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The Effects of Rootstock and Root-Interstem Combination on the Growth, Productivity, and Anchorage of a Spur and Standard Strain of Delicious Apple Tree[1]

WESLEY R. AUTIO AND FRANKLIN W. SOUTHWICK[2]

Abstract

The growth, productivity, and anchorage of 'Starkrimson Delicious' and 'Gardiner Delicious' apple trees on M.7A, M.26, M.9/MM.111, M.9/MM.106, and MM.111 rootstocks and rootstock-interstem combinations were assessed. 'Starkrimson' (spur strain) trees were smaller, more productive per tree, more efficient, and produced higher theoretical yields per hectare than did 'Gardiner' (standard strain) trees. Trees on MM.111 were the largest, least productive (per tree), least efficient, and produced the lowest theoretical yields per hectare. However, they were much better anchored than any other rootstock or rootstock-interstem combination.

Studies (1, 5, 11) have compared spur and standard apple strains but commonly have not assessed the additional effects of rootstock and rootstock-interstem combination. In this study we compared the effects of M.7A, M.26, M.9/MM.111, M.9/MM.106, and MM.111 on the growth, productivity, and anchorage of 'Starkrimson Delicious' (spur strain) and 'Gardiner Delicious' (standard strain) trees.

Materials and Methods

'Starkrimson Delicious' (Bisbee strain) and 'Gardiner Delicious' trees on M.7A, M.26, M.9/MM.111, M.9/MM.106, and MM.111 rootstocks were planted at the Horticultural Research Center, Belchertown, MA in the spring of 1981. The experimental design was a randomized complete block with 7 replications. Within each block 4 trees were planted per strain-rootstock combination, and the two middle trees were used for data collection. All rows were 6.1 m apart, but spacing within rows varied with the treatment. 'Starkrimson' trees on M.26, M.9/MM.111, and M.9/MM.106 were spaced 3.7 m. 'Starkrimson' trees on M.7A and MM.111 and 'Gardiner' trees on M.26, M.9/MM.111, and M.9/MM.106 were spaced 4.3 m. 'Gardiner' trees on M.7A and MM.111 were spaced 4.9 m.

In 1983 bloom was assessed as the number of blossom clusters per cm trunk circumference and in 1984 as the number of blossom clusters per cm limb circumference. In 1984 fruit set was determined per cm limb circumference, and yield was measured. In 1985 tree height, spread, trunk circumference, and yield were measured.

The 1985 tree spread values were used to calculate theoretical tree spacing and theoretical number of trees per hectare. It was assumed that the optimal distance between trees within a row should be 50 percent greater than the 1985 tree spread and that the distance between rows should be 2.4m greater than the distance between trees within a row. The value of 50% was used because it resulted in approximately the accepted densities for the 2

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[2]Assistant Professor and Professor Emeritus, Department of Plant and Soil Sciences, University of Massachusetts, Amherst, MA 01003

strains on M.7A, a highly tested rootstock. These values were used to calculate the theoretical number of trees per hectare and the theoretical yield per hectare in 1984 and 1985. Yield efficiency, in terms of kg fruit per cm^2 trunk cross sectional area, also was calculated in 1984 and 1985.

In September, 1985 these trees experienced the effects of Hurricane Gloria, which allowed an assessment of tree anchorage of these strains on the various rootstocks and rootstock-interstem combinations. The angle of lean from the vertical was used to determine anchorage since poorly anchored trees were partially or completely blown over.

Analyses of variance were performed with the ANOVA subprogram of the SPSS statistical software package (12). Means for each strain rootstock treatment are presented, and in those cases where a significant strain X rootstock interaction occurred Duncan's New Multiple Range Test (3) was used to separate rootstock means within each strain (14). However, where the interaction was nonsignificant the overall rootstock means were separated, and the letters denoting difference are presented between the rootstock means for each strain. Overall means for the 2 strains were separated by F-test (14).

Results and Discussion

Tree Size

Tree height, spread, and trunk circumference, obtained in November, 1985, are presented in Table 1. For each measurement 'Gardiner' trees were significantly larger than 'Starkrimson' trees. This relationship between a spur and a standard strain is not uncommon and has been shown by other researchers (4, 9, 16, 17) Also, significant differences existed among rootstocks within each strain. 'Gardiner' trees were tallest on MM.111, followed by those on M.7A. The two interstem combinations were similar in size, and trees on M.26 were the shortest. 'Starkrimson' trees were tallest on MM.111 and M.7A, and the M.26, M.9/MM.111, and M.9/MM.106 trees were of similar height. Tree spread was greatest for trees on M.7A, M.9/MM.106, and MM.111. Trunk circumference was greatest for trees on MM.111 and M.7A.

As expected, the size of the spur trees allowed for significantly more trees per hectare than the standard strain (Table 1). For both strains the M.26 and M.9/MM.111 rootstocks resulted in the smaller trees and most trees per hectare. The M.7A, M.9/MM.106, and M.111 trees were of similar tree spread which resulted in similar values for trees per hectare.

The theoretical tree densities calculated from tree spread in this study are somewhat lower but roughly similar to those recommended by Lord (8). The most prominent differences were between recommended and calculated densities for trees on M.9/MM.106 and MM.111, where calculated densities were 40% lower and 36% higher, respectively, than recommended. Whereas, other densities were within 17% of recommended values. The inconsistencies between theoretical and recommended values for trees on M.5/MM.106 likely relate to the precocity of those trees. The trees on M.9/MM.106 had the highest yields for 1984 and 1985, and as a result their growth rate may be slower than trees on M.7A, for instance. When a similar formula is used to calculate ultimate tree spread for trees on M.7A and M.9/MM.106, it would be expected that either the ideal density for M.9/MM.106 would be underestimated or that for M.7A would be overestimated. In this case it appears that the theoretical density for trees on M.9/MM.106 may be lower than the ideal density. The situation may be the reverse for trees on MM.111, where the theoretical density was substantially higher than the rec-

Table 1. Height, spread, trunk circumference, and calculated number of trees per hectare in 1985 of 'Gardiner Delicious' and 'Starkrimson Delicious' trees planted in 1981.

	Height (m)			Spread (m)			Trunk circumference (cm)			Theoretical density (trees per hectare)		
Stock	'Gardiner'		'Starkrimson'	'Gardiner'		'Starkrimson'	'Gardiner'		'Starkrimson'	'Gardiner'		'Starkrimson'
M.7A	4.17 b[z]		3.75 a	3.26	a[y]	2.41	26.6 a		23.8 a	48	b	77
M.26	3.47 d		3.08 b	2.80	b	1.95	19.2 d		18.1 bc	62	a	112
M.9/MM.111	3.72 c		3.05 b	2.74	b	1.89	21.3 c		16.9 d	65	a	118
M.9/MM.106	3.84 c		3.29 b	3.20	a	2.38	23.4 b		19.5 b	49	b	80
MM.111	4.54 a		3.75 a	3.14	a	2.56	26.9 a		23.7 a	51	b	71
$\bar{X}$	3.96	**[x]	3.38	3.02	**	2.25	23.5	**	20.4	55	**	91

[z]Means within columns not followed by the same letter are significantly different at the 5% level.
[y]Mean separation performed on the overall rootstock means.
[x]**, $p \leq 0.01$; $p \leq 0.05$; NS, nonsignificant.

Table 2. Flowering and fruit set of 'Gardiner Delicious' and 'Starkrimson Delicious' trees planted in 1981.

	No. of blossom clusters 1983 (per cm trunk circum.)			No. of blossom clusters 1984 (per cm limb circum.)			Fruit set 1984 (per cm limb circum.)		
Stock	'Gardiner'		'Starkrimson'	'Gardiner'		'Starkrimson'	'Gardiner'		'Starkrimson'
M.7a	8.3	c[zy]	9.9	4.0	b[y]	3.5	0.67	ab[y]	0.82
M.26	11.8	b	10.6	5.6	a	4.3	0.93	ab	0.53
M.9/MM.111	10.2	bc	9.2	4.9	a	4.5	0.52	bc	0.45
M.9/MM.106	13.6	a	12.4	5.3	a	4.0	1.18	a	0.91
MM.111	2.0	d	0.8	4.0	b	2.9	0.36	c	0.39
$\bar{X}$	9.2	NS[x]	8.6	4.8	**	3.9	0.73	NS	0.62

[z]Means within columns not followed by the same letter are significantly different at the 5% level.
[y]Mean separation performed on the overall rootstock means.
[x]**, $p \leq 0.01$; $p \leq 0.05$; NS, nonsignificant.

ommended value. These trees were not producing many fruit, and thus may have been growing at a faster rate than other trees. In this case theoretical densities likely are higher than ideal. These inconsistencies exist because the trees were not mature, and we would not expect these problems with trees in full production. However, we believe that this means of comparing theoretical densities is more accurate than any other available technique, even with the young trees, as long as it is recognized that prior to maturity factors such as precocity may alter growth rate.

The recommendation of specific tree densities is the most important result of measuring tree size. The use of spread is one means of estimating density. However, Lombard *et al.* (7) used comparisons of trunk cross sectional areas and comparisons of recommended planting distances to estimate density of rootstock-scion combinations. Their procedure assumed a very close correlation between trunk and top growth, but tree spread is a better measure of tree size because it directly measures the parameter which affects the number of trees which may be planted per hectare. Granted, the use of tree spread may have some inherent variation such as can be caused by pruning, but trunk growth can also be significantly altered by pruning (6).

Flowering and Fruit Set

Table 2 shows the flowering and fruit set data for 1983 and 1984. No significant differences existed between 'Gardiner' and 'Starkrimson' as to the quantity of bloom in 1983, but in 1984 'Gardiner' had significantly more bloom than 'Starkrimson.' These trees were in their fourth leaf in 1984 and the greater bloom on 'Gardiner' the standard strain, may have been due simply to variation in these trees which were just coming into production. In general the interstem trees and trees on M.26 had more blossom clusters than did trees on M.7A or MM.111.

Fruit set in 1984 (Table 1) was similar for the 2 strains, but trees on M.9/MM.106 had the highest set and those on MM.111 and M.9/MM.111 had the lowest.

Yield

Yield per tree, yield efficiency, and theoretical yield per hectare are presented in Table 3. On a per tree basis the cumulative yield for 1984 and 1985 was significantly higher for the 'Starkrimson' than the 'Gardiner' trees. Some studies (13, 15) have shown a similar relationship with the spur strain yielding more than the standard strain. However, other studies (2, 4, 9, 13) have shown the reverse. Cases such as this one, where the spur yielded more than the standard strain, may reflect precocity rather than ultimate yield potential. As the standard trees become much larger it would be expected that they would yield more than the spur trees, as was seen by Ferree *et al* (4).

The yield efficiency was significantly greater for 'Starkrimson' than for 'Gardiner' as would have been expected. Other studies (4, 9) have shown a similar difference between spur and standard strains. Theoretical production per hectare was also significantly higher for 'Starkrimson.' Since the spur strain was smaller and more productive it had a much higher theoretical yield per hectare.

Yields per tree for the various rootstocks showed that trees on M.9/MM.106 produced the most fruit, whereas those on M.9/MM.111 produced the least. The MM.111 root appeared to confer a low yield potential to the tree, or at least resulted in a lower precocity. There was also a lower fruit set for trees with these roots. It is particularly interesting to note the difference between the 2 interstem trees. Lord *et al.* (10) also showed that trees on M.9/MM.106 and

Table 3. Yield per tree, yield efficiency, and theoretical yield per hectare for 'Gardiner' and 'Starkrimson Delicious' trees on various rootstocks planted in 1981.

Stock	1984 'Gardiner'		1984 'Starkrimson'	1985 'Gardiner'		1985 'Starkrimson'	Cumulative 'Gardiner'		Cumulative 'Starkrimson'
Yield per tree (kg)									
M.7a	7.4	b[zy]	5.4	9.9 bc		23.2 bc	17.3	bc[y]	28.6
M.26	6.5	b	4.5	16.2 a		27.4 b	22.7	b	31.9
M.9/MM.111	2.5	c	1.4	15.7 ab		18.5 cd	18.2	c	20.0
M.9/MM.106	12.1	a	9.2	18.7 a		34.2 a	30.8	a	43.4
MM.111	2.0	c	1.4	6.5 c		14.4 d	8.6	d	15.8
$\bar{X}$	6.1	NS[x]	4.3	13.5	**	23.6	19.4	**	27.9
Yield efficiency (kg/cm² trunk cross sectional area)[w]									
M.7a	0.20	bc[y]	0.18	0.18	b[y]	0.53	0.32	c[y]	0.66
M.26	0.33	b	0.20	0.60	a	1.03	0.83	a	1.20
M.9/MM.111	0.09	bc	0.08	0.57	a	0.87	0.64	b	0.94
M.9/MM.106	0.42	a	0.64	0.43	a	1.14	0.70	a	1.46
MM.111	0.06	c	0.05	0.11	b	0.32	0.15	d	0.35
$\bar{X}$	0.22	NS	0.23	0.38	**	0.78	0.53	**	0.92
Theoretical yield per hectare (kg)									
M.7A	342	b[y]	415	459 ab		1822 b	794 ab		2236 b
M.26	357	b	422	1005 a		2804 a	1362 a		3234 a
M.9/MM.111	146	c	175	1048 a		2273 ab	1202 a		2448 b
M.9/MM.106	575	a	685	896 ab		2702 a	1471 a		3394 a
MM.111	109	c	87	306 b		991 c	415 b		1071 c
$\bar{X}$	306	NS	357	743	**	2112	1049	**	2477

[z]Means within columns not followed by the same letter are significantly different at the 5% level.
[y]Mean separation performed on the overall rootstock means.
[x]**, $p \leq 0.01$; $p \leq 0.05$; NS, nonsignificant.
[w]Cumulative yield efficiency was calculated as the cumulative yield per tree (kg) per cm² trunk cross sectional area.

M.9/MM.111 were of similar size, but trees on M.9/MM.106 yielded significantly more fruit than those on M.9/MM.111.

The yield efficiency was highest for trees on M.9/MM.106 and M.26 followed by those on M.9/MM.111, M.7A, and MM.111 in that order. MM.111 trees were the largest and least productive and thus the least efficient. Yield efficiency combines a size and yield value, but in cases where it is not known if circumference and tree size are well correlated, as in comparisons of different strain-rootstock combinations, yield efficiency does not necessarily represent true efficiency. Theoretical tree spacings were used to assess theoretical yield per hectare, which should be a better measure of efficiency. Trees on M.9/MM.106 had the highest theoretical yield per hectare, followed by those on M.26, M.5/MM.111, M.7A, and MM.111. These data suggest that the interstem trees and those on M.26 can result in the highest productivity.

Anchorage

Information already presented suggests that MM.111 is a poor rootstock for 'Delicious' because, first of all, it produces the largest tree, and secondly, it has the lowest yield per tree, yield efficiency, and theoretical yield per

Table 4. Tree lean after Hurricane Gloria, 1985.

	Lean from vertical (°)		
Stock	'Gardiner'		'Starkrimson'
M.7A	53 d[z]		33 c
M.26	20 b		19 b
M.9/MM.111	16 b		20 b
M.9/MM.106	34 c		19 b
MM.111	0 a		0 a
$\bar{X}$	25	NS[y]	18

[z]Means within columns not followed by the same letter are significantly different at the 5% level.
[y]NS = nonsignificant.

hectare. However, it is commonly thought to be well anchored. We were able to easily measure anchorage in 1985 because of the effects of Hurricane Gloria. Trees were subjected to winds in excess of 110 km per hour, and substantial tree movement resulted. After the hurricane, several trees were leaning, and the angle from vertical was measured (Table 4). The poorest anchorage was seen with trees on M.7A roots where the average angle of lean was 43°. Trees on MM.111 showed no signs of leaning and were by far the best anchored. Granted, the lower fruit load on MM.111 trees may have reduced somewhat the tendency to lean, but they also had the largest leaf surface and above ground portions, providing a larger area for wind action and more potential for damage.

Trees on MM.111 were undesirable in terms of yield, or at least precocity, but were much better anchored than any other rootstock or rootstock-interstem combination. Under certain conditions the better anchorage would make trees on MM.111 much more desirable than other rootstock or rootstock-interstem combinations.

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