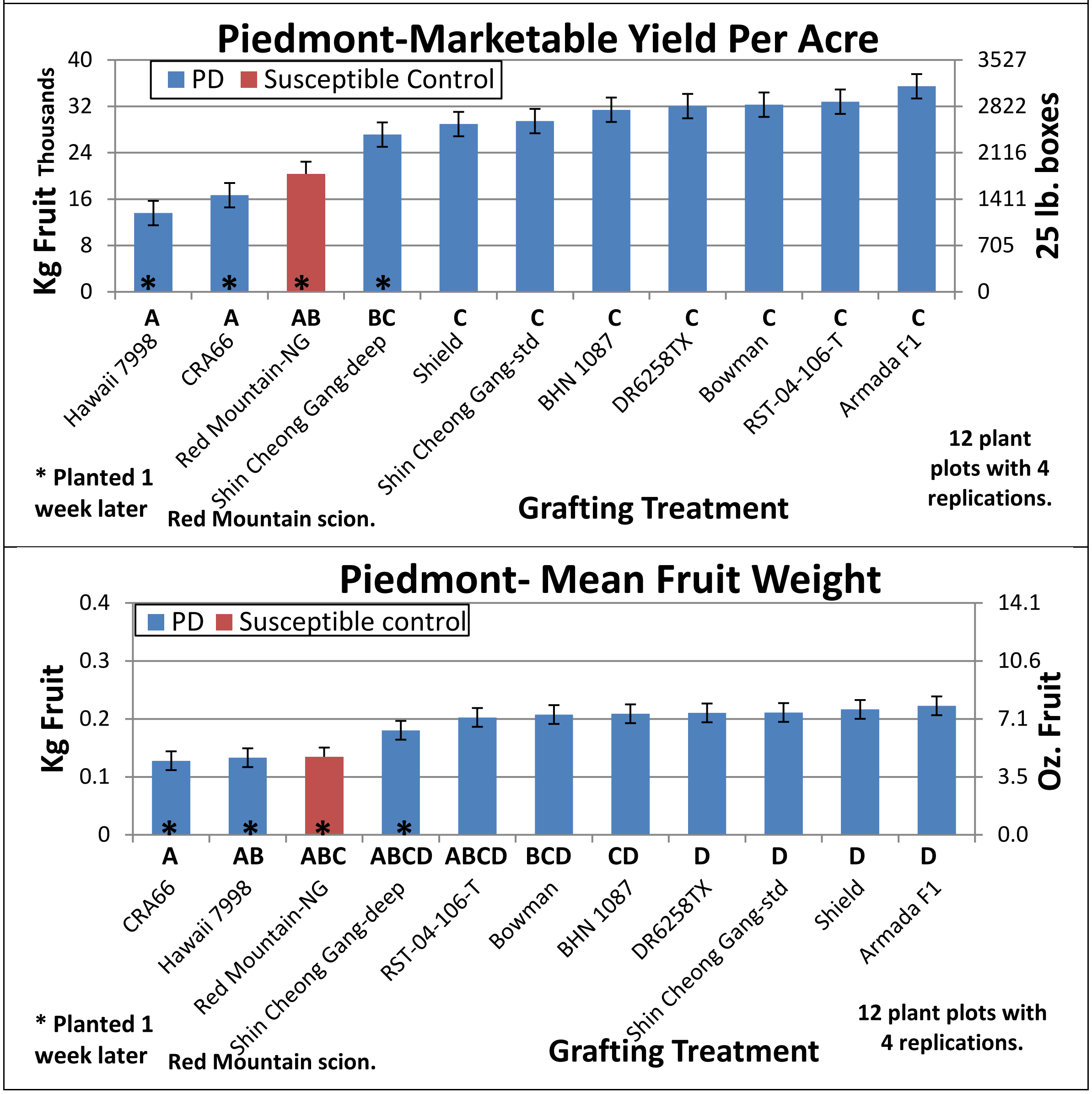


Figure 9: Mean fruit numbers per plant by size class within each grafting treatment for Pender (top-left), Brunswick (top-right), and Rowan (bottom) counties.

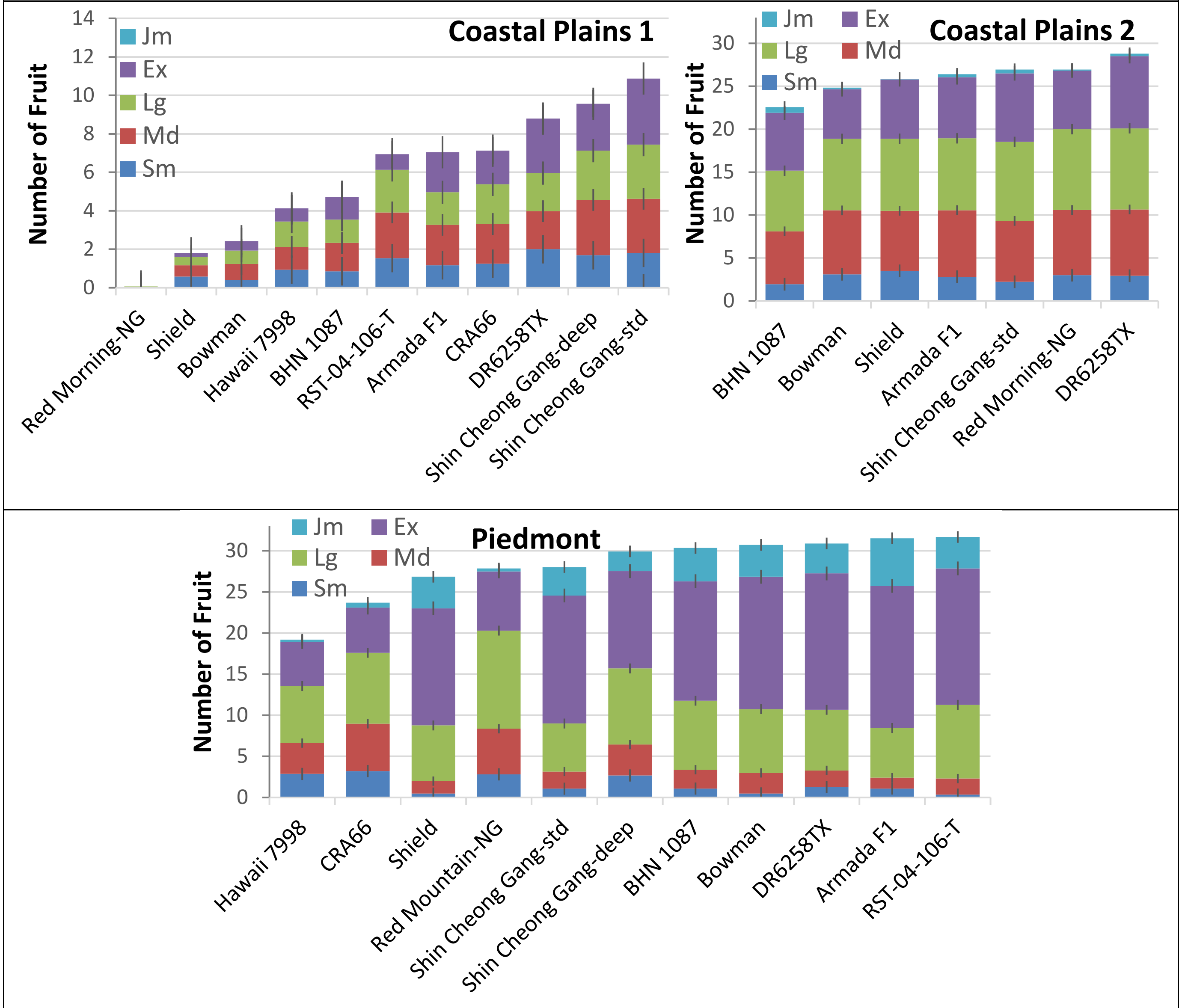
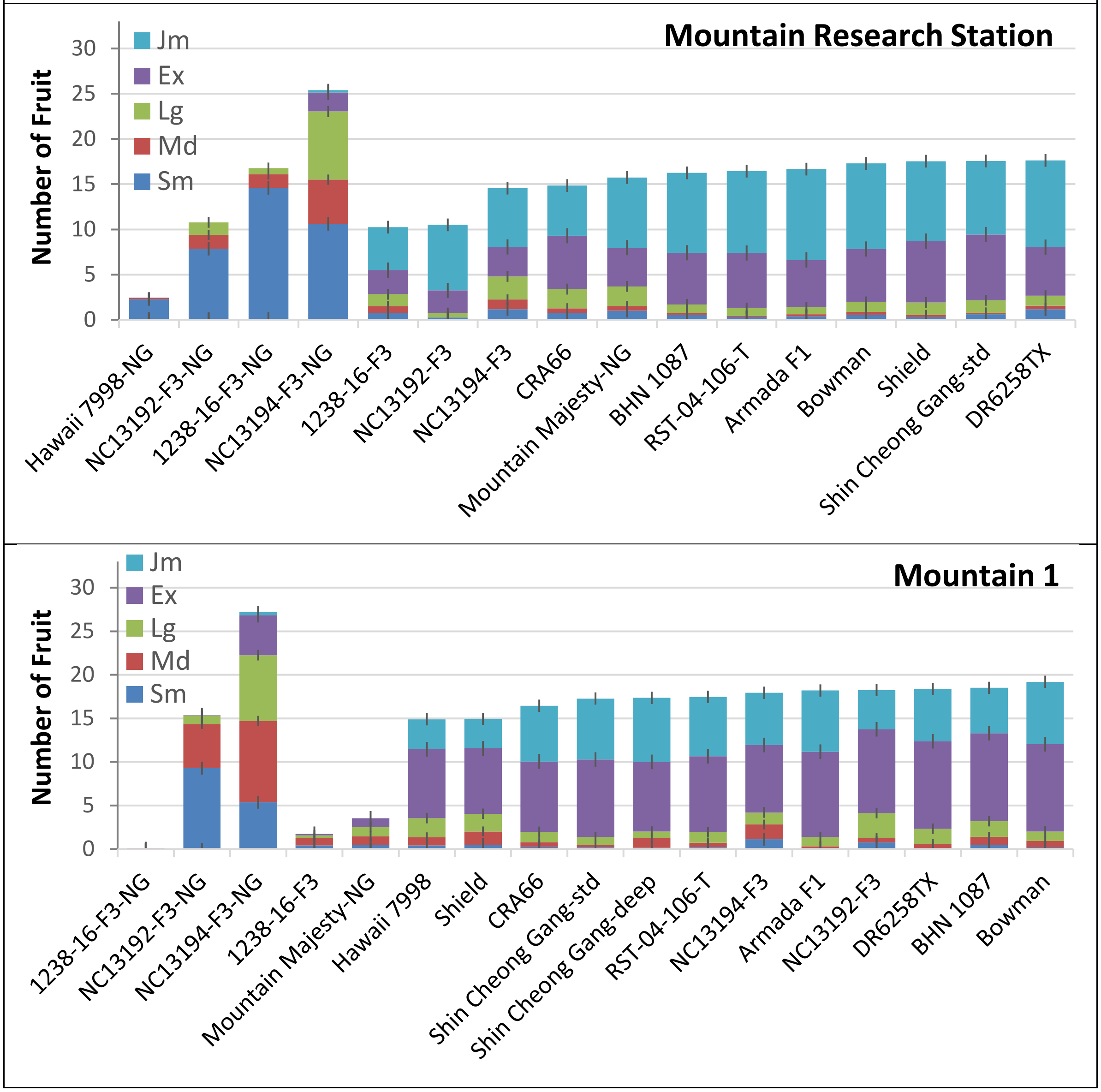


Figure 10: Fruit numbers by size class within each grafting treatment for Haywood (top) and Jackson (bottom) counties.



By far the strongest factor affecting yield was how much bacterial wilt developed within the grafting treatment plots (compare the disease vs. no disease fields). More disease development meant more dead plants and poorer yields. In the absence of disease development, very little differences were observed between rootstocks grafted with the commercial cultivars and the non-grafted standard. Rootstocks with the same basic amount of disease also tended to produce the same yields, which is excellent news for grafted management of bacterial wilt, because it means growers can rotate rootstocks and maintain both the same levels of resistance and yields.

Some overall patterns were that in the Coast Plains (‘Red Morning’ scion) fruit numbers were fairly evenly distributed between medium to extra-large, and little-to-no jumbos. In the Piedmont (‘Red Mountain’ scion) most of the fruit were extra-large, then large, then jumbo. In the

Mountains (‘Mountain Majesty’ scion), the fruit were nearly all extra-large and jumbo, with more jumbos in the no-disease field and more extra-larges in the heavily diseased field.

In Rowan co. there appeared to be some interesting differences, where the fruit size and overall yield of ‘Red Mountain’ may have been improved with some rootstocks, particularly ‘Armada F1’, whereas rootstocks like ‘Hawaii 7998’ and ‘CRA66’ performed the same or numerically poorer than the non-grafted standard. Within the Piedmont location, this difference was related to an overall increase in fruit size, particularly shifting larges into the extra-large category. For example, ‘Armada’ had significantly less mediums and larges ($p<0.0001$) than the non-grafted ‘Red Mountain’ but had significantly more extra-larges and jumbos ($p<0.0001$), yet ‘Armada’ and ‘Red Mountain’ non-grafted had the same number of total fruit per plant ($p=0.9175$). Overall, ‘Armada’ led the pack, but was not different from the other commercial rootstocks. ‘CRA66’ didn’t do as well compared to other locations, which may be related to the heavy clay soils in the Piedmont region or a particular interaction with ‘Red Mountain’.

We can consider the Brunswick co. field to be a no disease contrast with Pender. Between grafting treatments, there were no differences in any yield components or fruit class numbers, although ‘Shin Cheong Gang’ and ‘DR6258TX’ were numerically the highest yielders.

In Pender co., ‘Shin Cheong Gang’ again led the pack, but only had significantly higher yields than the non-grafted, although the mean yields suggest there are important differences. ‘Shin Cheong Gang’ also had significantly greater numbers of fruit than ‘Red Morning’ non-grafted ($p=0.0009$), ‘Shield’ ($p=0.0124$), and ‘Bowman’ ($p=0.0285$), and a greater average fruit size (except for ‘Bowman’). Apart from greater numbers, figure 9 suggests that numerically greater numbers of extra-large fruit contributed to the larger yields.

Moving up to the Mountain Research Station, ‘Shin Cheong Gang’ continued to lead the pack in yield per acre, while significant differences were small between some of the NCSU breeding program rootstocks in development and the commercial rootstocks. Fewer differences existed in average fruit size. There were no differences in ‘Mountain Majesty’ fruit number between the rootstocks or with the non-grafted standard. ‘Armada’ had the largest number of jumbo fruit, while ‘CRA66’, 1238-16-F3, and NC13194 had significantly lower numbers of jumbo. Some additional differences were observed between extremes in the extra-large category, which was led by ‘Shin Cheong Gang’ and ‘Shield’.

In Jackson co., the trend was similar, although the yield impact on the non-grafted standard was enormous. Because 1238-16-F3 had poor resistance, it had terrible yields as well. ‘Armada’ led the pack in yield per acre but was only numerically different from the moderately resistant ‘Shield’. Only ‘Armada’ and ‘Shin Cheong Gang’ had significantly greater average fruit size than ‘Shield’. Any rootstock with as good of resistance as ‘Shield’ had significantly more than the non-grafted standard in yield per acre, average fruit size, and the dominant size classes. There were no differences between the other rootstocks for ‘Mountain Majesty’ fruit number. ‘Shin Cheong Gang’, ‘Bowman’, and ‘Armada’ had the most jumbo fruit, and had significantly more than ‘Hawaii 7998’ and ‘Shield’ ($0.0413>p$ to $p=0.0131$). ‘BHN 1087’ and ‘Bowman’ had the most extra-larges but were not different from ‘Shield’ ($p=0.7267$) with the least.

As expected, the non-grafted rootstocks had much smaller fruit, even though the NCSU program has been breeding resistant material with the locally adapted large-fruited material. NC13194-F3-NG has the most promise so far, but needs a lot of work still with getting nice quality fruit. Breeders for decades have been trying to break the small-fruit and resistance link, but so far we are not there yet, which means we have to continue to rely upon rootstocks for management.

OVERALL SUMMARY:

In summary, we have generated a strong set of evidence for strengthening and amending our rootstock recommendations for managing bacterial wilt, and we now have more confidence about making recommendations in the Coast Plains, which had been lacking so far. While some of the new rootstocks available to NC growers show great promise, our recommendations about them are preliminary. We need at least an additional year of testing to make sure the patterns are stable over seasons. We intend to replicate this experiment in 2018, although we will not return to the Brunswick or Rowan co. locations. Together, we have made important strides towards sustainable, economical, long-term management of bacterial wilt in NC.

Since tomato bacterial wilt is a major disease problem in NC, we have put a lot of research effort into providing practical short-term and long-term management solutions for the NC tomato industry. In the short-term we have focused on evaluating rootstock selection, and in the long-term we want to advance the genetics of host resistance to major tomato diseases. Many researchers have wrestled with this difficult disease over the years, and we are encouraged by our successes for short-term management through grafting with resistant rootstocks. While we always hope to be able to eventually combine strong resistance with large fruit size, the long-term outputs of the tomato breeding efforts will most likely provide diverse, well-adapted, highly resistant rootstocks that can be grafted with any commercially competitive scion variety. NC13192 and NC13194 seem to have sufficient resistance. Now we need to improve the scion vigor component in future breeding cycles. These efforts are important because most of these rootstocks were bred for production in Asia, rather than N. America, and so they will not be as adaptable to NC conditions as material that has been developed for the Southeastern US region.

Bacterial wilt is not the only issue our broader research team is working on. We are working a project for Verticillium wilt resistance, focusing on diversity of the pathogen and finding effective sources of resistance for race 2, which overcomes the *Ve* gene used for resistance against race 1. So far we have begun a systematic collection of strains causing disease in tomato fields in Western NC for assessing the natural strain diversity and pathogenicity, which will guide our testing and deployment efforts. Recently, researchers in Japan have identified two novel sources of Verticillium wilt resistance and also uncovering race 3 and race 4 strains. We have obtained seeds for those materials and have begun testing them against NC strains. Along with those lines, we have some resistance to strains in South America, and are testing resistance independently derived from Hawaii 7998 (used in this study) by both the Ohio State tomato breeding program and Dr. Randy Gardner. If we can find rootstocks or design roots with tolerance to this problem it will help address one of the most important problems our western NC growers face.

We are also conducting studies to figure out how to measure rootstock traits—vigor, root types, and how they relate to biotic (disease) and abiotic (temperature, salt, flooding) stresses. This work will help us understand better methods to develop superior root systems for tomato production, which can be combined with improved disease resistance to provide superior, competitive rootstocks for NC growers. Much of our research is combined with graduate student training. We currently have four graduate students at the forefront of these important research projects. The research is on-going, and we are glad for the close working relationship we have with the NC tomato industry that helps us advance the science and practice of tomato production and disease management.

Thank you very much!
Sincerely,
The NC State Bacterial Wilt Management Team
www.GraftVegetables.org

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