tions used for solution containment and water (nutrient) flux are critical; further work in quantifying these effects are needed. Measurements of leaf and root water potential are also needed to characterize the properties of this tubular membrane system before using it in a CELSS.

Literature Cited

1. American Society of Agricultural Engineers. 1986. Guidelines for measuring and reporting environmental parameters for plant experiments in growth chambers. EP411.7, Amer. Soc. Agr. Eng., St. Joseph, Mich.
2. Bubenheim, D.L., T.W. Dreschel, and C.A. Mitchell. 1987. Comparison of plant growth in a tubular membrane hydroponic system with that in conventional hydroponic culture. HortScience 22:1051. (Abstr.)
3. Bugbee, B.G. and F.B. Salisbury. 1988. Exploring the limits of crop productivity. Plant Physiol. 88:869–878.
4. Dreschel, T.W., C.R. Hinkle, W.M. Knott, R.P. Prince, and J.C. Sager. 1987. Development of a membrane nutrient system. Proc. First Annu. Space Life Sci. Symp., NASA, Washington, D.C. p. 304–305.
5. Dreschel, T.W., R.P. Prince, C.R. Hinkle, and W.M. Knott. 1987. Porous membrane utilization in plant nutrient delivery. Mimeog. Paper # 87-4025, Amer. Soc. Agr. Eng., St. Joseph, Mich.
6. Kramer, P.J. 1983. Water relations of plants. Academic, New York.
7. Roscoe, J.T. 1975. Fundamental research statistics for the behavioral sciences. 2nd Holt, Rinehart, & Winston, New York.
8. Salisbury, F.B. and C. Ross. 1985. Plant physiology. 3rd ed. Wadsworth, Belmont, Calif.
9. SAS Institute, Inc. 1982. SAS user's guide: Statistics. SAS Inst., Cary, N.C.
10. Wright, B.D., W.C. Bausch, and W.M. Knott. 1988. A hydroponic system for microgravity plant experimentss. Trans. ASAE 31:440–446.

HortScience 24(6):947–949. 1989.

Replant Management Strategies Influence Early Growth of Apple Trees in a Sand Soil

F.J. Peryea[1] and R.P. Covey[2]

Tree Fruit Research and Extension Center, Washington State University, Wenatchee, WA 98801

Additional index words. *Malus domestica*, 'Granny Smith', water stress

Abstract. **Two field experiments were conducted to evaluate the influence of rootstock (seedling, M.26, MM.106), soil fumigation (metam-sodium, methyl bromide), and planting hole substrate (original soil, non-orchard soil, organic mix) on early growth of 'Granny Smith' apple trees (*Malus domestica* Borkh.) in a Quincy sand. Application of soil fumigants in the fall before tree planting the next spring or replacement of the original soil with non-orchard planting hole substrates having greater water-holding capacity and nutrient status significantly improved tree growth. Combination of fumigation and soil replacement had a synergistic positive effect on tree growth. The size-controlling characteristics of the rootstocks were evident in the non-orchard soil and organic mix treatments, but not when the trees were planted in the original orchard soil. Chemical name used: sodium *N*-methyldithiocarbamate (metam-sodium).**

Many young fruit trees grown on replanted orchard sites exhibit retarded early growth, a phenomenon called the "replant problem". Replant problems often result from soil factors that may act singly or in combination and may be physical, chemical, or biological (Traquair, 1984). These factors include compaction, poor aeration, drought stress, extremes of soil acidity, inorganic and organic chemical toxicities, nutrient deficiency or imbalance, and presence of soil-borne phytopathogenic organisms. Replant problems can also be differentiated as nonspecific (poor growth regardless of the previous fruit crop) or specific (poor growth when planted in orchards previously occupied by the same or a closely related species). Apple growers frequently select a vigorous rootstock, usually seedling, to compensate for potential growth reduction due to replant problems (Barritt, 1986). Replacement of the soil in the tree planting hole with a better-quality rooting substrate is a costly but often effective means of promoting early tree growth (Benson, 1968). Preplant soil fumigation with broad spectrum biocides often eliminates replant problems caused by soil-borne phytopathogens (Traquair, 1984).

Apple trees planted on soils formed in sands often exhibit inadequate growth rates even when the soils were not previously in orchard crops. This behavior is usually attributed to inadequate water or nutrient availability. The current study evaluated several strategies to maximize early growth of apple trees replanted in a former apple orchard on a sand soil. Three variables were examined: rootstock, planting hole substrate, and preplant soil fumigation. Midsummer leaf N concentration was measured to provide accessory information concerning its use as a fertilizer management tool.

The experimental site was a commercial 'Granny Smith' apple on seedling rootstock orchard planted in 1977, located north of Orondo, Wash., on a terrace on the east side of the Columbia River. The site is at 300 m elevation and has a 15% slope to the west. Average annual precipitation is <230 mm. The soil was classified as a Quincy sand (sandy, mixed, mesic Typic Torripsamments) and had been leveled by bulldozer during site preparation. The soil parent material was coarse-textured aeolian sand. Existing trees exhibited poor growth from the time of planting. In their ninth leaf they were often <2 or 3 m tall with small-caliper trunks and branches. Visual inspection of tree roots and soil assays showed no evidence of phytopathology due to nematodes. The experimental trees were planted in sites from which established 'Granny Smith' trees were removed the previous fall.

Experiment 1. In Mar. 1986, 144 'Granny Smith' branched nursery trees were planted in a split-plot experimental design. Four blocks were used. Main treatments were seedling, MM.106 and M.26 rootstocks; subtreatments were original soil, non-orchard soil, organic mix planting hole substrates. One block was incomplete because an insufficient number of trees was supplied by the nursery. The missing subplots were MM.106 trees planted in the original soil (OS) and non-orchard soil (NS) substrates. OS was the Quincy sand excavated from the planting holes. OS properties included: sand texture, saturated water content 0.46 $m^3 \cdot m^{-3}$, available water content <0.01 $m^3 \cdot m^{-3}$, pH 6.4, organic carbon 0.6%, selected elements ($mmol \cdot kg^{-1}$): Ca, 109; Mg, 14.6; K, 1.4; Na, 0.8; N, 8.8; P, 1.1; B, 0.02; As 0.04. NS was mapped as an Xerorthent. It was excavated from a colluvial deposit on a hillslope near the experimental orchard site. The parent material was weathered gneiss. NS properties included: loamy sand texture, saturated water content 0.46 $m^3 \cdot m^{-3}$, available water content 0.04 $m^3 \cdot m^{-3}$, pH 6.6, organic carbon 1.4%, selected elements ($mmol \cdot kg^{-1}$): Ca, 142; Mg, 23.0; K, 8.7; Na, 0.8; N,

---

Received for publication 13 Feb. 1989. Dept. of Horticulture and Landscape Architecture Paper no. 88-13, Project no. 0747, College of Agriculture and Home Economics Research Center, Washington State Univ., Pullman, WA 99164. We thank Grady Auvil and Jim Wright of the Auvil Fruit Company, Orondo, Wash. for their cooperation and support. The cost of publishing this paper was defrayed in part by the payment of page charges. Under postal regulations, this paper therefore must be hereby marked *advertisement* solely to indicate this fact.

[1] Assistant Soil and Horticultural Scientist.

[2] Plant Pathologist.

Table 1. Effect of rootstock and planting hole substrate on relative diameter and height increases of scion and mid-summer leaf N concentrations, Expt. 1.

Rootstock	Diameter at planting (mm)	Trunk diameter increase (%)						Height increase (%)								
		Mar.–Oct. 1986			Mar. 1986–Oct. 1987			Mar.–Oct. 1986			1986 leaf N (%)			1987 leaf N (%)		
		OS	NS	OM	OS	NS	OM	OS	NS	OM	OS	NS	OM	OS	NS	OM
Seedling	12.8	13.7	59.2	85.1	31.1	118	176	13.7	64.4	78.7	2.8	2.9	2.3	2.0	2.1	2.2
MM.106	15.2	17.7	49.4	64.0	30.4	89.5	124	20.1	65.0	82.8	2.7	2.4	2.1	2.1	2.1	2.2
M.26	16.8	15.2	41.8	50.4	32.7	73.5	102	22.2	35.5	64.4	2.5	2.1	2.1	2.1	2.0	2.0
LSD1[z]			9.5			18.9			12.1			0.4			0.2	
LSD2[y]			14.5			25.1			16.2			0.4			0.2	

[z] LSD1 = comparison of two planting hole substrate means in the same rootstock treatment ($P = 0.05$).

[y] LSD2 = comparison of two rootstock means in the same or a different planting hole substrate ($P = 0.05$).

Table 2. Effect of soil fumigation and planting hole substrate on relative diameter and height increases of scion and mid-summer leaf N concentrations, Expt. 2.

Fumigant	Trunk diameter increase (%)				Height increase (%)			
	Mar.–Oct. 1987		Mar. 1987–Oct. 1988		Mar.–Oct. 1987		1987 leaf N (%)	
	OS	OM	OS	OM	OS	OM	OS	OM
Control	4.1	40.7	36.3	88.6	14.8	35.7	2.0	1.9
Metam-sodium	42.5	69.8	140	171	45.8	56.8	2.5	2.0
Methyl bromide	49.7	71.4	157	177	52.0	59.1	2.4	2.0
LSD1[z]	10.8		27.5		11.2		0.3	
LSD2[y]	9.0		24.5		10.5		0.4	

[z] LSD1 = comparison of two planting hole substrate means in the same fumigant treatment ($P = 0.05$).

[y] LSD2 = comparison of two fumigant treatment means in the same or different planting hole substrate ($P = 0.05$).

23.9; P, 0.9; B, 0.04; As, 0.03. The organic mix (OM) was a commercial blend of hypnum peatmoss and waste compost used to grow mushrooms. OM properties included: mucky peat texture, saturated water content 1.14 $m^3 \cdot m^{-3}$, available water content 0.11 $m^3 \cdot m^{-3}$, pH 5.6, organic carbon 21.1%, selected elements ($mmol \cdot kg^{-1}$): Ca, 538; Mg, 68.4; K, 144; Na, 10.4; N, 458; P, 20.0; B, 0.14; As, 0.03.

Soil and leaf N properties were analyzed using methods described by Page et al. (1982): pH in a 1 soil : 1 distilled water (w/v) slurry, organic carbon by the Walkley–Black method, B by the hot water extraction method, P by $NaHCO_3$ extraction, As by acid digest and pyridine-AgDDC colorimetric procedures, extractable Ca, Mg, K, and Na by NH_4OAc exchange, total soil and leaf N by macro-Kjeldahl procedure, and sand content by wet-sieving. Soil clay content was determined by a micro-pipette method (Miller and Miller, 1987). Available water content was determined as the difference between water held at soil matric potentials of -0.033 and -1.5 MPa (Klute, 1986). With the exception of B, the nutrient levels of the planting hole substrates fell into the sufficiency ranges that are suggested for orchard soils in Washington (Tukey et al., 1984). Soil B concentrations in the OS and NS substrates were lower than the 0.046 mmol B/kg minimum value suggested for adequate soil B availability. In general, absolute concentrations of soil nutrients in the planting hole substrates increased in the order: OS < NS < OM. The very high concentrations of nutrients in the organic mix reflect in part its low bulk density (0.54 Mg/m^3).

The trees were planted in a double-row system with a tree spacing of 1.7 m within a row, 1.5 m between rows within the double-row planting, and 6.0 m between double-row centers. Nominal tree density was 1960 trees/ha. Planting holes were excavated with a 46-cm-diameter auger to a 60-cm depth. The trees were planted by back-filling the holes with the appropriate planting hole substrate to a level just below the graft union. After planting, the trees were pruned at 112 cm above the graft union. The tree rows were kept weed-free with herbicides. In April and November of each year, the orchard received broadcast applications of 280 kg NH_4NO_3/ha. A high-pressure impact sprinkler system delivered 0.15 ha-m of irrigation water during a 24-hr watering period once every fifth day. If visual symptoms of drought stress were observed, an extra 12-hr watering period was added within the normal watering cycle.

The basic observation unit (subplot) consisted of four trees—two adjacent trees from each adjacent row of the double-row planting. Data were recorded as mean values per subplot of four trees. Analysis of variance was accomplished using the SAS-GLM procedure for split-plot designs with unbalanced data (Freund and Littell, 1981). LSD values for comparing subplot means were calculated using the procedure for split-plot designs (Steel and Torrie, 1980).

Tree trunk diameter was measured 10 cm above the graft union both perpendicular and parallel to the tree row in late Oct. 1986 and 1987. Tree height was measured from the top of the rootstock pruning cut to the tip of the central leader in late Oct. 1986. The central leader was pruned during Winter 1986. Because initial tree diameters differed between rootstocks, the tree diameter and height data were normalized for comparison of rootstock effects. Relative diameter and height increases (%) were calculated as $100[(X_t - X_o)/X_o]$, where X_o is diameter (mm) or height (cm) at planting time and X_t is diameter (mm) or height (cm) at observation time t. Forty fully expanded mid-shoot leaves were collected randomly for each subplot in July 1986 and 1987 (10 per tree) and were composited for total N analysis. Soil samples (0- to 30-cm depth) were collected from each planting hole within a subplot 1 week after planting and were composited by subplot for pH and saturation percentage analyses. The soil samples were composited by planting hole substrate for other analyses.

Relative trunk diameter increase after one and after two growing seasons, relative height increase after one growing season, and leaf N concentration in 1986 were significantly influenced by rootstock ($P \leq 0.05$) and planting hole substrate ($P \leq 0.01$) treatments. The treatments did not influence leaf N concentration in 1987. Tree trunk diameter and height increases showed a significant rootstock × planting hole substrate interaction ($P \leq 0.01$). For a given rootstock, relative diameter and height increases tended to respond to planting hole substrates in the order: OS < NS < OM (Table 1). For the NS and OM planting hole substrates, relative diameter and height increases tended to respond to rootstocks in the order: M.26 < MM.106 < seedling, although in some cases the mean values for M.26 and MM.106, and for MM.106 and seedling, were not significantly different at $P = 0.05$. For the OS substrate, relative diameter and height increases were not influenced by rootstock.

Size-controlling characteristics of the rootstocks were manifested only when the trees were grown in the NS and OM substrates. This result suggested that the fruit industry practice of using seedling rootstock may not overcome the negative effects of replant problems unless coupled with other replant management strategies. For a given rootstock, leaf N in 1986 tended to be inversely related to relative diameter or height increases.

Experiment 2. In Mar. 1987, 100 'Granny Smith'/seedling branched nursery trees were planted in a split-plot experimental design. Four blocks were used. Main treatments were the control and methyl bromide or metam-sodium soil fumigants. The fumigants were applied in Nov. 1986. The content of a 0.7-kg can of methyl bromide was injected 46 cm deep at each future methyl bromide-treated tree planting site using an injection probe. A 22-cm-diameter × 70-cm-deep hole was excavated at each future metam-sodium-treated tree planting site. Forty-five liters of solution containing 2.38 g metam-sodium/liter was pumped into each hole from a nurse tank. Sub-treatments were the OS and OM planting hole substrates as described in Expt. 1. Planting holes were excavated in Mar. 1987 with a 46-cm-diameter auger to a 60-cm depth. The trees were planted and managed as in Expt. 1. The basic observation unit (subplot) consisted of two adjacent trees—one from each row of the double-row planting. Main treatment plots were separated by guard trees. Data were recorded as mean values per subplot of two trees. Statistics were computed as in Expt. 1.

At planting, mean tree trunk diameter was 14.9 mm and mean height after heading was 135 cm. Relative trunk diameter increase after one and after two growing seasons, and relative height increase after one growing season, were significantly influenced by fumigation ($P \leq 0.001$) and planting hole substrate ($P \leq 0.01$) treatments. Leaf N concentration in July 1987 was significantly influenced by planting hole substrate ($P \leq 0.01$) but not by fumigation. These results were consistent with those of Expt. 1. No significant treatment interactions were present. For a given fumigation treatment, relative trunk diameter tended to respond to planting hole substrates in the order: OS < OM (Table 2). After the first growing season, trunk diameter increases in unfumigated OM did not differ from the fumigated OS treatments. After the second growing season, fumigation alone or fumigation plus OM significantly increased trunk diameter compared to the non-fumigated treatments. For a given planting hole substrate, relative trunk diameter and height increases responded to fumigation in the order: control < metam-sodium = methyl bromide. In the fumigated plots, leaf N was inversely related to relative diameter and height increases.

Positive tree growth responses to fumigation implied the presence and control of soil-borne pathogens that inhibit early tree growth. Metam-sodium and methyl bromide produced positive tree growth responses of equivalent magnitude. The effects of the planting hole substrates are more complex. Because they were collected from non-orchard sites, the NS and OM substrates should have contained low levels of microorganisms that cause specific apple replant disease; hence, simple physical replacement of the original infested soil should have contributed to better tree growth. In addition to ameliorating stress due to soil pathogens, the NS and OM substrates had some physical and chemical properties that were more desirable from a soil management standpoint, including higher levels of available soil moisture, organic carbon, total Kjeldahl N, hot water-extractable B, and NH_4OAc-extractable Ca, Mg, and K. The leaf N concentrations from the first growing season of both experiments reflected in part a biomass dilution effect. For a given planting hole substrate, the trees that grew faster generally had lower leaf N concentrations. Across all treatments, the relationship was less consistent. In all cases, leaf N concentrations fell into the satisfactory range (Tukey and Dow, 1979), suggesting that N nutrition was not limiting. Fumigation plus soil replacement had a synergistic positive effect on tree trunk diameter increase, suggesting the presence of growth limitations in addition to soil-borne pathogens.

Literature Cited

Barritt, B.H. 1986. Variety, rootstock selection important to replant. The Goodfruit Grower 37:27–28.

Benson, N.R. 1968. Can profitable orchards be grown on old orchard soils? Proc. Washington State Hort. Assn. 64:109–119.

Freund, R.J., and R.C. Littell. 1981. SAS for linear models. SAS Institute, Inc., Cary, N.C.

Klute, A. 1986. Water retention: laboratory methods, p. 635–662. In: A. Klute (ed.). Methods of soil analysis, part 1—physical and mineralogical methods. Agronomy 9 (2nd ed.), Amer. Soc. Agron. and Soil Sci. Soc. Amer., Madison, Wis.

Miller, W.P. and D.M. Miller. 1987. A micropipette method for soil mechanical analysis. Commun. Soil Sci. Plant Anal. 18:1–15.

Page, A.L., R.H. Miller, and D.R. Keeney (eds.). 1982. Methods of soil analysis, part 2—chemical and microbiological properties. Agronomy 9 (2nd ed.), Amer. Soc. Agron. and Soil Sci. Soc. Amer., Madison, Wis.

Steel, R.G.D. and J.H. Torrie. 1980. Principles and procedures of statistics. 2nd ed. McGraw-Hill, New York.

Traquair, J.A. 1984. Etiology and control of orchard replant problems: A review. Can. J. Plant Pathol. 6:54–62.

Tukey, R.B. and A.I. Dow. 1979. Fertilizer guide–nutrient content—fruit trees. Washington State Univ. Coop. Ext. Bul. FG 0028f.

Tukey, R.B., A.I. Dow, and A.R. Halvorson. 1984. Fertilizer guide—fruit trees for the entire state. Washington State Univ. Coop. Ext. Bul. FG 0028a.