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Response of Apple Seedlings in Fumigated Soil to Phosphorous and Vesicular-arbuscular Mycorrhiza[1]

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Abstract. **Incorporation of phosphorous into fumigated soil at planting increased the height, dry weight, and P level in seedlings of apple (*Malus domestica* Borkh.). Nonmycorrhizal plants exhibited a twenty-fivefold growth response to P and obtained maximum size at 200 mg additional P/kg soil. Mycorrhizal plants exhibited less growth response to P (3.2× increase) but had greater maximum growth (78.0 vs. 67.9 cm) than nonmycorrhizal plants. Maximum growth of mycorrhizal plants occurred with the addition of 100–200 mg P/kg soil.**

Nutritional studies in the major fruit-growing regions of Washington state established that soil surface applications of P did not increase the growth or P levels of apple trees (1, 7). Most soils in the area are considered inherently high in P and without the capacity to fix significant quantities of P. A greenhouse study (2), however, indicated growth responses by apple to both added P and mycorrhizal infection. The soil used in the greenhouse study was atypical of Washington apple orchard soil, being low in P and with a high P-fixing capacity. Studies in other geographical areas have demonstrated significant increases in growth and P levels in tree fruits by applying P at the subsurface level (5, 9, 10, 11). Some soils in these studies were low in P while others were not, but none had a high degree of P-fixing capacity. It is well recognized that mycorrhizae aid plants in the efficient uptake of various nutrients, particularly P (3, 6). The apparent difference in growth response to P between Washington and other fruit-growing regions led to this investigation. This study was conducted to examine the growth response and P uptake of apple seedlings when P and mycorrhiza were added to a more typical Washington orchard soil.

The soil selected for this study was Okanogan loam, a common orchard soil of North Central Washington, and was collected at the 15–30 cm depth from an uncultivated site. Based on soil tests from Washington State University, soil characteristics included: pH 7.3; arsenic trace; zinc, 0.8 ppm; P, 5.8 ppm; and K, 147 ppm, with bicarbonate extraction. The majority of the soil was fumigated in plastic bags with 0.5 ml chloropicrin per 12 kg soil. After 3 weeks, the bags were opened and soil was mixed and allowed to air for 2 weeks prior to further treatment. Fumigated and nonfumigated soils were then amended with enough K_2SO_4 and $Mg(C_2H_3O_2)\cdot H_2O$ to provide 200 mg of K and Mg per kg soil. Individual soil lots were amended with $NaH_2PO_4\cdot H_2O$ to obtain the desired concentration of P.

The vesicular-arbuscular (VA) mycorrhizal fungus *Glomus mosseae* (Gerd. and Trappe), supplied from *Coleus* roots, was used for inoculation. The pots were inoculated by placing 28 g of a 1:1 mixture, by weight, of sterile sand and finely ground *Coleus* roots at the base of the planting hole immediately prior to planting. The uninoculated pots were treated similarly, except the mixture of sand and *Coleus* roots was sterilized prior to planting. Uniform 4-week-old apple seedlings were planted in 11 × 12-cm plastic pots containing about 1 kg soil. Five replicates of each treatment were grown in the greenhouse for 130 days during the fall and winter of 1979–80, in a randomized block design. Day length was supplemented to 13 hr with the aid of metal halide swing lights. The seedlings were watered as needed and provided with N every 2 weeks from 50 ml of a 0.85% solution of NH_4NO_3. Phosphorous determinations were based on plant tops by a standard colorimetric method (4). Mycorrhizal infection was confirmed by microscopic examination of the roots at the time of harvest (8).

Apple seedling height and dry weight increased with initial increasing concentration of P for both inoculated and noninoculated plants (Table 1). The noninoculated plants reached maximum size and dry weight at 200 mg P/kg soil and decreased substantially at levels beyond 600 mg P/kg soil. The total P level in the plants reached a maximum in the 400–600 mg P/kg soil range, with P levels in excess of 6 mg/g tissue dry weight. Based on previous studies (2), it was anticipated that any response to inoculation with *G. mosseae* would occur at low P levels. The inoculated plants actually showed similar but less spectacular response to added P, with maximum growth occurring at the 100–200 mg P/kg soil level. Although P levels were not included beyond 400 mg P/kg soil, the growth rate appeared to be decreasing at this level. Differences between inoculated and noninoculated plant growth and tissue P were more pronounced when P was not included in the fumigated planting soil. As the level of applied P was increased, the growth difference diminished, although the nonmycorrhizal plants never reached the level of growth of the mycorrhizal plants. Using the SAS general linear model procedure with mycorrhiza and block as class variables and added P as a covariate, the response curve for inoculated and noninocualted were statistically different ($F = 6.58$; 1.57 degrees of freedom for height and $F = 5.96$; 1.57 degrees of freedom for dry weight). Representative samples of the roots from each treatment were harvested to determine if mycorrhizal infec-

Table 1. Height, weight and phosphorous content of greenhouse-grown apple seedlings as influenced by mycorrhizal inoculation and added phosphorous.

Phosphorous applied (mg/kg soil)	Noninoculated plants: Plant ht (cm)	Dry wt (g)	Phosphorous (mg/g dry wt)	Inoculated plants (*G. mosseae*): Plant ht (cm)	Dry wt (g)	Phosphorous (mg/g dry wt)
			Fumigated soil			
0	2.3	0.18 ± 0.04	0.51	24.1	2.73 ± 0.58	1.13
50	29.7	2.57 ± 0.68	1.87	53.6	7.29 ± 0.77	1.90
100	56.7	7.07 ± 1.06	2.26	78.0	11.92 ± 1.15	2.16
200	67.9	8.72 ± 0.85	2.88	77.1	10.59 ± 0.48	2.46
400	58.2	7.71 ± 1.08	4.48	63.4	8.75 ± 0.71	3.25
600	51.5	5.65 ± 0.50	6.01	---	---	---
800	9.7	0.93 ± 0.44	5.63	---	---	---
1000	1.5	0.11 ± 0.02	4.88	---	---	---
			Nonfumigated soil			
0	20.7	2.21 ± 0.55	1.16	19.4	1.85 ± 0.37	1.21

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tion had occurred. Evidence of infection (generally vesicles) was abundant in all inoculated and nonfumigated treatments. Only one noninoculated root grown in fumigated soil showed mycorrhizal infection in trace amounts. While there was no attempt to quantify the infection data, the level of infection appeared to decrease with increasing P concentrations. All roots from plants growing in nonfumigated soil were infected with mycorrhiza.

Seedlings maintained in the nonfumigated and noninoculated soil grew at about the same rate as those in fumigated and *G. mosseae*-inoculated soil with no added P. This suggests that *G. mosseae* is an effective VA mycorrhiza, capable of assisting apple in obtaining P for adequate growth. There was no statistical difference in growth between inoculated and noninoculated seedlings maintained in nonfumigated soil (t = 0.282 height, 0.767 dry weight). The growth response obtained in this study supports the conclusion that P is important in plant establishment (12).

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Low-level Effects of H_2S and SO_2 on Grapevines, Pear, and Walnut Trees[1]

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Abstract. **Potted vines of 'Cabernet Sauvignon' and 'White Riesling' grapes (*Vitis vinifera* L.) and potted 'Bartlett' pear (*Pyrus communis* L.) and 'Hartley' English walnut trees (*Juglans regia* L.) were grown in greenhouses for 2 seasons and fumigated with ambient levels of H_2S, treble ambient H_2S, and amounts of SO_2 equivalent to the treble levels of H_2S. No foliar symptoms or deleterious effects on growth or fruiting were observed which could be ascribed to the treatments.**

Several areas of the United States have present or potential problems caused by emissions of H_2S into the atmosphere (6). Extensive geothermal power development at The Geysers, Calif., is increasing continuously. H_2S emissions have caused major complaints because of odor (1) and ranchers fear that crops are being injured (2, 3). The present study was designed to determine if injury occurs to 3 species of fruit crops produced in this area as a result of H_2S emissions. Grapes, pears, and walnuts were grown in air-conditioned greenhouses and were exposed to clean air plus simulated ambient levels of H_2S which occur near this geothermal development. Because The Geysers will triple present production in the future, treble present ambient exposures were applied to the same crops. Because H_2S is oxidized to SO_2 in the atmosphere (4), levels of SO_2 equal to treble levels of H_2S were tested.

One-year-old rooted cuttings of 'White Riesling' and 'Cabernet Sauvignon' grapevines, 1-year-old 'Hartley' English walnuts on black walnut rootstocks, and 1-year-old 'Bartlett' pear trees grafted on *Pyrus betulafolia* rootstocks were planted in pots with a soil mix of silt, sphagnum peatmoss, and perlite to which essential elements were added. The plants were grown outside at Riverside, Calif., from April to October, 1978. To meet chilling requirements, the plants were taken to the San Bernardino mountains at about 1300 m elevation where they were exposed to low temperatures from December 1978 to February 1979. Pears only were exposed to extra chilling from December 1979 to February 1980. In February 1979, the plants were returned to Riverside and were re-potted to accommodate the larger root systems.

Eight separate greenhouses equipped with air conditioning, gas dispensing lines, air sampling lines, wet-dry bulb thermocouples, and irrigation systems were divided into 4 groups of 2 each. Group 1 received carbon-filtered air; group 2, carbon-filtered air plus simulated H_2S concentrations which occur near The Geysers at "Anderson Ridge," the location which receives the highest measured levels of ambient H_2S as recorded by SRI International; group 3, carbon-filtered air plus 3 times the Anderson Ridge levels; and group 4, carbon-filtered air plus amounts of SO_2 equivalent to the H_2S in group 3.

Table 1. Hourly levels of H_2S (in ppb) showing comparison of programmed and measured levels over a 24-hr period.

Time	Programmed	Measured
1300	30	30
1400	30	30
1500	0	3
1600	60	50
1700	0	2
1800	30	35
1900	30	35
2000	60	60
2100	30	35
2200	60	60
2300	90	95
2400	120	130
0100	120	130
0200	90	95
0300	180	190
0400	9	95
0500	0	5
0600	30	35
0700	30	35
0800	30	35
0900	30	35
1000	30	30
1100	30	30
1200	30	28

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