Rootstock Tolerance to Apple Replant Disease for Improved Sustainability of Apple Production

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Abstract

In 2006, a multi-location field experiment of 12 apple rootstocks with and without pre-plant soil fumigation was established at 9 locations in the USA, Canada and Mexico by the NC-140 rootstock research group. Rootstocks were B.9, M.9T337, M.9Pajam 2, M.26, M.7, Geneva® 11 (G.11), G.16, G.30, G.41, G.210, G.935 and CG.4210. 'Royal Gala' was the scion cultivar. Over the 4 years of the project there was a strong interaction of rootstock and location on tree growth and yield. Generally, B.9 rootstock exhibited the weakest growth while M.7 had the most vigorous growth. There were no significant differences in tree size between the two clones of M.9 (T337 and Pajam2) and the two dwarf Geneva stocks (G.11 and CG.4210). G.41 and G.16 were similar in size to M.26 while G.935 was significantly larger than M.26 while G.30 and G.210 were slightly larger than G.935 but smaller than M.7. Trees on G.935 had the greatest cumulative yield followed by G.210, G.30, G.16, G.41, G.4210, G.11, M.9Pajam2, M.9T337, B.9, M.7 and M.26, which had the lowest yield. Cumulative yield efficiency was greatest for B.9 followed by G.935, G.41, CG.4210, G.11, M.9T337, G.16, M.9Pajam2, G.210, G.30, M.26 and M.7, which had the lowest yield efficiency. Rootstock tolerance to replant disease at each site was assessed by comparing the percentage improvement in growth and yield in fumigated plots to un-fumigated plots. G.16, G.41, CG.4210 and B.9 showed consistent tolerance to replant disease across sites while M.26 was the most susceptible. Other stocks, which showed some tolerance to replant disease were G.30, G.935, G.210, G.11 and M.9T337. There were large differences among locations in the effect of fumigation (severity of replant disease). At some locations growth and yield were greatly improved by fumigation while at other locations there was little effect of fumigation.

INTRODUCTION

Apple replant disease limits new tree growth in many traditional apple production areas of the world (Auvil et al., 2010). It is thought to be caused by a complex of several soil borne pathogenic bacteria and fungi (Mazzola et al., 2009). Soil fumigation has been the most common control option. Genetic resistance or tolerance of rootstocks would offer a more environmentally sustainable method of disease control.

The Cornell University/USDA apple rootstock breeding project, located at Geneva NY, has developed rootstock genotypes which are resistant to fire blight (*Erwinia amylovora*) and crown rot (*Phytophthora* spp.) (Cummins and Aldwinckle, 1983; Norelli, et al., 2003; Russo et al., 2007). Some have been shown to have tolerance to apple replant disease (Auvil et al., 2010; Isutsa and Merwin, 2000; Robinson and Hoying, 2005). Our objectives were to evaluate several new disease resistant rootstocks from the Geneva®

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(G) series, for tolerance to replant disease, in comparison to common Malling (M) and Budagovsky (B) rootstocks at several locations in North America. The project was conducted by the US national rootstock testing group NC-140.

MATERIALS AND METHODS

In 2006, a multi-location field experiment comparing the growth and yield of 12 rootstocks with and without pre-plant soil fumigation was established at 10 locations in the USA, Canada and Mexico by the NC-140 rootstock research group (Table 1). Rootstocks compared were: B.9, M.9T337, M.9Pajam2, M.26, M.7, G.11, G.16, G.30, G.41, G.210, G.935 and CG.4210. 'Royal Gala' was the scion cultivar. At each location, a site that was previously planted to apples was prepared for planting by fumigating randomized plots with Telone C-17 soil fumigant (Telone is a nematicide and the C-17 is 17% chloropicirin which is a general biocide) in August or September of 2005. Fumigated plots were 21m long and 2.4m wide. Control plots were not fumigated.

Experimental design at each location was a randomized complete block with split-plot treatments and 8 single tree replications. The main plot was soil fumigation treatment, and the sub-plot was rootstock genotype. Within each 21 m long sub-plot, one tree of each rootstock genotypes was planted in a randomized order.

Annually we measured trunk circumference, leader growth, lateral shoot growth and yield. Trunk cross-sectional area (TCA) was calculated from trunk circumference. Yield efficiency was calculated as the ratio of cumulative yield/final TCA. Growth and yield data were collected for 4 years. Data were analyzed by analysis of variance and all interactions were evaluated. The severity of replant disease at each location and rootstock tolerance to replant disease was assessed by comparing the percentage improvement in growth and yield in fumigated plots to un-fumigated plots. The resulting percentages were analyzed by analysis of variance.

RESULTS

Rootstock genotype had a large effect on tree size (as measured by TCA), shoot growth, yield and yield efficiency (Table 2). However, there was a strong interaction of location and rootstock genotype on tree growth and yield. Averaged over the 8 locations, tree size after 4 years was smallest on B.9 and largest on M.7. The two clones of M.9 were significantly larger than B.9 and similar to G.11 and CG.4210. G.41 and G.16 were slightly larger than M.9 and similar to M.26. G.935 was slightly larger than M.26 but smaller than G.30 and G.210 which in turn were smaller than M.7. Cumulative shoot growth and average shoot length for the 4 growing seasons also differed between the rootstocks but the differences were highly correlated to TCA (Fig. 1). Two rootstocks (M.26 and G.16) had less shoot growth than expected from their TCA's and 2 rootstocks (G.41 and G.210) had more shoot growth than expected from their TCA's.

Yield was not related to tree size (Table 2). Trees on G.935 had the highest yield followed by G.210, G.30, G.16, G.41, G.4210, G.11, the 2 clones of M.9, B.9, M.7 and M.26, which had the lowest yield. Yield efficiency was greatest with B.9 followed by G.935, G.41, CG.4210, G.11, M.9T337, G.16, G.210, M.9Pajam2, G.30, M.26 and M.7, which had the lowest yield efficiency.

There were large differences in growth of trees at the 8 locations. Averaged over all rootstocks, the greatest growth was at North Carolina and Pennsylvania while the least growth was at Nova Scotia (Table 2). Averaged over all 8 locations, there was a relatively small but significant positive effect of fumigation on tree growth, yield and yield efficiency (Table 2).

The tolerance of rootstock genotype to replant disease was evaluated by calculating the percentage increase in tree growth and yield for each rootstock averaged over all 8 locations. G.16, G.41 and CG.4210 were the most tolerant of replant disease since they exhibited almost no improvement in TCA due to fumigation while M.26 and M.7 were the most susceptible since they showed a strong improvement in TCA due to fumigation (Table 3). B.9, G.30, G.210, G.935, G.11 and the two clones of M.9 had an intermediate response to fumigation. Improvement in total shoot growth due to fumigation was greatest with M.26 and CG.4210 and least for G.16, G.41, G.935 and B.9. G.30, the 2 clones of M.9, G.210, G.11 and M.7 had an intermediate response to fumigation. All rootstocks showed an improvement in yield due to fumigation, with the greatest response by M.9Pajam2, G.210, G.11, CG4210, G.41 and M.7. M.26 had the least increase in yield due to fumigation. Averaged over the 8 locations, fumigation also improved yield efficiency of all rootstocks with the greatest effect with CG.4210 and the least effect with G.935 and the 2 clones of M.9.

There were large differences in the effect of fumigation on tree growth among locations (Table 3). At Nova Scotia, the improvement in growth due to fumigation was more than 50% while at the 2 New York locations, Pennsylvania and New Jersey there was little improvement in growth due to fumigation. At Chihuahua, Coahuila and North Carolina the growth response to fumigation was intermediate.

DISCUSSION

The significant interaction of location and rootstock genotype in this study indicates that rootstock performance varied at the different locations in North America. Such location by rootstock interactions have been seen in most national NC140 rootstock trials (Autio et al., 2005, 2008; Marini et al., 2006a, b, 2009). This indicates that local recommendations of rootstock should be based on local field performance trials. Nevertheless, the average performance across many locations can be instructive. In this study, B.9 was very efficient but was judged at all locations to be too dwarfing for high commercial yield. The best rootstocks which combined dwarfing similar to M.9 and high yield efficiency were G.41, G.935, G.11 and G.16. This is similar to results of other studies (Autio, 2005, 2008; Marini, 2009; Masseron and Simard, 2002; Robinson and Hoying, 2005; Robinson et al., 2003). G.41 and G.935 had significantly greater yield efficiency than the 2 clones of M.9, while G.11 and G.16 had similar efficiency as M.9. CG.4210 was also dwarfing and had high yield efficiency but had the highest mortality (data not presented).

We assessed apple rootstock tolerance to replant disease by calculating the percentage improvement in growth in fumigated plots compared to un-fumigated plots. The rootstocks which showed the highest tolerance to replant disease (similar growth in un-fumigated and fumigated soil) were G.16, G.41 and G.4210. Our results also confirm that M.26 is the most sensitive common rootstock to replant disease (Robinson and Hoying, 2005). Thus, in this trial, trees on M.26 were relatively small compared to M.26 grown in virgin soil. This complicates the size comparisons of the Geneva® stocks with M.26. In other trials, M.26 was similar in size to G.30 (Marini et al., 2006b). Although G.41 showed little difference in growth between fumigated and non-fumigated soils, it showed a significant improvement in yield efficiency due to fumigation. Similarly, G.16, G.210 and CG.4210 exhibited a small effect of fumigation on growth but a significant improvement in yield efficiency due to fumigation.

Our data have shown that over a broad range of climates and soils, that 2 Geneva® stocks, G.11 and G.41 are very similar in dwarfing to M.9. Previous studies have shown their significant fire blight resistance which is an advantage over M.9 and offer substantial benefits to North American apple growers (Russo et al., 2007). In addition, this study has shown that G.41 also has significant resistance to replant disease. Both G.41 and G.11 are being commercialized rapidly.

Among CG stocks similar in size to 'M.26' rootstock, our data shows G.935 has performed much better than M.26 with better yield efficiency than M.9. It also has good fire blight resistance (Russo et al., 2007), and in this study had excellent tolerance to apple replant disease. Its vigor level may make this stock ideal for organic production or with lower fertility soils. It is also being commercialized rapidly in North America.

Among Geneva® stocks similar in size to M.7 rootstock, this study shows that G.30 and G.210 performed much better than M.7 and have good tolerance to replant disease. Although these stocks are too vigorous for high density orchards, they could be useful in areas of the world which plant lower densities.

Although this study used soil fumigation to assess the genetic tolerance/resistance of apple rootstocks to apple replant disease, the identification of tolerant rootstocks could allow the discontinuance of soil fumigation when replanting old orchard soils. This would significantly improve the sustainability of apple production worldwide. The relatively high number of Geneva® rootstocks which have shown some tolerance to replant disease may stem from the screening for Phytophthora resistance done in the breeding program. This screening may also have selected for tolerance to the complex of soil organisms that cause replant disease.

CONCLUSIONS

1. The severity of apple replant disease varies considerably across North America. Some locations have a severe problem but other locations have no disease problem.
2. Several Geneva® rootstocks have shown significant tolerance to apple replant disease across different locations in North America.
3. The use of rootstocks that are tolerant to apple replant disease in new apple orchards will reduce the need for soil fumigation and will improve sustainability of apple production.

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Tables

Table 1. Project leaders and locations of the 9 experimental plots.

Project leader	Location
Rafael Parra	Cuauthemoc, Chihuahua, Mexico
Valdemar Gonzalez	Saltillo, Coahuila, Mexico
Moshbah Kushad	Urbana, Illinois, USA
Win Cowgill, Wes Autio, Jon Clements	Flemington, New Jersey, USA
Steve Hoying	New Paltz, New York, USA
Terence Robinson	Geneva, New York, USA
Mike Parker	Fletcher, North Carolina, USA
Charles Embree	Kentville, Nova Scotia, Canada
James Schupp	Biglerville, Pennsylvania, USA

Table 2. Main effects of rootstock, location and fumigation treatment on growth and cropping of 'Gala' apple trees over the first 4 years.

Stock[z]	TCA (cm^2)	Cum. shoot growth (cm)	Average shoot length (cm)	Cum. yield (kg)	Cum. yield efficiency (kg/cm^2 TCA)
B.9	8.7	2150	29.5	11.2	1.34
M.9T337	10.7	3084	33.7	11.9	1.03
M.9Pajam2	11.4	3314	36.1	12.1	0.98
G.11	11.6	3613	36.1	13.0	1.05
CG.4210	12.1	3325	35.1	13.3	1.13
G.41	12.8	4365	41.3	14.3	1.14
M.26	13.0	3221	35.5	10.7	0.81
G.16	14.0	3686	37.7	14.6	1.02
G.935	16.4	4916	42.0	19.5	1.22
G.30	18.8	6021	46.4	15.7	0.86
G.210	19.7	6811	48.4	17.7	0.96
M.7	24.0	7016	50.0	11.2	0.45
LSD $P \leq 0.05$	1.2	553	2.3	1.3	0.10
Location					
Nova Scotia	6.7	-	-	3.6	0.53
Coahuila	11.9	1088	32.2	2.0	0.18
New Jersey	13.5	5266	25.6	10.2	0.87
New York-East	13.6	2158	43.8	16.3	1.25
Chihuahua	15.3	2746	41.3	4.6	0.29
New York-West	16.3	5944	35.4	35.8	2.32
Pennsylvania	17.7	6453	62.2	24.1	1.51
North Carolina	17.9	5254	32.4	5.8	0.55
LSD	2.1	769	3.3	3.4	0.19
Fumigation Trt.					
Non Fumigated	13.9	4190	39.7	13.0	0.93
Telone C-17	15.0	4307	38.6	14.3	1.05
LSD	0.7	NS	1.1	0.6	0.06
Interactions					
Stock×Location	**[y]	**	**	**	**
Stock×Trt	NS	NS	NS	NS	NS
Location×Trt	NS	NS	NS	NS	NS
Stock×Loc×Trt	NS	NS	NS	NS	NS

[z]Rootstocks ranked by TCA.

[y]NS=Non-significant, *=significant at the $P \leq 0.05$ level and **=significant at the $P \leq 0.01$ level.

Table 3. Main effects of rootstock and location on the percentage increase in growth and cropping of 'Gala' apple trees over the first 4 years due to pre-plant soil fumigation.

Stock[z]	% Increase in TCA due to fumigation	% Increase in total shoot growth due to fumigation	% Increase in yield due to fumigation	% Increase in yield efficiency due to fumigation
G.16	3	-1	43	56
G.41	4	4	80	81
G.4210	4	106	81	102
B.9	8	1	56	49
G.30	8	71	56	52
M.9T337	11	15	53	42
G.210	17	47	96	62
G.935	18	-12	60	37
G.11	21	33	82	57
M.9Pajam2	21	30	97	39
M.7	28	31	80	60
M.26	33	109	33	50
LSD P≤0.05	19	82	83	70
Location				
New York West	4	3	10	13
New York East	5	6	24	21
Pennsylvania	6	70	13	15
New Jersey	8	78	140	120
Chihuahua	16	-7	2	-15
Coahuila	18	9	105	101
North Carolina	29	64	91	110
Nova Scotia	60	-	205	86
LSD P≤0.05	21	86	68	55
Interactions				
Stock×Location	**[y]	NS	NS	NS

[z]Rootstocks ranked by percentage increase in TCA due to fumigation.

[y]NS=Non-significant, *=significant at the P≤0.05 level and **=significant at the P≤0.01 level.

Figures

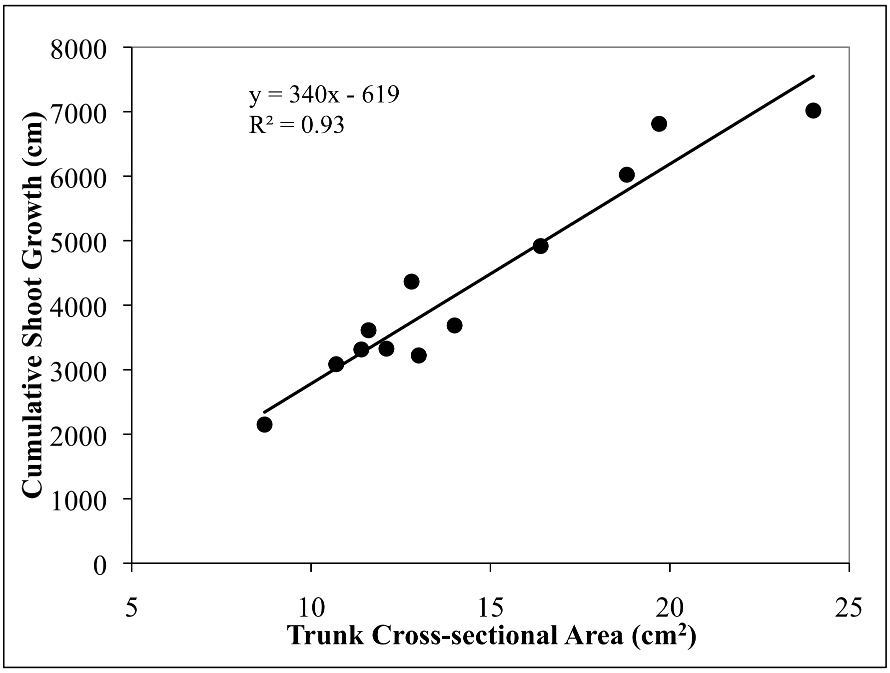

Fig. 1. Relationship of trunk cross-sectional area and cumulative shoot growth over 4 years of 'Gala' apple trees when grown on 12 rootstock genotypes.