Effects of Growing Location on Fruit Tree Root Suckers

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Abstract

Root suckers are vegetative shoots that develop from root buds and are generally considered a negative trait of a rootstock. Root sucker production for a given rootstock often varies with site. Published data from three peach and five apple multi-location NC-140 rootstock trials were used to determine if some sites are more prone to root sucker development than other sites. For each trial, the number of root suckers per site were ranked in ascending order and the correlations of the ranks for pairwise combinations of trials were evaluated with Spearman's rank correlation coefficient. Although the associations were usually not significant at the 5% level, certain sites consistently had higher rankings. Sites with high rankings for peach root suckers also tended to have high rankings for apple root suckers. Sites with consistently high rankings included Utah, Pennsylvania, Kentucky and South Carolina. British Columbia and Ontario had consistently low rankings. Sites with high rankings in some trials and low rankings in other trials included North Carolina, New York, and Maryland. Although root sucker production is ultimately controlled by genetics, these analyses suggest that factors related to the site, such as soil conditions, environmental factors or orchard practices also influence the development of root suckers.

Many fruit tree rootstocks have been evaluated in the NC-140 regional research project (www.nc-140.org). In most of these multi-location trials the number of suckers originating from the rootstock shank and roots varied with rootstock and location. Suckers are undesirable because they can interfere with weed management, they can absorb translocatable herbicides such as glyphosate that injure the tree, they can be infected by fireblight (Erwinia amylovora), leading to death of the root system (Vanneste and Eden-Greene, 2000), and suckering tended to be related to less growth and yield in interstem trees (Costante et al., 1983). The physiology of sucker initiation is poorly understood (Frey et al., 2003) and the literature concerning root buds and root suckers is confusing because the terminology is not consistent. The term "adventitious" generally refers to structures that develop at sites that are not usual, such as buds developing on roots instead of in leaf axils on shoots (Esau, 1977).

Adventitious buds may arise in different ways during the ontogeny of roots, but many remain as suppressed buds embedded in the periderm for varying periods of time. These buds that do not immediately develop into shoots have been referred to as concealed buds, inhibited buds, dormant buds, embedded buds, and suppressed trace buds (Bosela and Ewers, 1997).

The ability to form true adventitious buds varies with the age of a plant and with the clone. Adventitious buds often arise from callus tissue around wounds, in the cambium, or from mature tissues in the endodermis or pericycle (Eames and MacDaniels, 1947). Although root buds often develop from meristematic tissue in the pericycle of young roots, Priestly and Swingle (1929) reported that in non-injured roots, buds may form from callus around emerging branch roots and in callus of wound tissue. Dormant bud primordia may remain dormant indefinitely and the trace that connects it to the primary vascu-

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lar tissues elongates as cambial growth lays down new annual rings of secondary xylem. MacDaniels (1953) considered the presence of the branch trace as conclusive evidence that a bud is dormant rather than adventitious. Branch traces are vascular bundles that connect the bud to the vascular system of the axis (Esau, 1977). Based on the presence of branch traces, he concluded that true adventitious buds occur freely on the roots of 1-year-old seedlings and only rarely on the tops of seedlings. However, he did not study roots of vegetatively propagated rootstocks, which may differ in their ability to develop non-adventitious buds.

While reviewing data from several NC-140 multi-location rootstock trials, root sucker development seemed to be consistently greater at some locations than at others. For example, peach (Johnson, 2011) and apple trees (Autio et al., 2011a) growing in Utah usually produced more root suckers than trees growing in Ontario. Root sucker development in apple may be controlled by a single gene (*Rs*, Lawson et al., 1995). However cultural practices, such as planting depth (Rogers and Parry, 1968), and late-winter root and shoot temperatures (Arnold and Young, 1990) can also influence root sucker development. Since environmental factors and to a lesser extent, cultural practices vary with location, root sucker development might also be expected to vary with location. For this study published data were used to evaluate the relationships of root sucker numbers reported for eight NC-140 trials to categorize sites by their severity of root suckering.

Material and Methods

Published root sucker data were obtained from 3 peach and 5 apple multi-location rootstock trials coordinated by the NC-140 regional research project (www.nc140.org). The sites and the rootstocks that were evaluated varied with the trial, but from 4 to 10 sites were common to most trials selected for this study (Table 1). Specific orchard site within a state or province sometimes varied from one trial to another. Mean cumulative numbers of root suckers, averaged over all trees, for each site within a trial was calculated. The sites within each trial were then ranked in ascending order based on the number of root suckers. In a few cases two or three sites had the same number of root suckers, creating a tie. When a tie occurred, the average ranking was assigned to all the sites involved in the tie and the rankings for those sites may not be whole numbers. With 8 trials, there were 28 possible pair-wise comparisons and the root sucker rankings for each combination of trials were plotted against each other to visualize the relationship between rankings for various trials. Correlation of rankings for each pair of trials was evaluated with Spearman rank-order correlation coefficient (Spearman, 1904), with SAS's PROC CORR (SAS Inst., 2014). Spearman correlation coefficient (rho, ρ) is a nonparametric measure of association based on the ranks of the data values. The sign of ρ indicates the direction of the association between the two variables. A perfect Spearman correlation of +1 or -1 occurs when each of the variables is a perfect monotone function

Table 1. NC-140 rootstock trials from which data were obtained.

NC-140 Trial	Literature Citation	No. of sites	No. of rootstocks
1999 dwarf apple	Autio et al., 2011a	16	12
1999 semi-dwarf apple	Autio et al., 2011b	16	6
1994 dwarf apple	Marini et al., 2006a	25	18
1994 semi-dwarf apple	Marini et al., 2006b	20	4
2003 dwarf apple	Marini et al., 2014	23	11
2002 Red Haven peach	Johnson et al., 2011	17	8
2001 Red Haven peach	Reighard et al., 2011	11	14
1994 Red Haven peach	Reighard et al.,2004	20	19

of the other, but the relationship need not be linear. A positive monotonic relationship occurs when the value of one variable increases as the value of the other variable increases. A negative monotonic relationship occurs when the value of one variable decreases as the value of the other variable increases. Spearman correlation is a distribution-free test and does not assume that the data follow a normal distribution, and is less sensitive to outliers than the parametric alternative, Pearson correlation.

Results

For the five apple rootstock trials, correlations for all 10 possible combinations were evaluated and eight plots are presented (Figs.

1 and 2). Rootstock rankings for only two of the 10 combinations were significantly correlated (P=0.05), however the sample size was < 8 for all but one combination. Rho was positive for all but one combination (1994 semi-dwarf vs. 1999 semi-dwarf apple plantings, $\rho = -0.50$, P = 0.667, n=3). The reason for the negative relationship was because only three sites were common to both trials and none of the sites were among those with consistently high rankings (Michigan, North Carolina, and Ontario). When rootstock ranks were plotted against each other the ranks for New York, Ontario and North Carolina were consistently low (Fig. 1). Utah and Pennsylvania had consistently high rankings and British Columbia was inconsistent
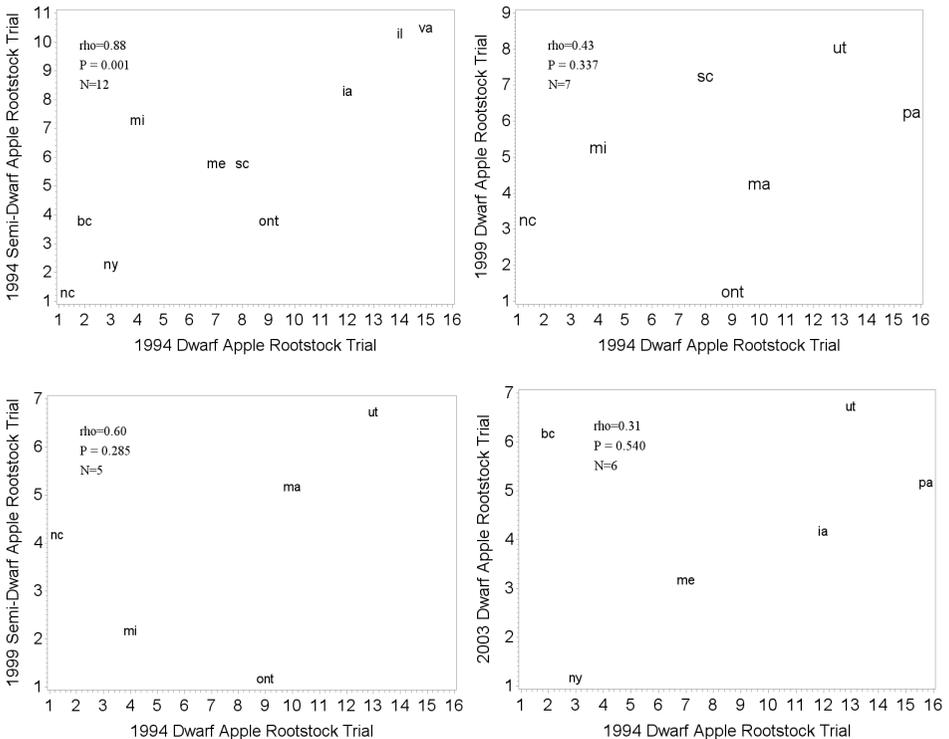

Figure 1. Relationship between root sucker rankings for the 1994 dwarf apple rootstock trial and four other NC-140 apple rootstock trials. The axes are the rankings for sites within a trial based on the mean number of root suckers per tree; where 1 is the site with the fewest root suckers and 16 is the site with the most root suckers.
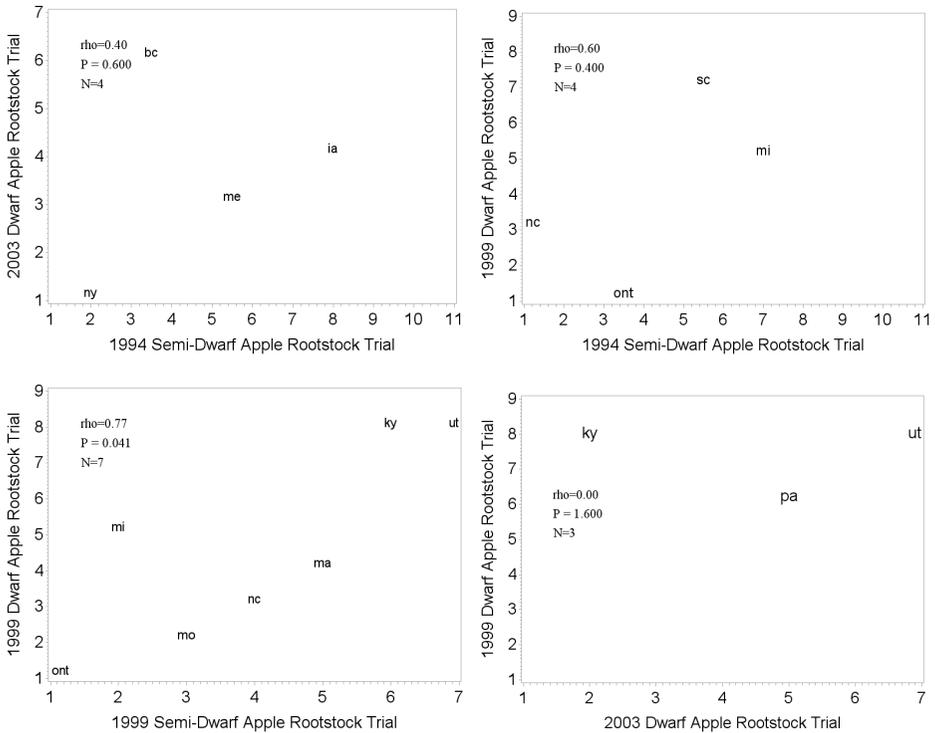
Figure 2. Relationship between root sucker rankings for combinations of the NC-140 1999 dwarf, 1999 semi-dwarf, 2003 dwarf, and 2003 semi-dwarf apple rootstock trials. The axes are the rankings for sites within a trial based on the number of root suckers; where 1 is the site with the fewest root suckers and 7 is the site with the most root suckers.

across trials. Root sucker rankings for Maine, Massachusetts, Michigan and South Carolina were intermediate. Kentucky, Illinois, Iowa and Virginia participated in only two trials, but rootstock rankings were high for all four sites in both trials. Missouri participated in two trials and rootstock rankings were low in both trials.

Plots for all three pair-wise combinations of the three peach rootstock trials are presented in Fig. 3. Rho was positive for all combinations, but rootstock rankings were significantly correlated for only the 2001 vs. 2002 trials. Root sucker rankings were high in all three trials for South Carolina and Utah. Ontario had the lowest rankings for all three trials, whereas rankings for Colorado,

Georgia and Missouri were intermediate. Rankings for Maryland were inconsistent; Maryland had a low ranking for the 2002 trial but had the highest ranking for the 1994 trial. Massachusetts and New York participated in only the 1994 and 2002 trials and Massachusetts had low rankings for both trials, whereas New York had high rankings in both trials. There were three or more common sites for 12 of the combinations of apple and peach trials (Fig. 4). No correlations were significant (P= 0.05), probably because the maximum number of observations was seven. Five of the 12 combinations had negative correlations. Utah participated in seven trials and in six of those trials had the highest root sucker ranking. North and South Carolina had high
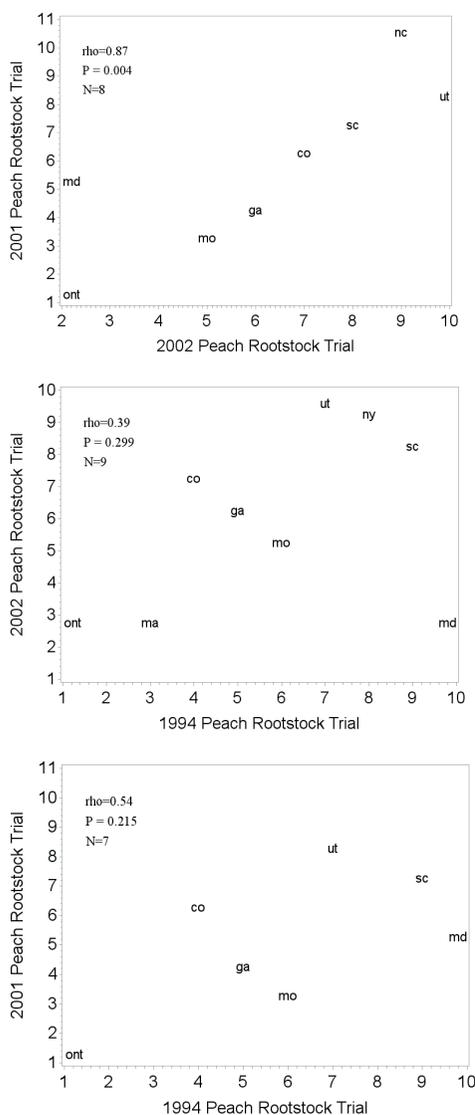
Figure 3. Relationship between root sucker rankings for combinations of three NC-140 peach rootstock trials. The axes are the rankings for sites within a trial based on the number of root suckers;

rankings for peach and moderate rankings for apple trials. Ontario had the lowest rankings in all three peach trials and in two of three apple trials. Massachusetts had low rankings

for peach and moderate rankings for apple trails. Root sucker rankings for Colorado and Missouri tended to be intermediate for both peach and apple trials.

Discussion

Data used for this study were the mean sucker number per tree of rootstocks common to all sites. It is possible that there was a rootstock x site interaction, where root sucker production for a given rootstock was more affected by site than for other rootstocks. In most multi-location rootstock trials, the site x rootstock interaction was significant for number of root suckers produced per tree. Due to the strong interaction, it is difficult to group rootstocks based on root suckers. For example, of the 18 rootstocks tested in the 1994 dwarf apple rootstock trial the ranking for P.16 (where 1 is the highest number of suckers) was 1, 1, 1, 1, 2, 3, and 9 at Iowa, New Jersey, Utah, Virginia, Pennsylvania-Rock Springs, Illinois and Pennsylvania-Biglerville, respectively. Rankings for M.9 Pajam2 were 1, 1, 2, 4.5, 5, 6.5, and 9 for Pennsylvania-Rock Springs and Biglerville, Iowa, Illinois, Virginia, New Jersey and Utah, respectively (Marini et al., 2006a).

This is the first attempt to combine data from several NC-140 trials to evaluate the influence of site on any response variable. A wide range of rootstock germplasm was evaluated in the eight trials considered in this study and the participating sites were not consistent for all trials. Although correlations were usually not significant, certain sites were clearly more conducive than others for root sucker development. Results from this study are also supported by data from the 1998 tart cherry rootstock trial where 11 rootstocks were evaluated at six locations and trees in Utah had the most root suckers (Roper et al., 2019).

Differences in numbers of root suckers may be due to differences in orchard practices such as cultivar/rootstock combinations and interstems, planting depth and tree age. In an 18-year rootstock trial in Virginia, root
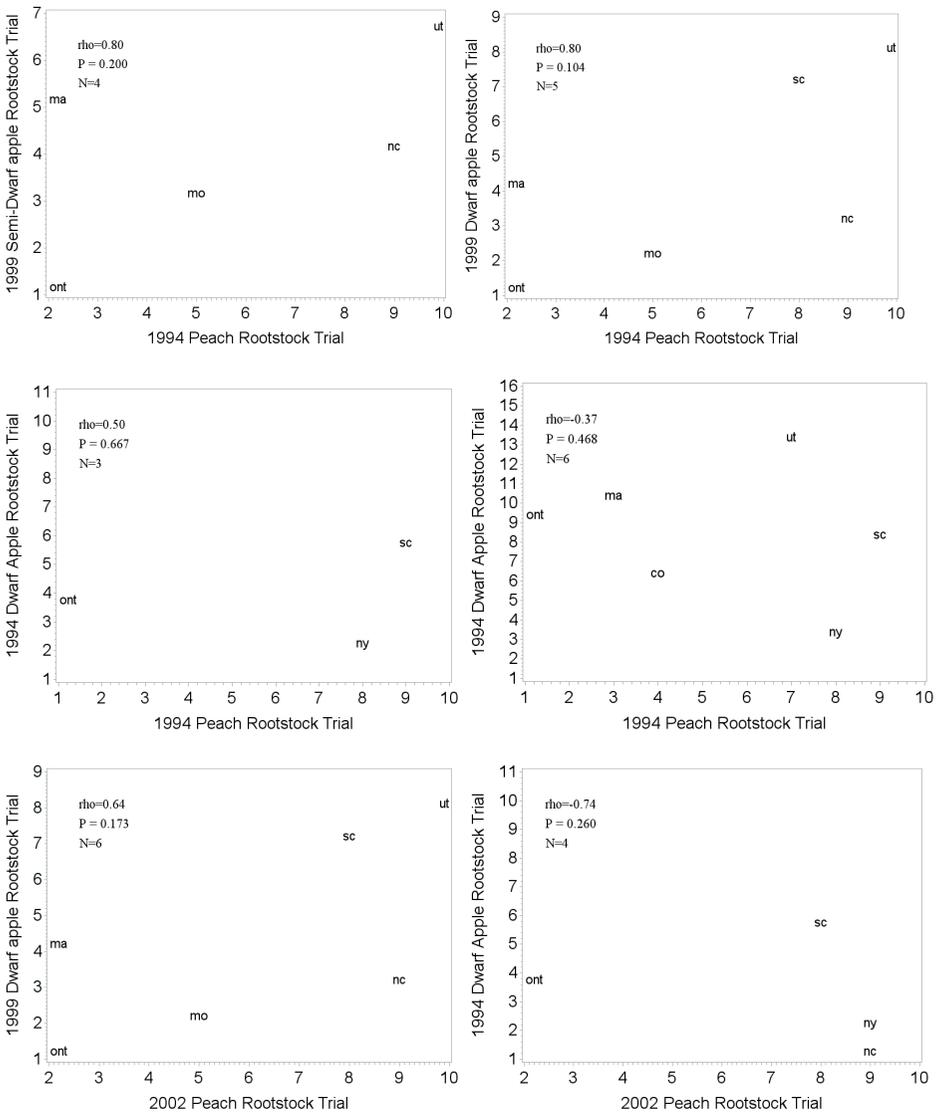
Figure 4. Relationship between root sucker rankings for all possible 12 combinations of NC-140 peach and apple rootstock trials. The axes are the rankings for sites within a trial based on the number of root suckers; where 1 is the site with the fewest root suckers and 10 is the site with the most root suckers.

sucker production increased through the 15th year; the number of root suckers per tree was 19% greater for spur-type trees than standard types, and 'Delicious' trees produced 40% more root suckers than 'Golden Delicious' or the same rootstocks (Barden and Marini 1997, 1999). Interstem trees produced more root suckers than non-interstem trees (Barden and Marini, 1997, 1999). Root suckers can be influenced by budding height and planting depth (Rogers and Parry, 1968). In a Massachusetts trial, the number of root

suckers per tree was influenced by the combination of rootstock, interstem, and scion cultivar, as well as planting depth (Costante et al., 1983). Exposing the entire stem-peace resulted in more root suckers than burying the stem-peace totally or halfway. Therefore, it is important for multi-location rootstock trial cooperators to closely follow the planting protocols provided by the coordinators.

Orchard floor management practices and environmental factors may influence root sucker development. Growth of shallow roots (0 to 10 cm depth) was greater when herbicides were used to control vegetation under apple trees, than when weeds were managed with cultivation or when grass was grown under the trees (Haynes, 1981). Competition from the grass may have inhibited suckering (Frey et al., 2003). In addition, shallow roots may be more prone to suckering because exposing sweetgum roots to light induced root suckering (Kormanik and Brown, 1967). Most of the afore mentioned factors affecting root sucker development should have been eliminated in the NC-140 trials because all trees in each trial were propagated by a single nursery with a common scion cultivar. Based on observations of these trials, it was apparent that planting depth sometimes differed from that specified in the protocols. Planting depth was likely not the primary factor involved in root sucker production because it is unlikely that planting depth was consistently incorrect at a given site for all trials.

In addition to competition from weeds and grass, orchard floor management practices that affect root and soil temperatures may influence root sucker development. Root sucker production from root cuttings of trembling aspen (*Populus tremuloides* Michx.) was affected by temperature in a quadratic manner, where maximum suckering occurred at 24°C (Maini and Horton, 1966). Following exposure to varying chilling hours, Arnold and Young (1990) exposed apple seedlings to forcing conditions of either 5 or 20°C. A regression model for sucker growth included significant terms for chilling hours and forcing conditions and the chilling hour x forcing condition interaction was significant (R^2 = 0.57).When the shoots were held at 5°C while the roots were in active growth conditions (20°C), root sucker growth of fully chilled (1800 chilling hours) plants exhibited more than a 10-fold increase in root suckers. This suggested that root sucker growth may be a response of the plant to maintain a root/shoot growth equilibrium. If temperature were the primary factor influencing root suckering, then sites near each other would be expected to have similar numbers of suckers. Pairs of sites in close proximity included New York and Ontario, Virginia and North Carolina, Kentucky and Missouri, and South Carolina and North Carolina, but sites within each pair did not have similar root sucker rankings when they participated in the same trial. In the 1994 dwarf apple rootstock planting, there were two sites in Pennsylvania and for the 16 rootstocks common to both sites, trees at Rock Springs had 3.5 times as many root suckers as trees at Biglerville (Marini et al., 2006a). In the 2009 peach rootstock trial, there were more root suckers at Kaysville than at West Payson, UT (Brent Black, personal communication). Therefore, temperature is likely not the primary factor affecting apple root suckering.

Exposure of trees to wind may influence suckering. Roots on the lee and windward sides are subjected to bending and compressive forces and on the windward side roots are subjected to shearing forces (Coutts, 1983). Injured roots of American beech produced more suckers than non-injured roots (Jones and Raynal, 1988), but the influence of root wounding on sucker development in aspen is poorly understood (Frey et al., 2003). Root sucker production by fruit tree rootstocks may be influenced by several factors that have not been well studied, such as nutrient availability, soil pH, or soil moisture (Frey et al., 2003). Very dry or water-saturated soils reduced sucker initiation on aspen root cuttings (Maini and Horton, 1964), but the influence of soil moisture on root suckering

Table 2. Correlations between mean trunk cross-sectional area (cm^2) and mean number of root suckers reported for six NC-140 trials.

NC-140 Trial	r-value	P-value	Number of sites
1994 dwarf apple	0.32	0.229	16
1994 semi-dwarf apple	0.58	0.037	13
1999 dwarf apple	0.34	0.514	6
1999 semi-dwarf apple	-0.79	0.203	4
1994 Red Haven Peach	0.09	0.751	15
2001 red Haven Peach	0.14	0.688	11
2002 Red Haven peach	0.67	0.102	7

of fruit trees has not been reported. It would be interesting to know if different types of irrigation (drip vs. micro-sprinklers or over-head) influence root sucker production.

In all NC-140 trials, tree vigor varies with site and like root suckers, certain sites tend to have consistently large trees for all trials. To evaluate the influence of tree vigor on root sucker development, data reported for six NC-140 trials were used to correlate trunk cross-sectional area (TCA) with the number of suckers per tree. When mean TCA was correlated with mean number of root suckers for a site, correlation coefficients ranged from -0.79 to 0.58 and the correlation was significant for only the 1994 semi-dwarf apple trial (Table 2). Therefore, differences in tree vigor does not explain the observed differences in root sucker production at different sites.

Results from this study can be used to group sites according to their propensity for root sucker development. Site differences for root suckering were fairly consistent across several rootstock trials in this study, but the factors influencing root suckering cannot be identified using the data that were reported for these trials. Although reporting detailed data for soil characteristics, wind, and soil moisture and temperature would be beneficial, it would add to the cost of the trial and the resulting large data set would be difficult to summarize and interpret, and to model root sucker development. Another more feasible approach would be to perform a series

of experiments where all, but one variable could be held constant. Growing trees in large containers with different soil types, soil pH's, or moisture, or exposing roots to varying temperatures, or exerting force on the trunk to simulate wind would help identify likely causes of root sucker development. The effect of planting depth could be studied by planting trees with the roots at different depths. Since root suckering is an important characteristic of a rootstock, it would be informative to ensure that at least one site with a history of prolific root suckering is included in every multi-site rootstock trial.

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About The Cover:

Two NC-140 multilocation uniform apple rootstock trials. Top Photo is a planting at the Russell E. Larson Agricultural Research Farm at Rock springs, PA (photo by H.J. Sommer III, Professor, Dept. of Mechanical Engineering, Penn State University). Bottom photo is a planting at UMass Cold Spring Orchard at Belchertown, MA (photo by Jon Clements, Extension Fruit Advisor, Center for Agriculture, Food, and the Environment, Univ. of Massachusetts).