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Performance of Geneva® Apple Rootstock Selections with 'Brookfield Gala' and 'Cripps Pink' in a Tall Spindle System

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Abstract

High density orchard systems have become standard in many apple production regions due to their earlier yield and higher cumulative yields, which results in greater return on investments. Growers in the Mid-Atlantic region have unique challenges compared to northern production regions—warm temperatures, long growing seasons, and high incidence of fire blight—which elevates the financial risk to growers that invest in the extremely high establishment cost of these systems. High density orchard systems have not been widely evaluated in replicated trials under these growing conditions, so it is unknown whether they are suitable for the region. In addition, there is little information on the performance of a suite of new rootstocks released from the Geneva breeding program designed for these high density systems in the Mid-Atlantic region. To test these high density systems and the relevant rootstocks, two scion cultivars ('Brookfield Gala' and 'Cripps Pink') were budded on stoolbed propagated G. 41, G. 202, and G. 935 as well as tissue-culture propagated G. 202.

Results support that the tall spindle system is appropriate for orchards in the Mid-Atlantic, but could be optimized with region-specific recommendations. The rootstocks tested were appropriate for tall spindle orchards in the Mid-Atlantic; however, there was a high incidence of tree death due to graft union breaks, particularly with 'Cripps Pink' on G. 41, and certain scion-rootstock combinations were too vigorous. Additionally, high amount of fire blight not controlled with standard practices indicate that care must be taken in determining a pruning and training regime for this planting system in the Mid-Atlantic. 'Cripps Pink' fruit quality was not affected by rootstock, while 'Brookfield Gala' quality was affected by choice of rootstock. Yield efficiencies for both cultivars were lower than expected. Propagation method did not appear to significantly impact production, but did have an effect on tree size.

High density orchard systems have become the industry standard for new plantings in many apple production regions due to their increased economic and production efficiency (Barritt, 1992). These systems have earlier yield and higher quality fruit which leads to earlier and greater lifetime return on investment for apple orchards (Robinson, 2008). Orchard system studies conducted since the 1970's in various regions of the world have consistently shown that marketable yields per ha increase with increasing tree density (Barritt, 1992; Jackson et al., 1987; Jackson, 1989; Marini et al., 2001; Robinson et al., 1991, 2004; Weber, 2000, 2001; Wertheim, 1980). However, there is a point of diminishing returns at which increased tree density does

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not lead to greater profits (Barritt, 1992). The most economic system and tree density for a specific scenario depends on many factors, including rootstock/scion combination, site, soil type, climate, management practice, and economic situation (Barritt, 1992; Robinson et al., 1991).

The tall spindle is one of the most economical systems for many regions (Robinson et al., 2011). In this system, tree spacing is 1 x 3 m (approximately 3' x 11') for a density of approximately 3,200 trees/ha (Robinson, 2008). In a successful system, trees begin to bear fruit in their second or third leaf, the orchard is in full production in year four or five, and investments can be recouped by year 11-12—approximately five years earlier than the central leader system (Robinson, 2008). Precocity and management during establishment are critical to the success of this system. With newer cultivars that can lead to greater wholesale prices and profits, growers have increasingly planted tall spindles to maximize early returns. These systems do require significant up-front investment in the form of establishment costs, learning new horticultural practices, training workers, and very precise management.

Rootstocks. High density orchard systems depend on fully dwarfing rootstocks to provide size control, reduced vigor, and pest resistance. Rootstock selection depends on site specific factors including regional climate, soil type and fertility, replant conditions, and pest pressures. Rootstocks should also be matched to the cultural characteristics of the orchard such as vigor of the scion and training system (Tworkoski and Fazio, 2015). Successful rootstock selection will lead to appropriate scion vigor and appropriately filled canopy space (Tworkoski and Miller, 2007).

In addition, rootstock selection influences other characteristics of the crop, such as yield and biennial bearing, which directly impact profitability (Al-Hinai and Roper, 2004; James and Middleton, 2011). Rootstock selection can also affect fruit quality, in terms of incidence of physiological disorders, fruit size, and color, thus impacting value of the crop (Webster and Wertheim, 2003). Scion compatibility and disease resistance are factors influenced by rootstocks that affect tree survival and therefore replacement costs (Webster and Wertheim, 2003). Growth habit and canopy volume, also affected by rootstock selection, influence pruning and management associated labor costs (Marini et al., 2002; Russo et al., 2007; Tworkoski and Miller, 2007). Therefore, rootstock selection is critical for the profitability of the system.

Recommended rootstocks for high density systems include B.9, M.9, G.11, G.16, G.41 or others of equivalent size (Robinson et al., 2008; Russo et al., 2007). Several selections from the joint Cornell University and US Department of Agriculture- Agricultural Research Service apple rootstock breeding program in Geneva, NY have recently become available commercially (Fazio, 2015; Fazio et al., 2015; Russo et al., 2007). These rootstocks provide size control, tolerance to replant disease, high productivity, and resistance to diseases and insects, including fire blight (caused by *Erwinia amylovora)*, wooly apple aphid, and crown rot (Fazio et al., 2015; Russo et al., 2007). Fire blight resistance in the Geneva series is notable, especially when compared to commonly planted M.9 or M.26 (Fazio et al., 2015).

Most of the research cited above has been conducted in cooler northern apple growing regions such as New York and Washington. In the Mid-Atlantic region, apple growers are challenged with warm temperatures, a long growing season, and high incidence of fire blight. Warm temperatures coupled with wet weather between bloom and the cessation of shoot growth exacerbate tree losses from fire blight. A less vigorous rootstock with fire blight resistance is desirable, although planting new cultivars on new rootstocks can lead to problems including unexpected scion vigor, fire blight damage and/or death to the scion.

'Brookfield Gala' is widely planted in the USA and its compatibility with older rootstocks is well known; however, less information is available on the performance of 'Brookfield Gala' with new Geneva rootstocks. There is little information on 'Cripps Pink' (Pink Lady™) in either this climate or with Geneva rootstocks.

The three rootstocks evaluated in this study—G.41, G.202 and G.935—have multiple benefits and are among the most widely available to growers (Robinson et al., 2011). All three are resistant to fire blight, apple replant disease, crown and root rots, and wooly apple aphids. G.41 and G.935 have shown cold hardiness while G.202 has been slightly less hardy. All produce few suckers and burr knots with productivity comparable to M.9 (Fazio, 2015). G.202 and G.935 are comparable in size control to M.26 while G.41 is more similar to M.9-T337 (Fazio, 2015).

Rootstock Propagation Method. Currently, grower rootstock selection is limited by rootstock availability from nurseries. Trees must typically be ordered two to four years ahead of planting. Even then nurseries are sometimes unable to fulfill requests. Improved propagation methods, including tissue culture propagation, have the potential to increase availability; however, tissue culture invigoration can potentially impact growth, productivity and trueness-to-type (Webster, 1995). Few studies have been conducted on propagation method, and those have reported mixed results (Autio et al., 2011). Some show that genetic fidelity of tissue culture propagation rootstocks is high (Gupta et al., 2009), while others reported genetic fidelity should remain a concern (Pathak and Dhawan, 2012). Micro-propagated rootstocks tend to have a fuller root system with 40-100% more primary roots than conventionally propagated material, which might explain the increase in vigor. While micro-propagated rootstocks have not yet played a major role in commercial orchards, several hundred thousand plants are being propagated each year to quench the demand for fire blight resistant rootstocks.

The goal of this research was to test several of the rootstock releases from the Geneva breeding program (G.202, G.41 and G.935) in a high density, tall spindle orchard system in the hot, humid, long-growing season Mid-Atlantic region with two scions ('Brookfield Gala' and 'Cripps Pink'). To gain additional insights, G.202 was propagated using both stoolbed and tissue culture liners.

Materials and Methods

Rootstocks G.41, G.202, and G.935 were propagated in traditional stool beds, and grafted with 'Cripps Pink' and 'Brookfield Gala'. G.202 was also propagated using tissue culture (TC) by Phytacell Technologies LLC (Dehli, NY), for a total of four rootstock treatments (G.41, G.202, G.202TC, and G.935). Grafted trees were grown by Willow Drive Nursery (Ephrata, WA). G.202TC trees were visibly different on arrival. TC trees had more fibrous root systems and fewer feathers when compared to stoolbed propagated trees.

Trees were planted at the Western Maryland Research and Education Center in Keedysville, MD (39°30'36.7"N and 77°43'59.9"W) in spring 2010. Trees were planted at 1.8 x 3.7 m spacing (approximately 1,481 trees/ hectare) in 7-tree panels, replicated 4 times in a Latin square design. This design was chosen due to elevation increases and concurrent soil depth decreases as the rows moved North to South, and due to strong prevailing West winds. The planting was supported by a tall spindle trellis with 4 wires. The top wire was at 2.7 m, and trellis support posts were spaced every 14.4 m. Irrigation and nitrogen (170g calcium nitrate applied around each tree) were provided at recommended rates during establishment. Standard insect, disease, and weed management program was used to control pests (Halbrendt 2012). Branch bending was practiced during the first two years, and annual pruning and tying were done per current tall spindle recommendations (Hoying, 2010). The trees had light bloom in the second leaf, and commercial cropping began in the third leaf (2012).

Fruit thinning protocol was the same for all trees of each cultivar regardless of rootstock. 'Brookfield Gala' trees received the same treatment every year: 2.7 kg/ha (4.9 pt/ha) carbaryl (Sevin™) + 4.4 kg/ha (158 oz/ha) 6-benzyladenine (Maxcel®) at 9 mm average fruit diameter. 'Cripps Pink' received 2.7 kg/ha (4.9 pt/ha) carbaryl (Sevin™) at 9 mm average fruit diameter in 2012, 2013, and 2014, and 2.7 kg/ha (4.9 pt/ha) carbaryl (Sevin™) + 4.4 kg/ha (158 oz/ha) 6-benzyladenine (Maxcel®) in 2015. Sprayer was calibrated to apply 378L/ha.

Tree height (m; 2012, 2013) from the graft union, and trunk circumference (cm) at 25 cm above the graft union (2012, 2013, 2015) were measured in select years. Neither height nor circumference were measured at the time of planting. Trunk circumference was used to calculate trunk cross-sectional-area (TCA, cm^2). Fruits were harvested at approximately 5 on the 8-point Cornell Starch-Iodine Index (Blanpied and Silsby, 1992). For each cultivar, all rootstocks were harvested on the same date. Yield (kg) was recorded per plot (2012-2015), and divided by the number of living trees. Yield efficiency (YE) was calculated by dividing the average yield per tree by the average TCSA within a plot, measured in each respective year. Approximate 2015 returns per ha were calculated, assuming 18.1 kg (40 lbs) per bushel and $8 per bushel ($0.20 per lb).

Fruit quality data at harvest were measured yearly from 2012-2015 using a random sample of 10 fruit per plot, harvested between 1 m and 1.5 m height along the trellis from each of the trees in the panel. Mean fruit weight (FW) was recorded for each sample. Red color was visually estimated as a percentage of surface coloration. Soluble solids concentration was measured once for each sample by collecting juice from each apple in the sample and measuring the aggregate juice with a Leica Mark II Plus Abbe Refractometer (Leica Microsystems Inc, Buffalo Grove, IL). Flesh firmness (kg) was measured on both the red and green sides of each fruit, using a vegetable peeler to remove a 18 mm diameter circle of skin, using a handheld FT 327 Fruit Penetrometer (Wagner Instruments, Greenwich, CT). Starch pattern index was recorded for each fruit (Blanpied and Silsby, 1992). Percent red color was not recorded on 'Cripps Pink' for 2012 and 2013. No fruit quality measurements were collected for 'Brookfield Gala' in 2012.

In July 2011 and August 2013, the planting experienced severe storms including high winds and hail. As a result, a considerable number of trees snapped at the graft union in 2011. Trees that were lost were not replaced. Further tree losses were experienced after data collection had ceased, in 2016 (not reported). Tree survival is reported as the percentage of trees surviving the duration of the study.

All analyses of variance were performed using the MIXED procedure of SAS 9.4 (SAS; SAS Institute Inc., Cary, NC, USA). Data were analyzed separately for 'Brookfield Gala' and 'Cripps Pink.' For fruit quality variables, analysis of variance was performed to test the fixed effects of rootstock (G.202, G.202TC, G.41, G.935). Replicate, column position, and harvest year were included as random effects. For yield and YE data, analysis of variance was performed to test the fixed effects of rootstock for each year (2012, 2013, 2014, 2015). For cumulative yield and cumulative YE, analysis of variance was performed to test the fixed effects of rootstock for the total yield (2012-2015). Replicate and column were included as random effects. Mean separations were performed using the Tukey option at the $P < 0.05$ level.

Results and Discussion

Fruit Quality. Rootstock had a significant effect on FW (P=0.0012) and soluble solids (P=0.0048) of 'Brookfield Gala' apples (Table 1). Fruit harvested from 'Brookfield Gala' on G.202 had smaller fruit than those on G.202TC or G.41; this fruit also had greater soluble solids concentrations than all other rootstocks, though likely not great

Table 1. Average fruit quality variables for 'Cripps Pink' and 'Brookfield Gala' on four rootstocks sampled from 2012 to 2015 at the Western Maryland Research and Extension Center in Keedysville, MD.

Cultivar	Root-stock	Fruit Wt. (g)	Red Color (%)	Soluble Solids (%)	Fruit Firm-ness (kg)	Starch Index	Cumul. Yield (kg/ha)[y]	Cumul. Yield (Kg/cm2)[x]
'Brookfield Gala'	G.202	126.5 b [z]	79.1	14.5 a	9.3	5.3	38.25 c	0.4 a
	G.202TC	142.4 a	64.2	13.7 b	9.0	5.3	55.52 b	0.5 a
	G.41	139.4 a	72.1	13.9 b	8.8	6.2	58.76 ab	0.8 a
	G.935	135.7 ab	65.5	13.9 b	8.9	6.1	70.55 a	0.8 a
	P-value	*0.0012*	*0.0507*	*0.0048*	*0.0942*	*0.1169*	*0.0011*	*0.03*
'Cripps Pink'	G.202	184.4	66.1	14.9	9.72	4.6 ab	74.4	0.4
	G.202TC	178.5	60.1	15.4	9.6	4.0 b	85.6	0.5
	G.41	181.6	60.1	15.3	9.4	5.0 a	87.1	0.6
	G.935	176.0	64.7	15.2	9.7	4.7 a	81.3	0.4
	P-value	*0.2467*	*0.0998*	*0.7453*	*0.124*	*0.0396*	*0.32*	*0.23*

[z] Means within columns and cultivars followed by common letters do not differ at $P < 0.05$ by Tukey HSD test.
[y] Cumulative yield calculated using 2012-2015 harvests.
[x] Cumulative yield efficiency calculated using cumulative yield divided by 2015

enough to be important from a consumer standpoint. 'Cripps Pink' FW and quality were not affected by rootstock.

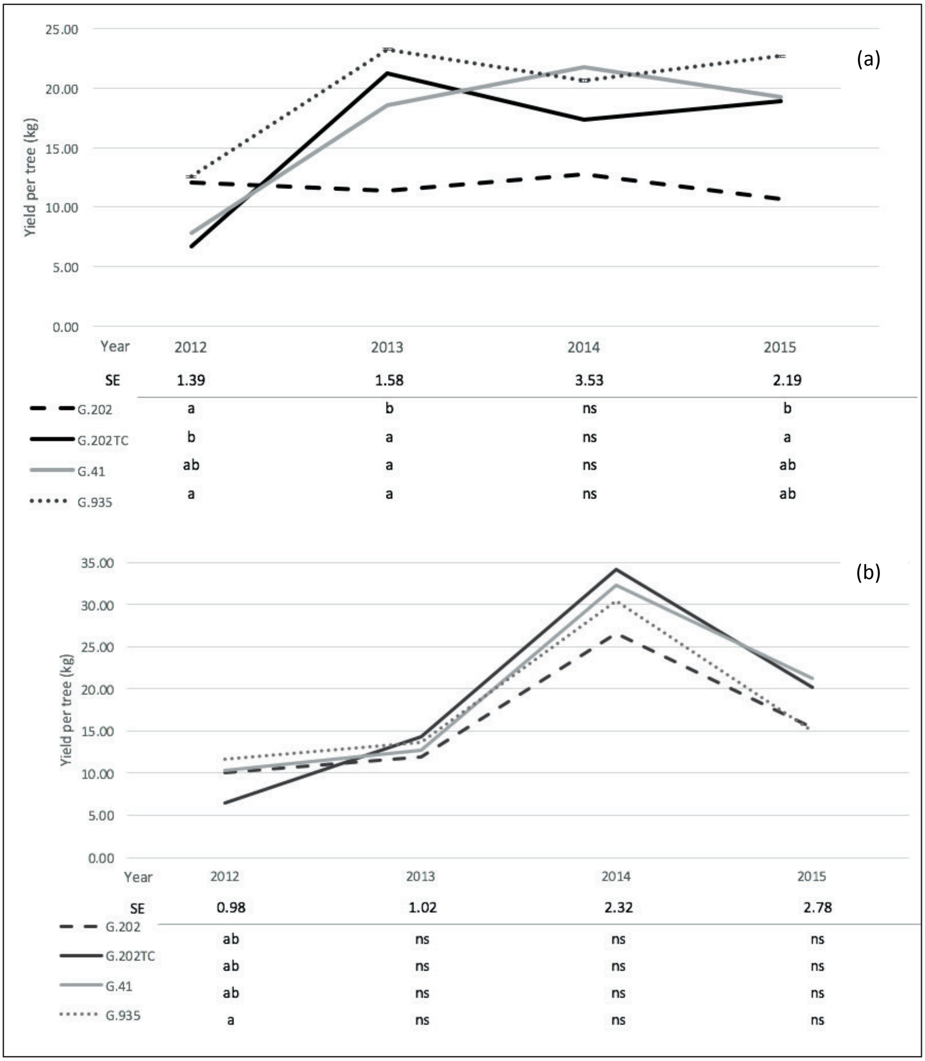
Tree size. Rootstock had a significant effect on tree height for both 'Brookfield Gala' (P=0.0011) and 'Cripps Pink' (P=0.0002), but was only measured until the 3rd leaf. For both cultivars, scions on G.202TC trees were taller than other rootstocks (Table 2). The effect of rootstock was significant for TCA (P=0.01) for 'Brookfield Gala', but not for 'Cripps Pink' in 2015. G.202TC had the largest TCA for both cultivars (Table 2). Due to an oversight, tree size was not measured at the time of planting, preventing evaluation of the influence of initial tree size. However, the findings of this work illustrate that both propagation method and rootstock selection can impact tree size.

The larger tree size observed for TC trees is consistent with other research findings, where TC-propagated trees were generally more vigorous in the nursery and the orchard (Webster, 1995). Specifically, 'Gala' trees grown on TC-propagated Ottawa-3 rootstock had larger rootstock circumference, and greater scion branching and shoot growth than stool bed cuttings, which was expected to lead to more vigorous, less precocious trees in the orchard (Hogue and Nielson, 1991). While more research examining the overall effects of micro-propagation and its interactions on specific scions and rootstock combinations is needed, in this study TC propagation increased vigor.

Yield and Productivity. For 'Brookfield Gala', rootstock significantly affected yield in 2012 (P=0.0114), 2013 (P=0.0016), and 2015 (P=0.021). In 2012, G.202 had higher yields than G.41 and G.202TC (Fig. 1). In each following year, G.202 had lower yields than other rootstocks, even in 2014 when yield differences were not significant. Yield efficiency for 'Brookfield Gala' was also significantly affected by rootstock (P=0.0318) for all three years. 'Brookfield Gala' on G.935 had the highest cumulative yield and yield efficiency.

For 'Cripps Pink', yield was affected by rootstock only in 2012 (P=0.04); G.935 had the highest yield and G.202TC had the lowest (Table 2). For 'Brookfield Gala' cumulative yield and yield efficiency were both significant (P=0.0011; 0.03); G.935 and G.41

Figure 1. The effect of four rootstocks on yield from 2012 to 2015 for cultivars (a) 'Brookfield Gala' and (b) 'Cripps Pink' planted at the Western Maryland Research Extension Center in Keedysville, MD. Yield (kg/tree) is reported as an average of trees in a plot, adjusted to account for tree death. Means in the same column followed by commonletters do not differ at P < 0.05, by Tukey's HSD test.



had the highest and G.202 had the lowest (Table 1).

The general trend in this work was for G.935 trees to have higher yield and YE. Russo et al. (2007) reported similar results, where G.935 had one of the highest cumulative yields and YE of the 64 rootstocks trialed.

Differences in yield per tree translate into appreciable differences in returns/ha. The following calculation is a useful illustration, albeit limited by not accounting for the influence of fruit size or color on returns. Assuming 18.1kg (40lbs) per bushel and $8 per bushel ($0.20/lb) with complete tree surviv-

Table 2. Tree height, TCA, average yield efficiency, tree survival, and approximate returns (with and without accounting for observed tree death) for 'Cripps Pink' and 'Brookfield Gala' on four different rootstocks planted at Western Maryland Research and Extension Center in Keedysville, MD.

Variety	Rootstock	Height (m)		TCA (cm^2)			Efficiency (kg/cm^2)[y]			Approx. Return ($/ha)[x]	Survival (%)[w]	Apprx Return ($/ha)[v]
		2012	2013	2012	2013	2015	2012	2013	2015	2015		2015
Brookfield Gala	G.202	2.6 b	2.9 b [z]	10.4 b	13.7 b	26.9 b	1.2 a	0.9 c	0.4 a	6,971	100	6,971
	G.202TC	3.5 a	4.1 a	17.3 a	22.4 a	38.9 a	0.4 b	1.0 bc	0.5 a	12,359	89	11,000
	G.41	2.9 b	3.5 b	11.2 b	14.8 b	26.0 b	0.8 ab	1.3 ab	0.8 a	12,581	100	12,581
	G.935	2.7 b	3.3 bc	13.5 ab	17.0 ab	29.5 b	0.9 ab	1.4 a	0.8 a	14,853	96	14,259
	P-value	*0.0011*	*0.0011*	*0.02*	*0.01*	*0.01*	*0.02*	*0.01*	*0.0318*	*NA*	*NA*	*NA*
Cripps Pink	G.202	2.5 b	3.0 b	13.2 ab	158.8 ab	36.6	0.8 ab	0.6	0.4	10,074	100	10,074
	G.202TC	3.0 a	3.6 a	15.8 a	22.5 a	43.4	0.4 b	0.6	0.5	13,186	96	12,659
	G.41	2.5 b	2.9 b	13.2 b	20.0 ab	35.4	0.8 ab	0.6	0.6	13,894	50	6,947
	G.935	2.4 b	2.4 b	12.2 b	18.5 b	37.4	1.0 a	0.8	0.4	9,803	68	6,666
	P-value	*0.0005*	*0.0002*	*0.02*	*0.02*	*0.13*	*0.04*	*0.29*	*0.2267*	*NA*	*NA*	*NA*

[z] Means within columns and cultivars followed by common letters do not differ at the 5% level, by Tukey's test.
[y] Yearly yield divided by the same year's trunk cross-sectional area (ie. 2012 yield /2012 truck cross-sectional area)
[x] Assuming 18.1kg (40lbs) per bushel and $8 per bushel ($0.20/lb) without any tree death
[w] Survival is presented as the percentage of trees that survived out of 28 total trees for each scion-rootstock combination.
[v] Assuming 18.1kg (40lbs) per bushel and $8 per bushel ($0.20/lb) accounting for observed tree death

al, approximate 2015 returns/ ha for 'Brookfield Gala' were highest on G.935 while approximate returns/ ha for 'Cripps Pink' were highest on G.41 (Table 2). Return/ ha for 'Brookfield Gala' on G.202 would likely be slightly less due to small fruit size (Table 1). The efficiencies measured at the end of the study were surprisingly low considering the precocious and productive scion cultivars chosen. This illustrates the difference in performance of different cultivars on the same rootstocks, and vice versa, and demonstrates the need for continued evaluation of cultivar-rootstock compatibility. Low efficiencies may also be related to growing region; in the Mid-Atlantic, vegetative growth can be more than double that experienced in regions with cooler temperatures and shorter seasons. This points to a need for continued evaluation of high density systems in various regions, and selection of appropriate scion and rootstocks for these systems in different regions.

Tree survival. The most notable difference observed between rootstocks was tree survival. Several high wind events during 2011 and 2013 led to graft union breaks that resulted in tree death. There were fewer graft union breaks in the 'Brookfield Gala' plots (Table 2); however, nine losses on G.935 and 14, or half of the total 28 trees, on G.41 were experienced for 'Cripps Pink'.

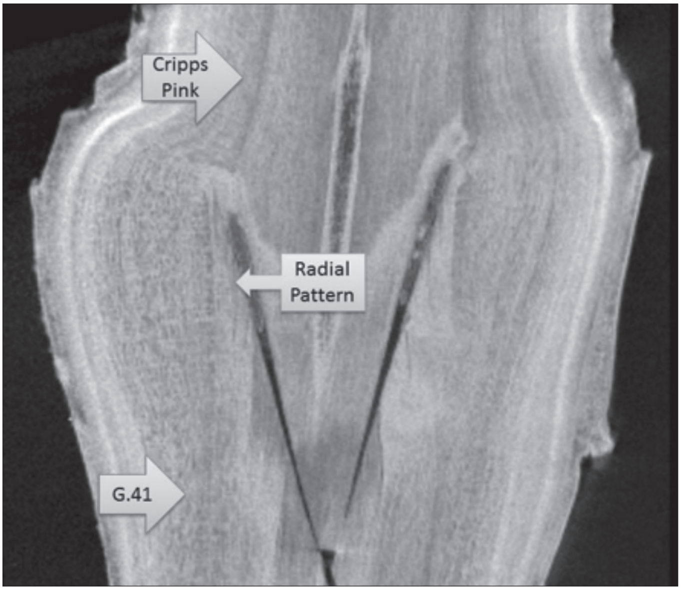
Weak graft unions have been reported by nurserymen and growers for G.41and G.935 in several growing regions, including the Mid-Atlantic. One nursery experienced approximately 60% losses on G.41 and 25% losses on G.935; losses appeared to depend on scion cultivar, with 'Stayman' having very few losses and 'Gala' with high losses (personal communication, Bill Makintosh). Weak graft unions are not uncommon, and have been reported with other rootstock/ scion combinations, including 'Honeycrisp' on M.26. Nonetheless, it is an undesirable condition, and these tree deaths have a considerable impact on returns for growers. Using the same assumptions to calculate returns as above (18.1kg (40lbs) per bushel and $8 per bushel ($0.20/lb)), but adjusting for surviving trees, approximate 2015 returns per hectare for 'Brookfield Gala' were relatively unchanged, but returns for 'Cripps Pink' on G.41 and G.935 were almost half of those on G.202 and G.202TC (Table 2).

Research has shown weak graft unions may be caused by vascular discontinuity (Warmund, 1993, Milien, 2012) and tissue composition, specifically higher parenchyma and lower fibrous tissue than stronger unions (Basedow, 2015). However, weak unions may become stronger over time. In one preliminary report of work examining rootstocks grafted to 'Honeycrisp', G.30 rootstock was among the weakest unions of 39 being investigated, requiring a force less than 70 $N \cdot cm^{-2}$ applied sideways at the union to bend the tree until it broke. After 10 years in the orchard, G.30 rootstock grafted with 'Gala' was the strongest union (requiring the most sideways force to break the union) as compared to eight other commercial rootstocks (Robinson et al., 2015).

Scion cultivar appeared to contribute to graft union strength in this study; there were 24 graft union breaks for 'Cripps Pink' as compared to four for 'Brookfield Gala.' These scion effects are being investigated anatomically through the use of X-Ray 3 D tomography (Fig. 2) at Cornell University where preliminary results suggest a variety specific hormonal effect on the organization of wood tissue within 1 cm of the graft union. More extensive research is necessary to determine the graft union strength of specific rootstock-scion combinations and the anatomical cause of decreased strength, as well as the differences between TC and stoolbed propagated rootstocks.

Fire blight. Fire blight control was provided each year in the form of dormant copper sprays, streptomycin following infection events in the spring for blossom blight applied according to disease forecast models, and strike removal; no summer sprays were applied due to early harvest of 'Brookfield Gala fruit' preharvest interval label restric-

Figure 2. Graph union of a bench grafted 'Cripps Pink' scion (upper portion) on G.41 rootstock (lower portion) visualized by 3D X-ray tomography[z]. The radial patterns seen in the rootstock right above where the two tissues meet is indicative of less organized wood and possibly the reason for weaker wood formation.



[z] Trees, not planted in the experiment, were imaged using a Zeiss Versa XRM-520 CT at the Cornell University Biotechnology Resource Center. Specimens were scanned at 100k V source setting at a 25-30um/pixel resolution with 1600 frames per scan.

tions (both cultivars were treated uniformly). Despite these standard control practices, the planting experienced troublesome amounts of fire blight infections. This was particularly problematic in 2015 when a shoot blight epidemic affected the Appalachian region following warm wet weather in June and July. Trees were dormant pruned in Feb. 2015, leaving Dutch stubs for renewal shoots primarily in the lower third of the trees where the heaviest wood needed to be removed to renovate the spindle. These cuts responded well with excellent shoot growth in the spring and summer of 2016. However, multiple storm events (high winds, hail, and temperatures in mid-80s) from April – July damaged foliar and stem tissues. Renewal shoots on both ‘Brookfield Gala’ and ‘Cripps Pink’ developed shoot blight infections in summer 2015 (Fig. 3). Infections were pruned out where possible in mid-summer, but no trees were removed. No tree losses were experienced at the end of the 2015 season, but cankers developed on many trees at the height of the first wire on the main trunk and significant losses are expected in the future.

Fire blight is a major concern for apple growers in the Mid-Atlantic, where optimal conditions for fire blight infections are experienced many times each year, and the pathogen is considered ubiquitous. Rootstock resistance protects the scion from tree death due to rootstock blight; however, it is not yet clear if it improves the resistance of the scion variety as some report that it does not (Norelli et al., 2003). Others indicate there is a measurable effect on expressed genes that interdict the gravity of fire blight strikes (Jensen et al. 2003 and 2012). Other strategies need to be investigated to provide recommendations for fire blight prevention, control, and replanting decisions for high

Figure 3. Dutch stub infected with fire blight (*Erwinia amylovora*) seen on 'Brookfield Gala' on G.202 in 2015 after dormant pruning cuts.

density orchards in this region, especially as these orchard systems are increasingly adopted.

Conclusion

Consistent with other research and anecdotal information, high density trellised orchard systems are effective systems for the Mid-Atlantic. However, it is evident that appropriate rootstock, scion, and management decisions should take regional characteristics into account. In particular, orchardists need to account for longer growing season and warmer temperatures, which contributed to more vegetative growth, and management of fire blight needs to be a top priority. At the conclusion of this project (sixth leaf), the trees had filled their space and the second phase of management began which is to sustainably manage the planting with the trees achieving their full size. It was at this point fire blight ravaged the 'Brookfield Gala' and damaged the 'Cripps Pink' trees to a lesser degree. Further long term study is definitely warranted.

This system has many attributes and has been easier to manage than other trials in terms of pruning, harvesting, and spraying. Less ladder work, wood to move, and need for other equipment affects the possibility of more efficient work. Future trials comparing orchard systems are necessary to quantify differences in labor and materials efficiency as well as economic impact for the Mid-Atlantic region.

Propagation method did not appear to have significant impact on production but did affect tree size. For the one rootstock that was propagated both via stoolbed and tissue culture (G.202), fruit quality was largely unaffected, with the exception of larger than average fruit weight of 'Brookfield Gala'. The tissue culture propagated stock did appear to increase the vigor of both scions which influenced management decisions for the excessively large trees; however, this increased vigor did not affect yield. There were few differences between stoolbed propagated stocks G.41, G.202 and G.935.

G.935 and G.41 had the most graft breakages, particularly with ‘Cripps Pink’. Coupled with unexpectedly low yield efficiencies for both ‘Brookfield Gala’ and ‘Cripps Pink’, additional physiological understanding is needed.

Rootstock, scion, and planting system selection for commercial plantings of high density apple orchards depend on region, site, and resources available. Recommendations for using these rootstocks in high density systems in the Mid-Atlantic should take into consideration scion selection, planting system, adequate support systems, and site-specific pest pressure.

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About the Cover:

Pioneers in Pomology - from top left in clockwise direction: George M. Darrow, Wilfred Gordon Brierley, Paul Howe Shepard, and Marshal Pinckney Wilder**.** In the last two issues of the Journal we published biographical sketches of these early leaders of American pomology.