Rootstock Choice Affects Yield per Acre, Fruit Nutrient Profile, Bitter Pit Incidence and Crop Value

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Keywords: Apple rootstock, K/Ca ratio, N/Ca ratio yield efficiency, crop value, optimum spacing, projected yield

This research was supported by the New York Apple Research and Development Program

We have calculated what would be the optimum planting density of various new rootstocks from field data of rootstock trials. At the optimum density there are large differences in projected yield and projected crop value among rootstocks. The difference can be as high as $87,000 per acre over 8 years or $200,000 per acre over 14 years. Thus, the practical decision of which rootstock to use for a new orchard can have very large economic consequences that often are not appreciated by growers.

Field comparisons of apple rootstocks have long evaluated survival, level of dwarfing and yield efficiency. Over the many trials we have done we have almost always seen a positive correlation of dwarfing and yield efficiency (Autio et al., 2017, 2020; Lordan et al., 2019b; Marini et al., 2001, 2009, 2014; Reig et al, 2018). Using yield efficiency as the primary criteria of selecting superior rootstocks generally results in the most dwarfing rootstocks being judged superior to the more vigorous rootstocks. However, with weak growing cultivars like 'Honeycrisp' and 'NY1', often the most dwarfing rootstocks do not grow enough to fill the space and thus are not the best practical choice for apple growers (Lordan et al., 2019b). To better evaluate the commercial value of rootstocks we have begun to estimate the optimum planting density and a projected cumulative yield at the optimum density of any given rootstock based on its trunk cross-sectional area (Lordan et al, 2019b; Autio et al., 2020).

In this paper we will present data on the optimum planting density and projected cumulative yield of various new rootstocks to guide planting decisions by growers. We will also present estimates of cumulative gross crop value and the cumulative crop value after removing the cost of trees.

Materials and Methods

2007 Geneva, New York rootstock trial. A replicated field rootstock comparison trial was planted in 2007 at Cornell University's AgriTech campus in Geneva, NY, USA with 19 rootstock genotypes and with 'Honeycrisp' as the scion cultivar. The experimental design was a randomized complete block with 10 replications and 1 tree per rep. The incidence of bitter pit was evaluated in 2019. Cumulative yield over 14 years, trunk cross-sectional area (TCSA) and cumulative yield efficiency were calculated. An optimum planting density for each rootstock was calculated based on the final TCSA relative to the TCSA of M.9T337. The optimum planting density of M.9 was set to 1320 trees/acre (3' X 11' plant spacing). This optimum planting density for M.9 was based on long-term studies we have conducted (Lordan et al., 2019). The optimum planting density for the other rootstocks was adjusted up or down based on the percentage TCSA of each rootstock relative to M.9. Actual cumulative yield per tree was then multiplied by the optimum plant density to calculate a projected cumulative yield for each rootstock. The projected cumulative yield was adjusted down by the percent incidence of bitter pit to give a projected yield of bitter pit free fruit. We then calculated a projected cumulative gross crop value ($/acre) by multiplying the cumulative yield/acre by $0.63/lb which is a reasonable farm gate fruit price for 'Honeycrisp' in the USA (Lordan et al., 2019b). Finally an estimate of net economic crop value for each rootstock was calculated by subtracting the cost of trees using a cost of $10/tree (Lordan et al., 2019b).

2014 Geneva, New York rootstock trial A replicated field rootstock comparison trial was planted in 2014 at Cornell Universities' AgriTech campus in Geneva, NY, USA with 15 rootstock genotypes and with 'Honeycrisp' as the scion cultivar. The experimental design was a randomized complete block with 10 replications and 1 tree per rep. The calculation of projected optimum density, projected yield and projected crop value was done similarly as with the 2007 experiment but percentage bitter pit data was not available.

Data from both trials was analyzed by ANOVA and mean separation was done by LSD (P≤0.05) (SAS statistical software, Cary, NC, USA)

Results

2007 rootstock trial. The incidence of bitter pit in 2019 varied significantly among rootstocks with B.9, G.65 and G.214 having less than 5% bitter pit (). G.210 had the greatest incidence of

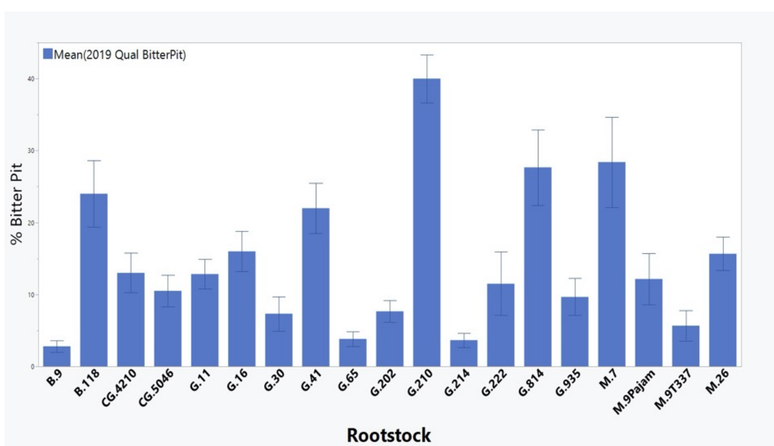

Figure 1. Incidence of bitter pit with mature Honeycrisp apple trees on 19 rootstocks in 2019 when grown in Geneva, New York.

bitter pit (40%) followed by M.7, G.814, B.118 and G.41 which all had more than 20% bitter pit. G.11, G.16 G.30, G.935, G.4202, G.4210, G.5046, G.5202, M.26, M.9T337 and M.9Pajam2 all had between 5 and 15% bitter pit.

Cumulative yield from 2008-2020 was greatest for G.935 followed by G.210, G.214, G.11, G.30, G.41, G.5046 and G.202 (Figure 2) The lowest cumulative yield was with G.65 followed by B.118, G.814, B.9 and M.7. When the percent bitter pit from the 2019 crop year was applied to the cumulative yield the greatest calculated bitter pit free yield was with G.214 (810 t/ha) followed by G.935, G.11, G.30, G.5046, G.16, G.202, M.9T337, M.9Pajam2 and G.202 which all had more than 600 t/ha cumulative yield of bitter pit free fruit.

Cumulative crop value from 2008-2020 was greatest for G.214 ($1.3million/ha) followed by G.935, G.11, G.30, M.9T337, G.202, M.9Pajam2, CG.5046 and CG.4202 which all had cumulative crop values of more than $1million/ha (Figure 3). The lowest cumulative crop value was with G.65 followed by G.814, M.7, G.118, M.26, G.210 and B.9.

Tree size of the 19 rootstocks after 14 years ranged from 17.4 cm^2 to 112.5 cm^2 (Table 1). The projected optimum planting density of rootstocks ranged from 414 trees/acre for B.118 to 2677 trees/acre for G.65. Using the optimum planting density, we grouped the rootstocks into 5 tree size classes. Two rootstocks (G.65 and B.9) were in the super dwarf class with optimum planting densities >2000 trees/acre. There were 11 rootstocks in the next size category (dwarf) with optimum planting densities between 1000 and 2000 trees per acre. There were 3 rootstocks in the next size class (large dwarf) with optimum planting densities between 700 and 1000 trees/acre. There were two rootstocks in the next category (semi-dwarf) with optimum planting densities between 500 and 700 trees per acre. There was only one rootstock (B.118) in the last category (semi-vigorous) with optimum planting densities below 500 trees per acre.

When rootstocks were ranked based on yield efficiency the best rootstocks were G.11, followed by G.222, G.935 and B.9 (Table 1). The rootstocks with the lowest yield efficiency were M.7 and B.10. When projected gross economic value of production at the optimum density was estimated (minus the yield of bitter pitted fruit), the best rootstocks were B.9 followed by G.11, G.935, G.222 and G.30. The rootstocks with the lowest cumulative crop value were M.7, G.210 and B.118. Some stocks had high yield but also high bitter pit thus low bitter pit free yield (G.210 and B118). When the net economic crop value was estimated by subtracting the cost of trees at optimum planting density and using yield of bitter pit free fruit, the best rootstock was G.11, followed by B.9, G.935, G.222, and G.30. Although B.9 had the highest gross crop value it also had a very high optimum tree density (2,491) and high tree cost which reduced its net crop value more than G.11. The most dwarfing stock (G.65) did not have the highest yield efficiency and its optimum planting density was 2,677 trees per acre. Even at that super high planting density its rank among all the rootstocks was 14th of 19 stocks.

<u>2014 rootstock trial</u> Tree size after 8 years ranged from 14.9 cm^2 to 49.9 cm^2 (Table 2). The optimum planting density for each rootstock ranged from 518 trees/acre for G.890 to 1630 trees/acre for G.11. Using the optimum planting density, we grouped the rootstocks into 3 tree size classes. No rootstocks were in the super dwarf class with optimum planting densities >2000 trees/acre. There were 9 rootstocks in the dwarf class, 1 rootstock in the large dwarf class, and 3 rootstocks in the semi-dwarf.

When rootstocks were ranked based on yield efficiency the best rootstocks were G.11, followed by G.41, G.969 and B.10. The rootstocks with the lowest yield efficiency were V.1, V.5, V,6, V.7 and G.214. When projected gross economic value of production was estimated using the projected yield at the optimum planting density, the best rootstocks were G.11 followed by G.41, B.10 and G.969. The stocks with the lowest cumulative crop value were V.1, V.5, V,6 and V.7. When the projected net economic crop value was estimated by subtracting the cost of trees at the optimum planting density, the best rootstock was G.11, followed by G.41, B.10, G.969, and G.30. Although G.890 was the largest tree in the trial and had an optimum planting density of only 518 trees/ha (6ft X 14ft spacing), it also had relatively high yield efficiency (similar to M.9) resulting in a ranking of net crop value of 7th place well ahead of M.9 which ranked 13th.

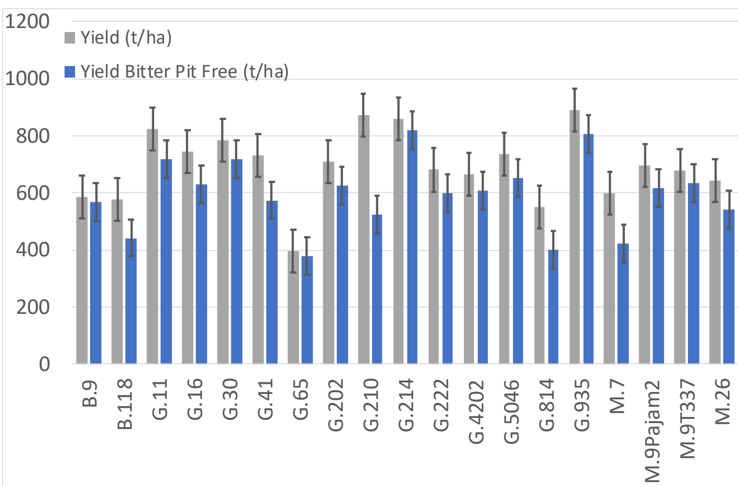

Figure 2. Cumulative total yield and yield of bitter pit free fruit of Honeycrisp apple trees on 19 rootstocks from 2008-2020 when grown in Geneva, New York.

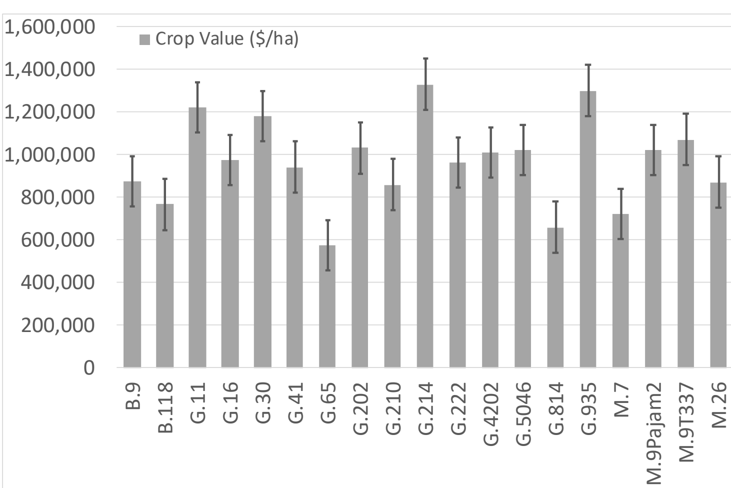

Figure 3. Cumulative crop value of Honeycrisp apple trees on 19 rootstocks from 2008-2020 when grown in Geneva, New York.

Discussion

The selection of rootstock is an important decision for apple growers which has large economic consequences (Lordan et

Table 1. Tree size, projected cumulative yield and projected crop value of 'Honeycrisp' in a 2007 rootstock planting with 19 rootstocks at Geneva, NY over 14 years (2007-2020). Rootstocks grouped into 5 size classes: Yellow=Super dwarf with optimum density >2000 tree/acre; Green=Dwarf with optimum density 1000<trees/acre<2000; Blue=Large dwarf with optimum density 700<trees/acre<1000; Pink=semi dwarf with optimum density 500<trees/acre<700; Gray=semi vigorous with optimum density <500 trees/acre.

Rootstock*	Trunk Cross-sectional Area (cm2)	Yield Efficiency (kg/cm2 TCA)	Cumulative Yield/ tree (kg)	TCA as a % of M.9	Projected Planting Density (trees/ acre)	Projected Cumulative Yield (bu/acre) based on TCA	% Bitter Pit	Projected Cumulative Yield (bu/ acre) of bitter pit free fruit	Projected Cumulative Gross Crop Value ($/acre)	Projected Cumulative Crop Value minus tree cost ($/ acre)	Ranking based on cumulative crop value
G.65	17.4	4.6	80.6	49	2,677	11,299	4.5	10,790	285,510	258,736	14
B.9	18.7	6.5	119.4	53	2,491	15,569	3.0	15,102	399,605	374,699	2
G.222	31.5	6.7	208.7	89	1,480	16,170	12.0	14,229	376,505	361,707	4
M.9T337	35.3	6.1	207.8	100	1,320	14,361	6.5	13,428	355,294	342,094	7
G.11	36.0	7.0	252.5	102	1,294	17,108	13.0	14,884	393,832	380,891	1
M.9Pajam2	36.2	6.0	213.4	103	1,288	14,388	11.5	12,734	336,934	324,055	8
G.41	39.6	5.7	224.4	112	1,176	13,822	21.5	10,850	287,098	275,333	13
CG.4202	40.4	5.2	204.1	114	1,154	12,330	8.5	11,282	298,517	286,978	12
M.26	40.4	5.0	197.2	114	1,154	11,913	15.5	10,066	266,359	254,821	15
CG.5046	41.3	5.5	225.2	117	1,128	13,302	11.0	11,839	313,259	301,976	9
G.16	41.5	5.5	228.8	118	1,122	13,446	15.5	11,362	300,632	289,408	11
G.935	42.1	6.5	272.5	119	1,106	15,786	9.5	14,286	378,012	366,947	3
G.214	45.8	5.8	263.3	130	1,018	14,030	4.5	13,398	354,523	344,346	6
G.814	52.4	4.8	245.5	148	889	11,433	27.0	8,346	220,837	211,942	16
G.30	57.5	6.1	349.1	163	810	14,810	8.5	13,552	358,575	350,472	5
G.202	59.2	5.4	315.6	168	787	13,006	11.5	11,510	304,563	296,692	10
M.7	68.3	4.1	266.2	194	682	9,508	29.0	6,750	178,614	171,792	19
G.210	76.2	5.1	388.6	216	611	12,439	40.0	7,463	197,484	191,370	18
B.118	112.5	4.1	450.7	319	414	9,773	23.5	7,477	197,832	193,691	17
LSD P≤0.05	11.6	0.9	103.8								
						Total	2433	50,450			

al., 2019b). In recent years the number of possible rootstocks has increased significantly giving many options for apple growers. The optimum choice depends on rootstock adaptability to a specific climate, planting density and estimated total production over the lifetime of the orchard. In Figure 1 which shows bitter pit incidence, the best stocks are B.9, G.65 and G.214 but incidence of bitter pit only tells half of the story. The total yield of bitter pit free fruit is more important and can be used to calculate the actual crop value. When this was calculated (Figures 2 and 3) a more complete picture emerges of which is the best stock. This method shows that the best stocks were G.214, G.935 and G.11 and the super dwarfing stock B.9 was significantly inferior to 12 other stocks. However, a more complete picture emerges when yield is calculated at the optimum planting density not just the density used in the experimental planting. When using the optimum planting density to calculate yield and crop value, the best rootstock was G.11 followed by B.9, G.935, G.222, and G.30. This method gives a more complete picture and is a more easily understood to assist growers in selecting the best rootstocks.

Our results have shown that there are large economic differences in cumulative crop value with a high priced cultivar like 'Honeycrisp' that are due to rootstock genotype. In the 2007 experiment the difference in cumulative net crop value between the best rootstock and worst rootstock was $200,000/acre over 14 years. In the second study the difference was $87,000 over 8 years. Thus, the decision of which rootstock to use for a new orchard can have very large economic consequences.

Our results have also shown that the super dwarfing rootstocks which require planting densities greater than 2,000 trees/acre do not produce the highest projected cumulative yield or projected cumulative crop value. With G.11, which was the best rootstock in both studies, the optimum density was 1294 trees/acre in the first study and 1630 trees/acre in the second study. The difference in optimum planting density for G.11 between the two studies is likely due to the difference in age of the two plantings. As orchards age the cumulative yield curve of a given rootstock begins to show less difference between super high density plantings and intermediate density plantings (Lordan et al., 2019a). Thus the older an orchard gets the lower the optimum tree density for any rootstock.

Honeycrisp has low scion vigor and with B.9 it often does not fill the allotted space. Our work showed that B.9 should be planted at extremely high densities (~2,500 trees/acre) to produce high yields and high crop values. At the more common densities between 1,000 and 1,600 trees/acre (Robinson, 2008), the best rootstocks are those that have sufficient vigor to fill the space in the first 3 years but are also efficient and produce low incidence of bitter pit. In our studies, the rootstocks which were the best at 1,000-1,600 trees/acre (dwarf class) include G.11, G.935, G.222, G.41, B.10 and G.969. At lower densities between 700 and 1,000 trees/acre (semi-dwarf class) G.30 and G.890 had high crop values which were only slightly lower than the best rootstocks in the dwarf class.

The method we have used to compare rootstock performance results in rootstocks classified into various size classes and then includes a practical way to compare rootstocks in each size class by calculating net predicted crop value. This will help apple growers both appreciate the economic consequences of rootstock choice and to select those that will significantly improve their economic results.

We have previously shown that some rootstocks such as G.41 and G.11 have greater uptake of K than other rootstocks such as G.214 and G.969 (Fazio et al., 2013, 2020; Lordan et al., 2020). It appears that bitter pit incidence is greater with rootstocks which are efficient in uptake of K and N while high K uptake is associated with greater fruit size. Greater K and N uptake is often associated with greater rootstock vigor (e.g. M.7) but can also be associated with dwarfing stocks such as G.11. The difference in K uptake of various rootstocks can be used to match rootstock to scion variety in a "designer rootstock" fashion. The best rootstock for a small fruit size cultivar like 'Gala' would be a stock with high K uptake like G.11 or G.41. The best rootstocks for a bitter pit sensitive cultivar like 'Honeycrisp' would be stocks that have sufficient vigor to fill the space but which also have low K uptake. It appears that G.969 and G.214 have both sufficient vigor to fill the space and low K uptake resulting in low bitter pit incidence.

Table 2. Tree size, projected cumulative yield and projected crop value of 'Honeycrisp' in a 2014 rootstock planting with 15 rootstocks at Geneva, NY over 8 years (2014-2021). Rootstocks grouped into 3 size classes: Green=Dwarf with optimum density 1000<trees/acre<2000; Blue=Large dwarf with optimum density 700<trees/acre<1000; Pink=semi-dwarf with optimum density 500<trees/acre<700.

Rootstock*	Trunk Cross-sectional Area (cm2)	Yield Efficiency (kg/cm2 TCA)	Cumulative Yield/ tree (kg)	TCA as a % of M.9	Projected Planting Density (trees/acre)	Projected Cumulative Yield (bu/ acre) based on TCA	Projected Cumulative Gross Crop Value ($/acre)	Projected Cumulative Crop Value minus tree cost ($/acre)	Ranking based on cumulative net crop value
G.11	14.9	9.1	76.8	81	1,630	6,553	173,318	157,021	1
M.9T337	18.4	7.1	55.0	100	1,320	3,801	100,538	87,338	13
G.935	18.4	6.4	65.2	100	1,320	4,506	119,183	105,983	8
G.41	19.2	8.9	93.4	104	1,269	6,207	164,165	151,472	2
B.10	20.1	8.2	84.8	109	1,211	5,377	142,212	130,102	3
G.202	21.5	7.2	77.4	117	1,128	4,572	120,926	109,644	6
G.969	23.1	8.2	87.5	125	1,056	4,838	127,957	117,397	4
G.214	23.4	6.4	75.9	127	1,039	4,130	109,246	98,852	9
M.26EMLA	24.0	6.7	76.8	130	1,015	4,083	107,990	97,836	10
V.1	28.0	4.9	65.1	152	868	2,960	78,290	69,605	15
G.30	35.0	6.6	124.4	190	695	4,525	119,683	112,736	5
V.6	35.5	6.0	106.8	193	684	3,824	101,153	94,314	12
V.7	40.9	6.4	124.6	223	592	3,861	102,136	96,217	11
V.5	46.0	5.4	125.5	250	528	3,469	91,763	86,483	14
G.890	46.9	6.8	159.9	255	518	4,334	114,624	109,447	7
LSD P≤0.05	5.7	1.5	17.2						

**Rootstocks ranked by increasing TCSA.*

The differences in rootstock nutrient profiles indicate that different soil fertility management programs are needed for each rootstock. For stocks with natural high K uptake much lower fertilizer inputs of K are needed. For stocks with low natural K uptake higher levels of fertilizer inputs of K are needed. In New York State, our recommendations for fertilizer K inputs are based on M.9 rootstock but for G.11 or G.41 new standards need to be developed. Recently Lailiang Cheng (2021) has published revised recommendations for Honeycrisp that are lower than for Gala.

The ratio of fruit peel K/Ca can be used as a prediction of bitter pit incidence (Cheng et al., 2021) and as a guide for fertilization inputs. For orchards on rootstocks that have high K/Ca or high N/Ca ratios in the fruit and therefore high bitter pit incidence there are several mitigation strategies that can be employed such as:

- Increase the quantity of Ca through foliar sprays (Rosenberger et al., 2004)
- Eliminate annual N applications
- Eliminate annual K applications
- Increase Lime applications.
- Avoid application of AVG or 1-MCP. Watkins et al. (2021) have reported that applications of these plant growth regulators as preharvest drop control agents exacerbated bitter pit in trees which have high K/Ca ratios.

Summary

Rootstock trials usually rank rootstocks based on yield efficiency. Using yield efficiency as the primary criteria of selecting superior rootstocks generally results in the most dwarfing rootstocks being judged superior to the more vigorous rootstocks. To better evaluate the commercial value of rootstocks we estimated the optimum planting density of any given rootstock based on its trunk cross-sectional area. We then calculated a projected cumulative yield per acre and cumulative crop value at the optimum spacing. This effort has shown that some of the most dwarfing rootstocks would not produce the highest cumulative crop value even when planted at very high densities. The economic differences in estimated crop value among rootstocks using the projected yield differences was very large, especially with high priced varieties like 'Honeycrisp'. The difference can be as high as 87,000 per acre over 8 years or $200,000 per acre over 14 years. Thus, the decision of which rootstock to use for a new orchard can have very large economic consequences which are often not appreciated by growers.

Acknowledgments

This work was supported by the NY State Apple Research and Development Program and by the USDA National Institute of Food and Agriculture Specialty Crop Research Initiative through their sponsored project "AppleRoot2Fruit: Accelerating the development, evaluation and adoption of new apple rootstocks" (2016-51181-25406).

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