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Effect of Rootstock and Cultivar on the Growth and Precocity of Young Apple Trees

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Abstract

'Gala' and 'Triple Red Delicious' apple (*Malus domestica* Borkh.) were grafted onto M.9EMLA, MM.106EMLA, MM.111 EMLA, and B.118 ('Gala' only) rootstocks and grown in a greenhouse to determine the relative influence of scion and rootstock on growth and flowering. In addition, ungrafted micropropagated trees of each cultivar, growing on their own roots, were included. Rootstock exerted more influence than cultivar on total growth, with micropropagated trees making more total growth than trees on clonal rootstocks. The largest trees had the most lateral branches, therefore rootstock affected branching via a tree size influence. Branch density (branches per meter of tree height) however, was primarily under cultivar control. Rootstock affected flowering the year after grafting, but not the subsequent year, whereas in both years much more flowering was observed on 'Gala' than on 'Delicious.'

Introduction

Commercial apple trees are composed of a scion cultivar grafted or budded onto a rootstock, thus forming a genetically compound system. Tree growth and development can be dramatically influenced by both cultivar and rootstock. In order to determine their relative importance, a number of studies were carried out at the East Malling Research Station in England (6, 8, 11, 12, 13, 14) in which reciprocal grafts of a number of rootstock clones were made to examine the relative effects of the same genetic material acting as either scion or rootstock. Both scion and rootstock affected tree growth additively, although rootstock had the greater effect. Flowering effects were reported in only three of these studies, two of which found no difference in flowering when the same material was acting as a scion or as a rootstock (6, 13) while another (8) suggested that the number of flowers was affected by scion to a greater extent than by rootstock. When interpreting these data, it should be borne in mind that in both scion and rootstock positions, clones were used that are normally employed as rootstocks. These have been bred and selected for their influence on a scion grafted on them and not for their performance themselves as a scion, and as such their effects are not necessarily representative of those of commonly used scion cultivars.

Other more recent studies with different cultivars growing on a range of rootstocks, have indicated that growth and flowering are dependent on scion, rootstock and the scion X rootstock interaction (5, 15, 20). The present study was initiated to determine the relative influence of scion and rootstock on various parameters of vegetative and reproductive growth using cultivars of known and differing precocity as scions in combination with rootstocks covering a wide range of vigor and precocity.

Materials and Methods

Wood was collected from trees of 'Triple Red Delicious' (hereafter referred to as 'Delicious') and 'Gala' and grafted onto rooted M.9EMLA (dwarfing, precocious), MM.106EMLA (semi-dwarfing, precocious), MM.111EMLA (semi-vigorous, non-precocious), and B.118 (vigorous, precocious) rootstocks

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during March 1991. Grafting wood was collected from mature trees that had been produced by tissue culture. Micro-propagated (MP) trees originating from the same source and growing on their own roots were produced as detailed by Zimmerman and Fordham (19) and included in the study. This resulted in a factorial arrangement of cultivar and rootstock, although the 'Delicious'/B.118 combination was absent due to grafting failure. The cultivars were selected to represent differing degrees of precocity with 'Gala' considered to be highly precocious and 'Delicious' less precocious. Similarly, the rootstocks ranged in expected precocity from M.9EMLA (highly precocious), to own rooted trees (nonprecocious).

At planting, grafted trees were slightly larger than MP trees, and their root system was more highly developed. Trees were grown in a greenhouse in 5.5 liter pots containing a medium consisting of equal amounts of soil (Wooster silt loam), peat and perlite. They received approximately 400 ml of 20-20-20 liquid fertilizer weekly and pesticides were applied as necessary. All trees were staked, headed at 65 cm during August to encourage lateral branching, and blocked according to tree height. From December until April, trees were removed to a storage area maintained at approximately 5°C. Flowers appeared in late April 1992 and were classified into those borne laterally or terminally, counted and immediately removed. On one set of trees consisting of 5 single tree replicates of each cultivar/rootstock combination, the shoot length of the central leader was measured at approximately weekly intervals from April until trees were removed from the greenhouse in early November. This gave an effective growing season of 226 days.

In order to determine growth distribution, a quantity of trees of each scion/rootstock combination was produced so that 5 replicate trees could be harvested on each of the following dates; 13 July, 10 August, 21 September and 3 November. An additional set of trees was placed into storage on 4 November to measure flowering the following year. On each harvest date, measurements were made of total tree height, number and length of lateral branches, shoot leaf size, spur leaf number, size, and area, and total tree leaf area. Lateral growths of more than 5 cm were classed as branches. A high degree of variability was evident in foliar measurements over the course of these harvests, especially for the first and last harvest dates. Due to this variability and some leaf fall prior to the last sampling time, foliar measurements from the second and third sampling dates were combined and are presented here. Shoot growth had ceased by the time these samples were taken, except for 'Gala'/MM.106 and 'Gala' MP trees. Measurements of total leaf area per tree therefore, may have slightly under-estimated the true leaf area of these trees. Trees were returned to the greenhouse during early March 1993 and counts made of the number of flower clusters produced on lateral, spur and terminal sites. Trunk diameters were measured at the time of flowering, from which trunk cross-sectional areas (TCSA) were calculated.

Results

Growth. Micropropagated trees growing on their own roots were generally the most vigorous trees in the study. 'Gala' MP trees had greater tree height, TCSA, total growth and leaf area than similar trees grafted on clonal rootstocks (Table 1). The same trends were evident in 'Delicious' trees, although tree height and TCSA for own rooted trees were not significantly greater than those for trees on MM.106 rootstock. No differences in any of these variables were evident among grafted 'Gala' trees but 'Delicious' trees on MM.106 had higher leaf area than trees on MM.111, and were taller and of greater girth than trees on M.9 and MM.111 rootstock. By the end of the experiment, 'Gala' trees were larger than those of 'Delicious,' but the differences were relatively small with cultivar accounting for less than 11% of the total treatment variation (Table 4).

'Gala' trees grew rapidly during the first 50 days following their return to the greenhouse, with trees on M.9 being the slowest growing over this period at 8.2 mm.day^{-1} and own rooted trees the most vigorous at 15.4 mm.day^{-1}(Table 1, Figure 1). The shoot growth rate of trees on the other rootstocks was intermediate. After 70 days in the greenhouse, shoot growth of all 'Gala' trees had virtually ceased, and remained at a low level (< 3 mm.-day^{-1}) for approximately 20 days. At this time, shoots of MP trees were 31% longer than those on M.9 rootstocks. The main differences in final shoot growth however, were due to a second flush of growth which occurred during the latter half of the growing season. At 90 days, shoots of 'Gala' on B.118, MM.106, and MP trees resumed growth (4.1, 4.7, and 7.1 mm.day^{-1} respectively) until 180 days, after which shoot growth on all rootstocks was negligible. The final length of shoots on 'Gala' MP trees was 130% greater than those growing on M.9 rootstock.

Rootstock did not have a significant effect on the shoot growth of 'Delicious' trees. The early season shoot growth rate was 10 mm.day^{-1} which persisted until day 45 when a gradual decline occurred until shoot growth terminated 100 days after trees were placed in the greenhouse (Table 1, Figure 2).

At the end of the second growing season, 'Gala' MP trees had more lateral branches than 'Gala' trees on clonal rootstocks, among which no rootstock effect was observed (Table 2). The number of lateral branches on 'Delicious' trees however was unaffected by rootstock. There was a trend for 'Gala' trees to have more branches

Table 1. Effect of rootstock on vegetative growth of 'Gala' and 'Triple Red Delicious' apple trees after 2 years growth.

Scion	Rootstock M.9	MM.106	MM.111	MP	B.118
		Tree height (cm)			
'Gala'	181 a	211 a	197 a	B 312 b	211a
'Delicious'	193 a	221 b	177 a	A 245 b	
		Trunk cross-sectional area (cm²)			
'Gala'	1.6 a	2.4 a	2.3 a	3.9 b	2.1 a
'Delicious'	1.5 a	2.6 b	1.5 a	3.1 b	
		Total growth (cm)			
'Gala'	449 a	609 a	B 527 a	B 1249 b	620 a
'Delicious'	379 a	486 a	A 320 a	A 881 b	
		Leaf area (cm²)			
'Gala'	4140 a	6164 a	5406 a	B 11922 b	5893 a
'Delicious'	3642 ab	5515 b	2952 a	A 8304 c	
		Early season shoot growth rate (mm.day^{-1})			
'Gala'	8.2 a	13.7 bc	12.6 bc	B 15.4 c	10.6 ab
'Delicious'	11.2	11.0	10.9	A 10.2	
		Late season shoot growth rate (mm.day^{-1})			
'Gala'	1.4 a	4.7 ab	1.5 a	B 7.1 b	4.1 ab
'Delicious'	0.6	0.8	1.1	A 0.6	

Upper case letters indicate significant differences between scions within rootstocks and lower case letters indicate significant differences among rootstocks within scions ($p \leq 0.05$).

Table 2. Effect of rootstock on lateral branching of 'Gala' and 'Triple Red Delicious' apple trees after 2 years growth.

	Rootstock				
Scion	M.9	MM.106	MM.111	MP	B.118
	Number of lateral branches (> 5 cm)				
'Gala'	6.8 a	10.4 a	8.2 a	B 17.0 b	8.0 a
'Delicious'	5.4	4.1	5.4	A 7.8	
	Total growth of lateral branches (cm)				
'Gala'	268 a	398 a	331 a	B 937 b	409 a
'Delicious'	187 a	265 b	143 a	A 635 b	
	Mean lateral branch length (cm)				
'Gala'	38.3 a	38.2 a	40.4 ab	B 55.7 b	54.4 ab
'Delicious'	35.6	81.6	33.7	A 85.6	
	Lateral branch density (branches.m^{-1} tree height)				
'Gala'	3.9	5.1	4.3	B 5.5	3.8
'Delicious'	2.8	1.9	3.0	A 3.2	

Upper case letters indicate significant differences between scions within rootstocks and lower case letters indicate significant differences among rootstocks within scions ($p \leq 0.05$).

than 'Delicious' trees on similar rootstocks, but this was only statistically significant for MP trees. When the number of lateral branches was standardized for tree height (branch density), no rootstock effect was evident. As was the case for lateral branch number, 'Gala' trees tended to have higher branch densities than 'Delicious' trees, but this was only significant for MP trees (Table 2).

'Gala' trees on their own roots had longer branches than 'Gala'/M.9 or 'Gala'/MM.106 trees, while 'Gala' trees on MM.111 and B.118 rootstocks had branches of intermediate length (Table 2). Rootstock had no effect on lateral branch length of 'Delicious' trees, and the only cultivar effect was for MP trees, where 'Delicious' had longer branches than 'Gala' trees. The total length of branches followed a similar

Table 3. Effect of rootstock on flowering of young 'Gala' and 'Triple Red Delicious' apple trees.

	Rootstock				
Scion	M.9	MM.106	MM.111	MP	B.118
	Number of flower clusters per tree in 1992				
'Gala'	B 15.6 a	B 4.2 b	B 3.0 b	0.2 b	4.6 b
'Delicious'	A 0.8	A 0.0	A 0.0	0.0	
	Number of flower clusters per tree in 1993				
'Gala'	23.2	B 42.2	B 26.6	B 34.4	34.8
'Delicious'	1.4	A 3.0	A 1.8	A 3.0	
	Number of flower clusters in 1993 per cm^{-2} TCSA				
'Gala'	B 13.7	B 17.2	B 11.4	B 9.4	19.8
'Delicious'	A 1.0	A 1.1	A 1.2	A 1.0	
	Number of flower clusters in 1993 per m shoot length				
'Gala'	B 5.0	7.6	4.8	B 2.8	4.5
'Delicious'	A 0.3	0.2	0.1	A 0.4	

Upper case letters indicate significant differences between scions within rootstocks and lower case letters indicate significant differences among rootstocks within scions ($p \leq 0.05$).

trend to that described for total shoot growth. Cultivar had no effect on spur leaf characteristics or shoot leaf size, while rootstocks effects were small and inconsistent (data not presented).

Flowering. Some flowers were borne in 1992, one year after grafting. The most flowers were produced by 'Gala'/M.9 trees with a small degree of flowering observed on other 'Gala' trees (Table 3). Flowering was absent on 'Delicious' trees in 1992 except for a small number of flowers produced by trees on M.9 rootstock. The increased flowering of 'Gala'/M.9 trees was due to lateral bloom rather than flowers borne on terminal sites (data not presented).

In 1993, rootstock had no effect on the flowering of either cultivar (Table 4). Cultivar however, had a profound effect on flowering with 'Gala' trees producing 10-15 times as many flowers per tree as 'Delicious' (Table 3). With 'Gala,' about 70% of flowers were borne on lateral sites, while spur and terminal sites contributed about 15% each (data not presented). The data on flower position for 'Delicious' were extremely variable due to low numbers of flowers. Total flower number over the 2 years showed similar trends to the 1993 flowering data, with a strong cultivar effect and no influence of rootstock (Table 4). The same patterns in the data were evident when flower numbers were standardized for tree size using either TCSA or total growth as indicators of tree size (Tables 3, 4).

Discussion

The total growth of MP trees was approximately double that of grafted trees and the only rootstock effects on these measures of vigor was between these two groups. A major difference between MP trees and those on clonal rootstocks is the absence of a graft union on MP trees. To determine the effect of the graft union, McKenzie (7) compared self-budded trees with unworked controls. Four years after budding, the total stem dry weight of self-budded trees was 4-26% lower than

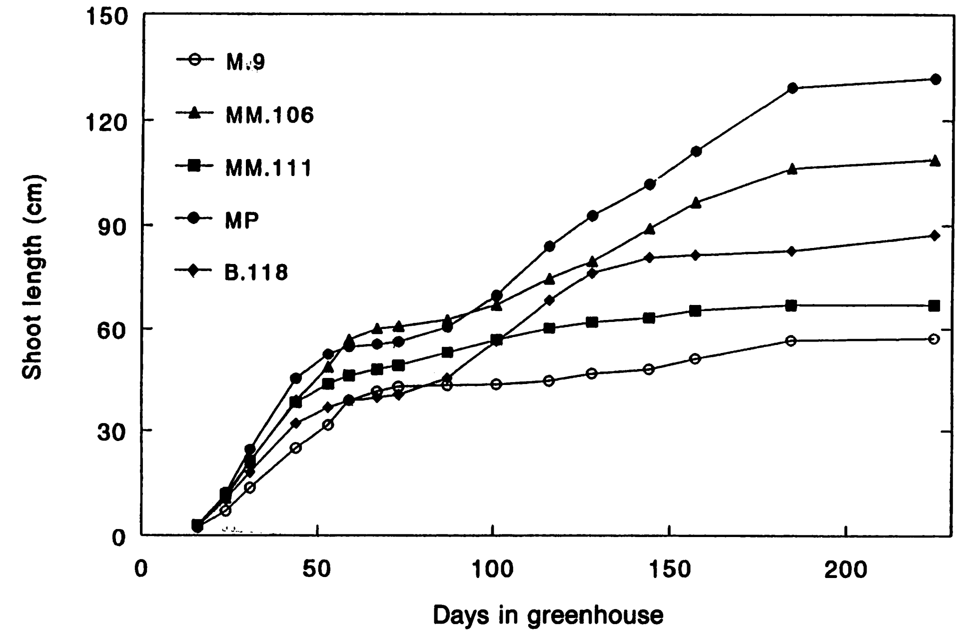

Figure 1. Influence of rootstock on the growth of terminal shoots of 'Gala' (day 1 = March 30, 1992).

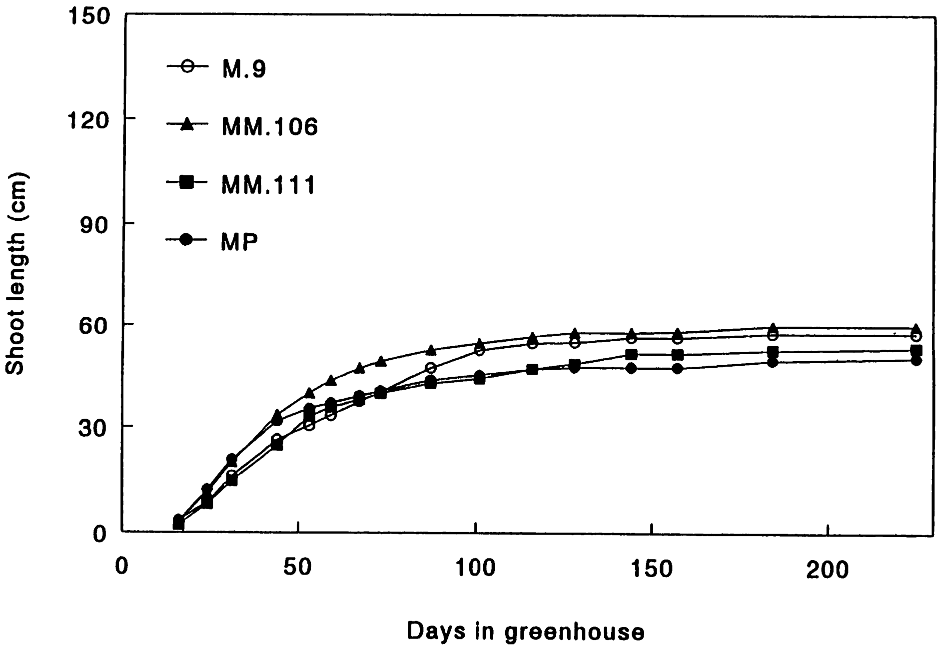

Figure 2. Influence of rootstock on the growth of terminal shoots of 'Triple Red Delicious' (day 1 = March 30, 1992).

unworked trees. Therefore the graft union itself may play a role in the growth potential of the scion. It has been shown that the union between the scion and a dwarfing rootstock is responsible for a lower concentration of nutrients in the xylem sap above the union than below it, and although this effect was dramatic with a dwarfing rootstock such as M.9, in more vigorous rootstocks no effect was observed (3).

Differences in total growth among clonal rootstocks were insignificant, confirming previous results for young trees of a number of cultivars (5, 10, 20, 21). Rootstock effects on the growth of older trees are commonly observed (9) therefore it would seem that rootstock differences may become more apparent in older trees after fruiting begins.

Trunk cross-sectional area has long been used as a non-destructive indicator of tree size (17, 18). Westwood and Roberts (17) found strong relationships ($r^2 > 96\%$) between TCSA and tree fresh weight for a number of cultivars after 3, 5 or 15 years growth. In this study TCSA was closely related to other measures of tree size, tree height, total growth and total leaf area per tree (r^2 of 91%, 88% and 93%, respectively). Despite significant cultivar X rootstock interactions for tree height, total growth and leaf area, rootstock had the major effect accounting for over 80% of the treatment variation for each of these variables. Previous studies (4, 8, 14) have also found scion X rootstock interactions for tree size and attributed rootstock to be the predominant factor controlling tree size. The relatively small interactions support earlier suggestions of additive rootstock and scion effects on tree size (11, 12).

'Gala' trees demonstrated two distinct flushes of growth with the second flush responsible for most of the root-

Table 4. Proportion of total treatment variation (adjusted SS) of growth and flowering variables explained by rootstock, cultivar or rootstock x cultivar interaction as determined by analysis of variance.

Variable	Rootstock	Cultivar	Rootstock x cultivar
TCSA	87%***	5%*	8%
tree height	82%***	3%	15%**
leaf area	84%***	10%***	6%*
total growth	86%***	10%***	4%*
no. of lateral branches	45%**	39%***	16%*
mean lateral branch length	56%***	16%*	28%*
lateral branch density	12%	73%**	15%
shoot growth rate - day 16-44[a]	32%*	15%*	53%***
- day 87-184[a]	28%	40%**	32%
flower clusters 1992	32%***	46%***	22%***
flower clusters 1993	6%	89%***	5%
flower clusters 1992 + 1993	3%	95%***	2%
flower clusters 1993.TCSA^{-1}	4%	90%***	6%
flower clusters 1993.m^{-1} shoot growth	10%	79%***	11%

*, **, *** represent statistical significance at $p \leq 0.05, 0.01, 0.001$ respectively.
[a]day 1 = March 30, 1992.

stock effect on final shoot length. For example, for trees on M.9 rootstock, the second flush accounted for only 25% of the final shoot length, whereas for own rooted trees, 54% was due to growth during the second half of the growing season. The greenhouse environment under which these trees were grown provided a long growing season (226 days). In fruitgrowing areas with long growing seasons, such as New Zealand, 2 flushes of growth are commonly observed with 'Gala' whereas 'Delicious' only has one flush of growth. This corresponds to the periodicity of growth observed in this study. Although this pattern of shoot growth was controlled by cultivar, rootstock and the interaction between them, cultivar had the largest effect (Table 4).

The highly precocious nature of trees on M.9 compared with other rootstocks is well documented (1, 6, 16). In our study 'Gala'/M.9 trees produced the most flowers in 1992, but rootstock had no effect on flowering the following year. Lack of effect of rootstock on flowering held true for 1993 data and 1992 + 1993 flowering, whether expressed on per tree, per unit of shoot length, or per unit TCSA bases. In field plots, various rootstocks have exhibited more precocious flowering than MP trees (15, 21), but in other studies the relative performance of MP trees has been inconsistent or cultivar dependant (4, 20). Trees in this study were grown in a greenhouse under near ideal conditions, especially in terms of water availability (trees were watered up to 2 times per day as necessary) and cooling during the day to reduce the maximum temperature. These conditions were probably less stressful than the field grown trees in previous studies where rootstock had an effect on flowering. Data from field studies (unpubl.) have indicated that differences among rootstocks in flowering performance may be more pronounced under higher stress conditions, perhaps explaining the lack of rootstock effect on flowering in the current study. The large difference in precocity between cultivars observed here has been reported previously (20, 21).

Larger trees generally produced more lateral branch growth. In comparing various treatments on the growth of branches in nursery trees, Hogue and Neilsen (2) found that treatments which resulted in larger trees, also led to the production of more lateral branches. Increased branching on more vigorous trees was also reported by Ferree (1). Lateral branch growth was affected to a greater extent by the number of lateral branches than the mean branch length. Rootstock had more effect on total lateral branch growth and number of laterals than did cultivar but when the number of branches were standardized for tree size, the rootstock influence disappeared and the cultivar effect remained. Similar trends were evident in the data of Tubbs (11). Rootstock was the main determinant of tree size and it was probably via this effect that rootstocks affected branching. Cultivar, however, influenced lateral branching independently of tree size, presumably through apical dominance and correlative inhibition of lateral buds. These data support the hypothesis proposed by Moore (8) that "rootstock largely controls total growth, but the distribution of growth within the scion is largely controlled by the scion."

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