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Early Season Root and Shoot Growth of 'Golden Delicious' Apple on Four Rootstocks as Affected by Pruning at Planting[1]

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Abstract. **Apple trees (*Malus domestica* Borkh. cv. Smoothee Golden Delicious) on 4 rootstocks Malling (M) 9, Malling-Merton 106/M 9, MM 106, and seedling, received 4 pruning treatments at planting: no pruning, shoot pruned to 70 cm above graft union and branches removed, root pruned to 1/3 its original volume, or shoot and root both pruned as above, to determine effects on early shoot and root growth. Shoot pruning stimulated rapid new shoot growth and resulted in the highest new shoot relative growth rate and new shoot/total shoot dry weight ratio. Also, shoot pruning, with and without root pruning, resulted in very little root dry weight increase up to 8 weeks after planting, indicating a competitive inhibition of root growth by rapid new shoot growth. Root pruning, with and without shoot pruning, stimulated the greatest amount of new, white root formation soon after planting, but these contributed very little to root dry weight. Shoot- and root-pruned trees had the lowest shoot and root dry weights with all rootstocks. Pruning treatments significantly altered the root/shoot ratios of trees on M 9 and MM 106/M 9, but not on MM 106 and seedling. Shoot pruning of trees on M 9 caused the greatest deviation of root/shoot ratio from unpruned, heavily favoring shoot growth.**

Current apple orchard establishment recommendations include pruning the shoot back to 70–75 cm at planting (3, 4). This practice stimulates new lateral shoot growth for the primary purpose of selecting scaffold limbs to develop the tree's fruiting structure. The effect of this treatment on new root growth after planting and its subsequent effect on the root/shoot ratio of different rootstocks/scion combinations has not been studied in detail. In earlier reports, it was shown that moderate shoot pruning at planting increased new shoot production and decreased new root growth while maintaining a constant root/shoot ratio (6, 10). Preston (11) found that pruning the leader and lateral shoots at planting decreased total root weight compared to pruning only the leader or no pruning. His results showed a greater difference between treatments with M 7a rootstock than with the more vigorous M 16, indicating a rootstock-pruning interaction. Preston also found that severe root pruning alone reduced shoot growth, but shoot pruning alone produced the same effect (12). Root growth was not measured. A recent report (9) showed that moderate root pruning stimulated root growth of apple seedlings grown in liquid culture, while severe root pruning decreased growth.

The importance of an optimum root/shoot ratio in woody plants and the constancy of this ratio has been well-established (7). Root-shoot relationships in various apple rootstock/scion combinations have been studied extensively (1, 14, 15). Apple root/shoot ratio can be changed by such factors as soil moisture (2) and applied hormones (13). However, there is some doubt as to whether these changes resulted simply from changes in plant size, rather than from actual differences in relative growth of root and shoot (8). The balance between growth rate of root and shoot with increasing plant weight can be described by the equation of allometric growth (8):

$$\log R = a + b \log S,$$

where R = root dry weights, S = shoot dry weight, and a and b = constants. The constant b has also been referred to as K in growth analysis formulas (5) and is the slope of the line generated by this equation. Ledig and Perry (8) state that if the slope is not different, then differences in root/shoot ratio are merely a reflection of differences in total plant weight. They also point out that the alteration of the slope generally requires drastic treatment and does not appear to favor healthy growth.

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The purpose of this study was to investigate the effects of shoot and root pruning at planting on early shoot and root growth of different apple rootstock/scion combinations, and to determine if any changes in root/shoot ratio were due to relative growth differences.

Materials and Methods

'Smoothee Golden Delicious' apple trees of similar caliper on rootstocks, M 9, MM 106/M 9, MM 106, and seedling were obtained from a commercial nursery in early March, 1981, and stored in a coldroom at 4°C until planting on March 27. Trees were planted in 57-liter pots containing a 2:1 (v/v) bark and sand mixture with lime and Osmocote added to bring pH up to 6.5 and provide fertilization. Immediately before planting, each tree received one of 4 pruning treatments: no pruning, shoot pruned to 70 cm above the graft and branches removed, root pruned to 1/3 its original volume, or shoot and root both pruned as above. Nine trees of each rootstock/scion combination received each treatment to give a total of 144 trees. After pruning, fresh weight was taken on each tree and the root and shoot volume was determined by water displacement. Volume measurements gave an estimate of the root/shoot ratio after treatment. After planting, pots were set in the field at Raleigh, N.C., under ambient temperature and light and were irrigated as needed from overhead sprinklers.

Four weeks after planting, when vegetative growth was just beginning, 3 trees of each rootstock-scion-treatment combination were removed from the pots. Roots were washed, all new shoots were removed, and the tree was cut at the soil line (about 5 cm below the graft union). New shoots and the original shoot were then placed in paper bags for drying. The root system was visually rated based on the relative amounts of new, white roots vs. older, dark roots, with 1 = very little white root and 5 = a large proportion of white root. The root system was then placed in a paper bag for drying. After 4 to 5 days at 80°C in a drying oven, dry weights of the original shoot, new shoots, and root system were taken. The same sampling and measuring procedures were followed again 8 and 12 weeks after planting.

Statistical differences among means were determined from analysis of variance and Tukey's Least Significance Range test. Relative growth rate (RGR) was calculated according to the following formula:

$$RGR = \frac{\ln DW_2 - \ln DW_1}{t_2 - t_1}$$

where DW = dry weight and t = time. The allometric constant, K, for relative root and shoot growth was determined by linear regression of the log of root dry weight on the log of shoot dry weight for each treatment within rootstock. Significant differences among K values were determined from the F-test of the independent variable and treatment interaction.

Results and Discussion

All trees remained healthy and actively growing throughout the study. None of the root systems at the last sample date showed any signs of becoming pot-bound or curling or bending due to pot restriction. New shoot growth had started 4 weeks after planting and dry weights of the first sample indicate no differences due to treatment (Fig. 1). Any total shoot dry weight differences at 4 weeks were probably due to carryover from original treatment differences at planting (Fig. 2). By 8 weeks, some separation in shoot dry weights due to treatment had occurred. In general, shoot dry weight was high in unpruned trees and low in shoot- and root-pruned trees (Fig. 1 & 2). Root pruning resulted in the lowest new and total shoot growth at 8 weeks in trees on the vigorous rootstocks, MM 106 and seedling, while the same treatment resulted in the most total shoot growth with the dwarfing rootstocks, M 9 and MM 106/M 9. New and total shoot relative growth rates (RGR) between 4 and 8 weeks after planting followed the same general pattern as absolute dry weights (Table 1). Shoot pruning generally stimulated rapid new shoot growth and resulted in the highest new shoot RGR between 4 and 8 weeks (Table 1). Trees receiving this treatment had the highest new shoot/total shoot ratio at 4 and 8 weeks (Table 2), indicating that new shoots were a major photosynthate sink.

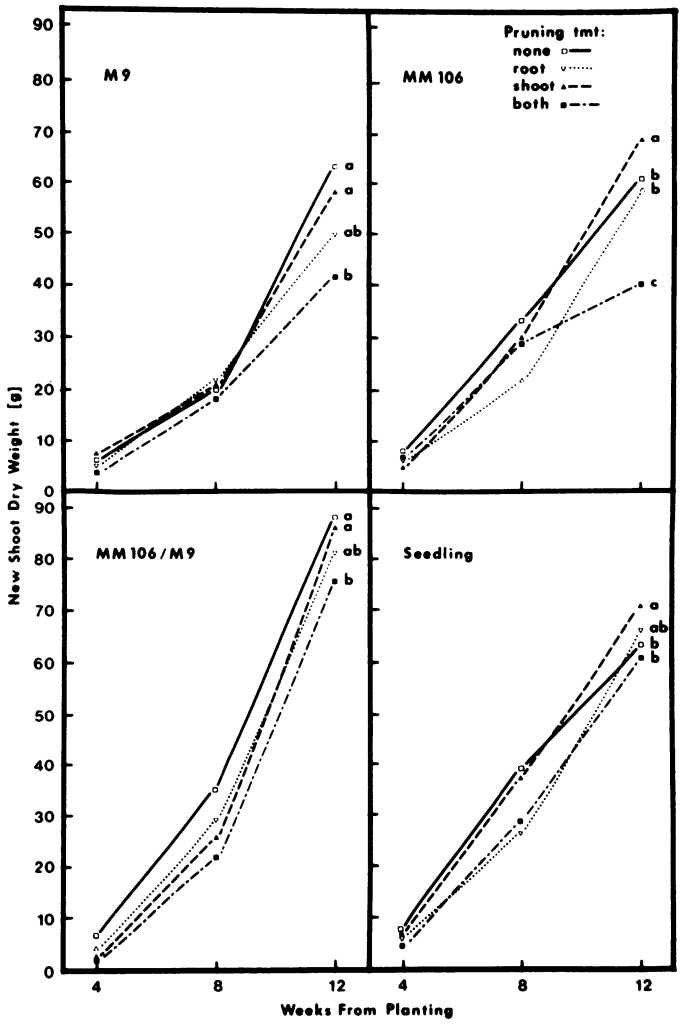

Fig. 1. New shoot dry weights of 'Golden Delicious' on 4 rootstocks at 4, 8, and 12 weeks after planting. Mean separation at 12 weeks by Tukey's least significant range test, 5% level.

At 12 weeks, all rootstock combinations receiving no pruning or shoot pruning had the highest new shoot dry weight and those receiving shoot and root pruning had the lowest (Fig 1). However, total shoot dry weight was greatest in trees receiving no pruning or root pruning (Fig. 2). Rapid new shoot growth in the shoot and root-pruned and shoot-pruned trees may have reduced stored photosynthate and inhibited root growth enough to reduce total shoot dry weight accumulation. It seems unlikely that this difference is only a result of the dry weight loss at pruning, because differences in total shoot dry weight were very small at 4 weeks (Fig. 2). New shoot/total shoot ratio remained highest

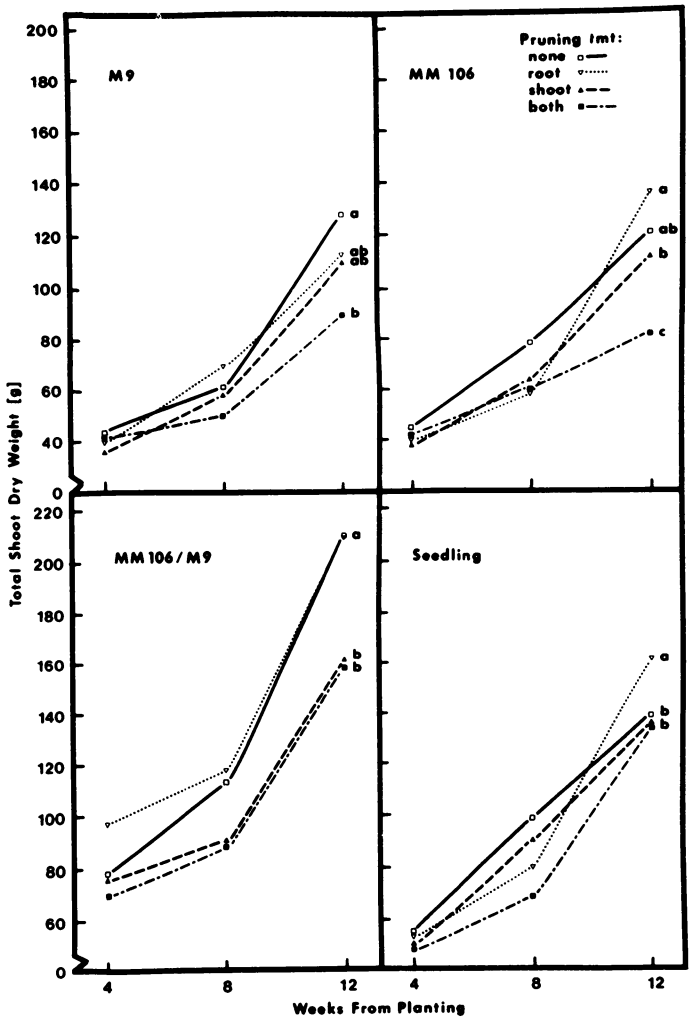

Fig. 2. Total shoot dry weights of 'Golden Delicious' on 4 rootstocks at 4, 8, and 12 weeks after planting. Mean separation at 12 weeks by Tukey's least significant range test, 5% level.

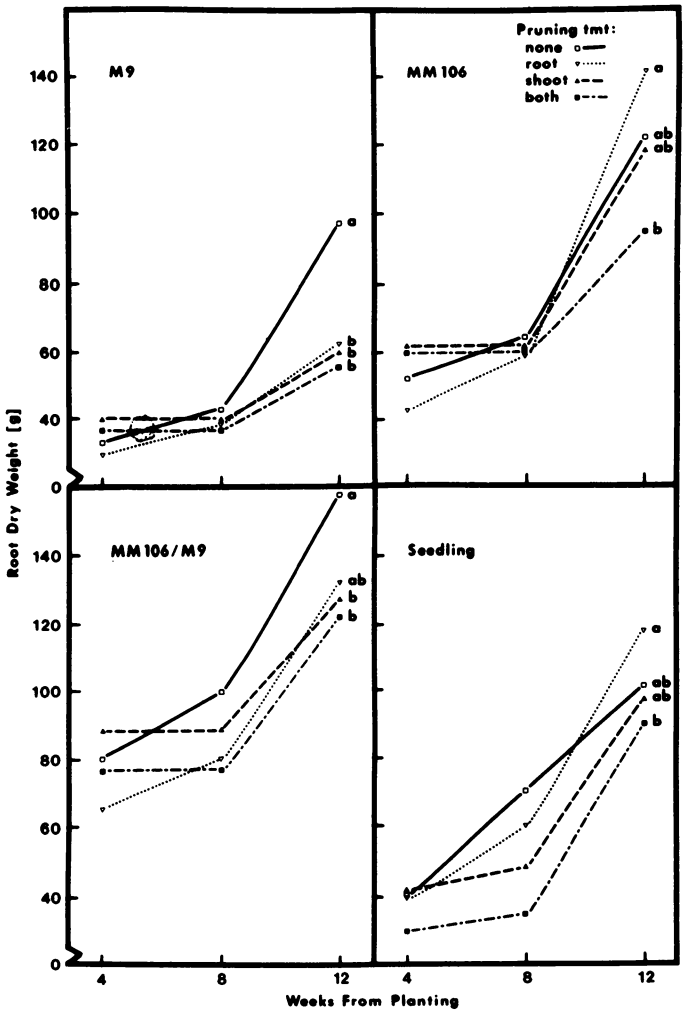

Fig. 3. Root dry weights of 'Golden Delicious' on 4 rootstocks at 4, 8, and 12 weeks after planting. Mean separation at 12 weeks by Tukey's least significant range test, 5% level.

in shoot-pruned trees at 12 weeks (Table 2), although differences had diminished.

Root dry weight increased very little between 4 and 8 weeks in all trees receiving shoot pruning or shoot and root pruning (Fig. 3), while trees not pruned or root pruned showed significant root dry weight increases. Root RGR between 4 and 8 weeks followed the same pattern (Table 1). This indicates a strong competition between shoot and root for stored photosynthate during early season growth. Also, the shoot can apparently act as a stronger sink than the root, because trees that were shoot and root pruned, which should stimulate growth of both parts, had very little early root growth (Fig. 3). This was similar to shoot pruning alone. This lack of root dry weight increase due to shoot pruning was still apparent at 12 weeks, when root-pruned and unpruned trees had the highest root dry weights (Fig. 3), in spite of greatly reduced differences in root RGR (Table 1).

Root rating based on the relative amount of new, white roots to old, dark roots showed slightly different results than root dry weight. Root-pruned and shoot- and root-pruned trees had consistently higher ratings than those that were shoot-pruned or unpruned at 4 and 8 weeks (Table 3). By 12 weeks, however, the differences were much less significant (Table 3). Apparently, root pruning, alone or with shoot pruning, will stimulate rapid growth of new roots regardless of how the shoot is responding. However, these new roots contribute very little to root dry weight relative to old roots. After 12 weeks, all trees had a large amount of new, white roots, with only M 9 remaining consistently lower in its root rating over all treatments (Table 3).

Root/shoot ratios at planting, based on volume measurements, followed the expected pattern due to pruning treatments. For each rootstock, root/shoot ratios were highest in shoot-pruned trees, intermediate in unpruned and shoot- and root-pruned, and lowest in root-pruned trees (Table 4). In general, root/shoot ratios, based on dry weight, were lower at 4, 8, and 12 weeks than at planting and had a downward trend over the 12-week sampling period. Root/shoot ratios of root-pruned trees tended to remain low and only decreased slightly, whereas ratios in the other treatments showed a more rapid decline down to the level of the root-pruned trees. Differences between treatments diminished over time and were essentially gone by the 8-week sample for MM 106 and seedling. However, differences among treatments remained significant at 12 weeks for M 9 and MM 106/M 9 (Table 4).

As mentioned above, the allometric constant, K, was calculated for root and shoot growth to determine if differences in root/shoot ratio were due to relative growth differences or were merely a reflection of plant size. K was below 1 in almost every

Table 1. Total shoot, new shoot, and root relative growth rates (RGRg $g^{-1}day^{-1}$) of 'Golden Delicious' on four rootstocks at 4, 8, and 12 weeks after planting.

Rootstock & pruning	Total shoot RGR (wk) 4 to 8	Total shoot RGR (wk) 8 to 12	New shoot RGR (wk) 4 to 8	New shoot RGR (wk) 8 to 12	Root RGR (wk) 4 to 8	Root RGR (wk) 8 to 12
M 9						
None	.011 b[z]	.026 a	.048 ab	.040 a	.013 a	.029 a
Root	.017 a	.018 b	.040 b	.035 ab	.011 a	.019 b
Shoot	.017 a	.023 ab	.056 a	.026 b	.001 b	.013 c
Both	.004 c	.022 ab	.048 ab	.032 ab	.001 b	.018 b
MM 106/M 9						
None	.013 a	.023 a	.058 c	.033 b	.005 a	.021 ab
Root	.006 ab	.021 a	.067 bc	.036 ab	.003 ab	.024 a
Shoot	.003 b	.020 a	.087 a	.042 a	.000 b	.018 b
Both	.009 ab	.022 a	.076 ab	.042 a	.000 b	.018 b
MM 106						
None	.014 a	.022 b	.054 ab	.023 b	.008 a	.023 ab
Root	.015 a	.029 a	.044 b	.039 a	.007 a	.025 a
Shoot	.015 a	.025 ab	.064 a	.035 a	.001 b	.020 bc
Both	.013 a	.010 c	.059 a	.009 c	.001 bc	.017 c
Seedling						
None	.023 a	.011 b	.057 ab	.017 b	.015 ab	.013 b
Root	.017 b	.026 a	.049 b	.037 a	.017 a	.020 a
Shoot	.023 a	.015 b	.068 a	.032 a	.012 b	.016 ab
Both	.016 b	.026 a	.060 ab	.023 b	.013 ab	.017 ab

[z]Mean separation within rootstock and column by Tukey's least significant range test, 5% level.

case, which indicates a trend toward more shoot growth. However, significant differences occurred only with M 9 and MM 106/M 9 root-stocks (Fig. 4). The magnitude of differences among K values was directly related to the dwarfing ability of the rootstock, even though there were no great differences in overall tree size. Also, the largest deviation from unpruned was in the K value of shoot-pruned trees on M 9 (Fig. 4). If Ledig and Perry (8) are correct in their conclusion that a large alteration

Table 2. New shoot/total shoot dry weight (DW) ratio of 'Golden Delicious' on four rootstocks measured at 4, 8, and 12 weeks after planting.

Rootstock & pruning	New shoot/total shoot (DW) 4 weeks (g/g)	8 weeks (g/g)	12 weeks (g/g)
M 9			
None	.148 ab[z]	.338 b	.497 ab
Root	.119 b	.339 b	.445 b
Shoot	.195 a	.381 a	.537 a
Both	.113 b	.367 ab	.479 ab
MM 106/M 9			
None	.089 a	.311 a	.415 b
Root	.035 b	.256 b	.393 b
Shoot	.068 a	.335 a	.488 a
Both	.308 b	.249 b	.450 ab
MM 106			
None	.157 a	.427 ab	.546 ab
Root	.133 b	.389 b	.515 b
Shoot	.168 a	.463 a	.564 a
Both	.139 b	.497 a	.504 b
Seedling			
None	.154 a	.400 ab	.459 b
Root	.139 ab	.347 b	.474 b
Shoot	.157 a	.443 a	.516 a
Both	.112 b	.423 a	.530 a

[z]Mean separation within rootstock and column by Tukey's least significant range test, 5% level.

Table 3. Root rating of 'Golden Delicious' on four rootstocks based on amount of new, white roots vs. older, darker roots at 4, 8, and 12 weeks after planting.

Rootstock & pruning	Root rating (1–5)[z] 4 weeks	8 weeks	12 weeks
M 9			
None	1.3 b[y]	2.7 b	3.7 a
Root	3.0 a	3.3 ab	3.7 a
Shoot	1.7 ab	3.0 ab	3.7 a
Both	2.3 ab	4.0 a	3.3 a
MM 106/M 9			
None	3.0 b	3.0 b	4.0 ab
Root	5.0 a	4.7 a	4.7 a
Shoot	2.3 b	2.7 b	3.0 b
Both	3.3 b	3.7 ab	4.7 a
MM 106			
None	2.0 b	3.3 b	3.7 b
Root	4.3 a	5.0 a	5.0 a
Shoot	2.0 b	3.0 b	4.7 a
Both	4.0 a	5.0 a	4.3 ab
Seedling			
None	1.7 b	3.0 ab	4.3 ab
Root	3.0 a	3.7 a	4.7 a
Shoot	2.3 ab	2.3 b	3.7 b
Both	3.0 a	3.7 a	4.7 a

[z]1 = very few white roots; 5 = very large amount of white roots relative to dark roots.

[y]Mean separation within rootstock and column by Tukey's least significant range test, 5% level.

Table 4. Root/shoot ratios of 'Golden Delicious' on four rootstocks at planting and at 4, 8, and 12 weeks after planting.

Rootstock & pruning	Root-shoot (vol) Planting (v/v)	Roots/shoot ratio (DW) 4 weeks (g/g)	8 weeks (g/g)	12 weeks (g/g)
M 9				
None	1.03 ab[z]	0.71 b	0.73 a	0.77 a
Root	0.83 b	0.73 b	0.55 b	0.60 ab
Shoot	1.18 a	1.13 a	0.71 a	0.55 b
Both	0.97 ab	0.82 ab	0.68 ab	0.62 ab
MM 106/M 9				
None	1.28 ab	1.28 a	0.89 bc	0.84 ab
Root	0.91 b	0.90 b	0.77 c	0.73 b
Shoot	1.51 a	1.39 a	1.11 a	0.87 ab
Both	1.17 ab	1.39 a	1.02 ab	0.92 a
MM 106				
None	1.65 ab	1.23 b	0.85 a	1.10 a
Root	1.32 b	1.32 ab	1.01 a	0.89 a
Shoot	1.96 a	1.59 a	0.98 a	1.16 a
Both	1.59 ab	1.43 ab	0.95 a	1.18 a
Seedling				
None	1.20 ab	0.77 ab	0.71 a	0.76 a
Root	0.96 b	0.81 ab	0.62 a	0.73 a
Shoot	1.53 a	0.87 a	0.65 a	0.69 a
Both	1.11 ab	0.73 b	0.73 a	0.65 a

[z]Mean separation within rootstock and column by Tukey's least significant range test, 5% level.

in K value does not favor normal growth, then these results raise some question about current pruning practices at planting on full dwarf apple trees. This would be particularly true where moisture may be limiting and early root system establishment is necessary for tree survival. However, before revisions in early pruning recommendations can be considered, studies must be done to determine how these treatments affect growth and survival during the first 2 or 3 years after planting with a number of different scion cultivars.

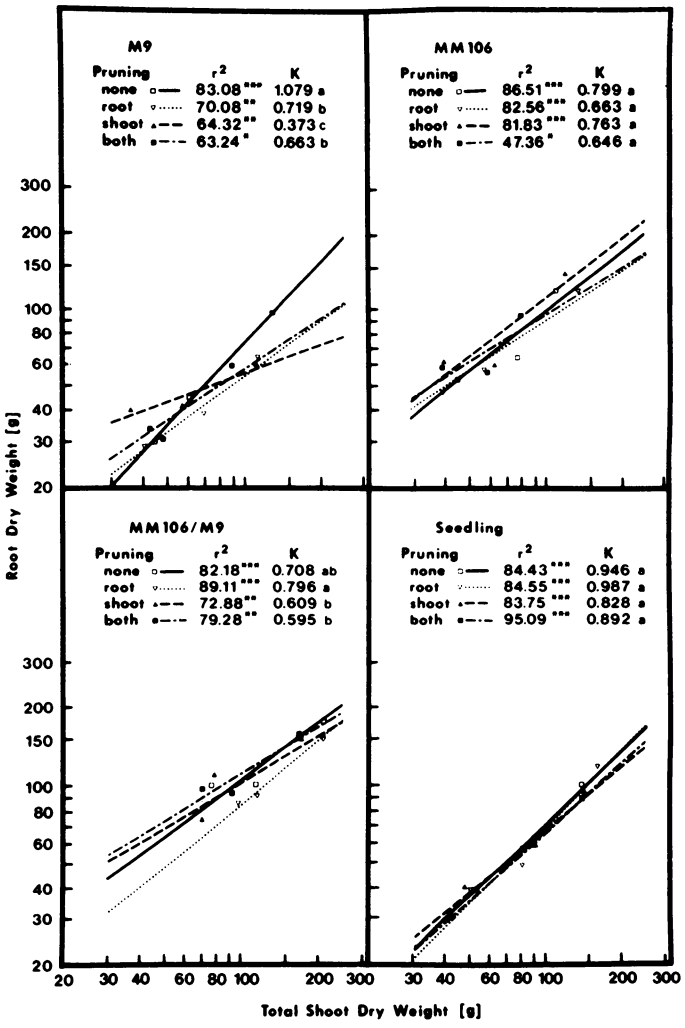

Fig. 4. Linear regressions of log root dry weights on log total shoot dry weights of 'Golden Delicious' on 4 rootstocks. K represents the slope of each regression line. Significant differences between K values for each rootstock were determined from the F-test of the total shoot dry weight and pruning treatment interaction. Each data point is the mean of 3 samples. Probability levels at 5% (*), 1% (**), or 0.1% (***) level.

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