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The Apple Replant Problem in Washington State[1]

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Abstract. **The growth of apple seedlings (*Malus domestica* Brokh.) is negatively correlated with soil arsenic and zero growth occurs at about 450 ppm total arsenic. Soil arsenic concentrations less than 150 ppm, which are frequently found in orchard soils, contribute less to the replant problem than biological factors. Growth of apple trees was increased 50% or more by preplant soil fumigation with methyl bromide or trichloronitromethane (chloropicrin) in 87.5% of the trials in 17 apple orchard soils tested. Non-specific plant pathogens in orchard soils attack cereals as well as apple seedlings, but apple orchard soils also contain an entity that specifically affects apples. This is probably the same unknown entity that is responsible for specific apple replant disease in Europe, Australia, and elsewhere.**

Over the world apple trees often fail to grow satisfactorily in soil which has recently supported an apple orchard. Savory (4) reviewed this subject and named the problem "Specific Apple Replant Disease" (SARD). In Washington state, poor tree growth has long been associated with high soil arsenic (As) content (1), and the assumption has been that soil As was the primary cause of poor tree growth. The correlation between soil As and apple tree growth, however, was poor (1). It therefore seemed probable that some other factor also contributed to the poor growth. This paper is concerned with the relative importance of soil As and some apparently biological factor(s), which we presume to be primarily SARD, that restricts apple tree growth in old apple orchard soils in Washington state.

Methods

Soil was collected from 2 adjacent apple orchards. Orchard A was about 8 years old and growing vigorously. Previously the land had not been cultivated. Orchard B was first planted about 50 years before sampling. This orchard exhibited a severe replant problem. Even the older trees failed to grow, regardless of culture. Arsenic analyses (total) were made on the soil from both orchards. The 2 soils were mixed in a cement mixer to obtain the following calculated As contents: trace, 50, 100, 200 and 240 ppm. The lowest value was all Orchard A soil and the highest all Orchard B. The resulting soil mixtures were placed in 15 × 17 cm pots; seedling apple liners were then planted, 1 per pot, and grown in the greenhouse for 120 days. The tops were cut, dried and weighed. There were 4 replicates.

Soils were collected from 17 apple orchards, 2 pear orchards, and 1 nursery. The soils had a range in As content from a trace to 375 ppm. The samples were well distributed over this range. These soil samples were brought into the greenhouse and divided into 2 units. One was fumigated by injecting 454 g methyl bromide into 0.1 m^3 of soil in a container kept closed for 2 weeks, then aerated for 2 additional weeks. Both units of soil were then placed in 19 × 24 cm fiber pots and seedling apple liners, corn and rye were planted in 4 replicates. Apples were grown for 120 days, corn for 60 days (until tasseling), and rye for 90 days. The top growth was cut, dried and weighed.

Soil samples were collected from a peach orchard and an adjacent apple orchard. These orchards were planted on virgin land 25 years before sampling. Neither orchard had received arsenical sprays. Each soil was divided into 3 units and treated as follows:

a. Check, not treated;
b. methyl bromide, 454 g in 0.1 m^3 of soil as above;
c. chloropicrin, 12 ml in 0.1 m^3 of soil, then handled as the methyl bromide.

After treatment, all units were potted in 19 × 24 cm fiber pots. Seedling apple liners and peach trees were planted and grown for 125 days, then all the new growth was cut, dried and weighed. There were 6 replicates.

All soils were collected moist and maintained moist to preserve the natural biology prior to treatment and use.

The soils used in these experiments were representative of the orchard soils of eastern Washington. They were neutral to slightly acid in reaction, ranged in texture from loamy sand to loam and in organic matter from 0.6 to 4.9%.

In all studies the plants were fertilized semi-monthly with a 0.25% solution of NH_4NO_3. In addition, corn and rye were fertilized twice with a solution of 17–8–19 (N–P–K) soluble fertilizer.

Soil As was determined by extraction with concentrated HCl, AsH_3 was generated on the extract by the Gutzeit procedure, and then estimated by the silver diethyldithiocarbamate procedure (3).

Results

The growth of apple seedlings on a series of mixtures of 2 soils, one with a replant problem and one without, is shown in Fig. 1. The response to increasing increments of the soil with the replant problem is a curvilinear decrease.

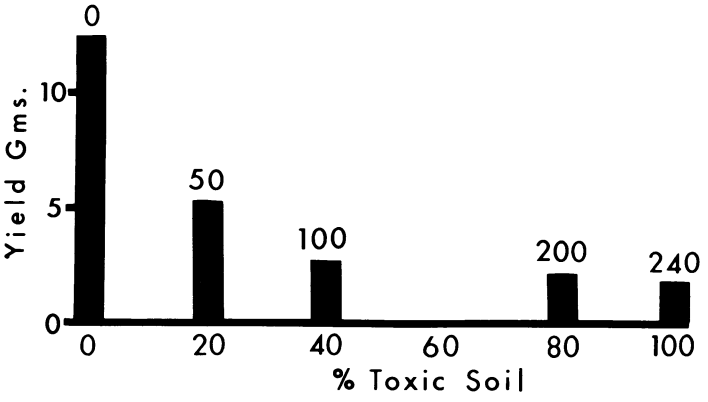

Fig. 1. Apple seedling wt with increasing proportion of soil from a problem orchard with high soil As and decreasing proportion of soil from an adjacent orchard without a problem. Numbers above each column represent ppm of total As in each mixture. (There was no sample at 60%.)

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Table 1. Correlation between plant growth and soil As concn.

Crop	Soil treatment	Intercept on Y axis –yield at 0 As– (g dry wt)	Slope (g/ppm As)	r[z]
Corn[y]	Fumigated	50.2	–0.42	0.79**
	Not fumigated	28.0	–0.23	0.87**
Apple[x]	Fumigated	21.0	–0.046	0.62**
	Not fumigated	13.8	–0.037	0.69**
Rye[x]	Fumigated	9.7	–0.004	0.24
	Not fumigated	8.7	–0.011	0.56*

[z]*,**Significance at 5% (*) and 1% (**) level.

[y]9 samples calculated over the range 0 to 100 ppm As.

[x]20 samples calculated over the range 0 to 375 ppm As.

The intercept on the y axis, the slope of the regression line, and the coefficient of correlation between soil As and plant size of three crops grown on 20 soils with and without soil fumigation are shown in Table 1. For corn, the plant in this group most sensitive to As, the soil samples with an As level above 100 ppm were omitted in the regression and correlation calculations because corn failed to grow in these soils. Growth was almost doubled by preplant soil treatment with methyl bromide, but the suppression of growth by soil As was comparable as indicated by the greater negative slope in the fumigated series, and the calculated zero growth occurred at 120 ppm As in both series. The growth of apple was also increased by soil fumigation and as with corn, soil As decreased growth to a comparable degree in both series. On the regression, zero growth of apple occurred at 450 ppm As in the fumigated series and 375 ppm in the unfumigated series. In fumigated soils, rye showed no response to soil As, but in unfumigated soils there was significant negative response to soil As (P = 1%). Since the number of soils was limited (n = 20), it is not possible to conclude soil As has no negative effect on the growth of rye; the slope indicates, however, that zero growth would have occurred at about 2,500 ppm soil As in fumigated soils and at 800 ppm As in unfumigated soils. To reconcile this difference, one may hypothesize that increasing soil As increased the susceptibility of the plant to soil pathogens.

If we assign an arbitrary response value of 50% increase in growth due to preplant soil fumigation as the least economically acceptable response, and then compare the 3 plant species grown on 17 apple orchard soils, we find responses as shown in Table 2. Because some plants grew poorly in soils of high As concn, we have excluded those where the growth in the fumigated soil was less than 10% of the highest for that species. When a 50% response was found exclusively in one species, we concluded that a specific plant pathogen was involved. Apple seedlings responded in excess of 50% to soil fumigation in 14 of the 17 apple orchard soils, and in 5 of those 14 the response was only on apple. Corn and rye had similar responses in 4 and 6 soils, respectively, but in only one instance for each crop was the response exclusive to that crop.

Table 2. Number of different apple orchard soils[z] with growth responses to soil fumigation in excess of 50% of the control.

Crop	Inclusive of all species	Exclusive of other species	Discard due to As[y]	% with response
Apple	14	5	1	87.5
Corn	4	1	10	57.1
Rye	6	1	0	35.3

[z]Means of 4 replicates from each of 17 orchards.

[y]In soils where plant growth was less than 10% of that of the best in the series, the soil was discarded due to the excessive depression by soil As.

Table 3. Plant wt of apple seedlings planted in soils from an apple and an adjacent peach orchard with and without preplant treatment with biocides.

Source of soil[z]	Plant wt (g) by soil treatment: Methyl bromide	Chloropicrin	Control
Apple orchard	33.8	36.3	7.6
Peach orchard	41.5	37.7	25.5

LSD, 5% = 9.2; 1% = 12.3

[z]Statistical significance between soils exceeds 1% level.

The responses to soil fumigation with methyl bromide and chloropicrin of apple and peach planted in soils from an apple and an adjacent peach orchard are shown in Tables 3 and 4. There is a highly significant difference between the response of apple to soil fumigation (by either methyl bromide or chloropicrin) of apple soil and peach soil (P = 1%). Growth of apple seedlings was more than 3 times greater in untreated peach soil than in untreated apple soil. The apple seedlings did respond to soil fumigation in both soils, but the response was greater in the apple soil, and after fumigation tree growth was approximately the same in both soils. Peach trees planted in these 2 soils grew similarly; the differences were not statistically significant. Peach trees did respond to soil fumigation in the peach soil (P = 1%), but response in the apple soil was less distinct. The increase attributed to methyl bromide was statistically significant (P = 5%), but with chloropicrin the increase was not significant.

Discussion

In eastern Washington apple orchard soils, As causes a decrease in growth of some plant species and the decrease is a linear function of the As concn (1). Hoestra (2) working with soils without As residues showed that mixing an apple orchard soil in graded amounts with a similar non-orchard soil resulted in a curvilinear decrease in growth with increasing amounts of the apple orchard soil. We obtained a similar curve by mixing a soil from an apple orchard with a replant problem with a soil of the same type but without a replant problem. In our experiment (Fig. 1) soil As probably was a factor in apple seedling growth reduction but because of the similarity between the growth reduction curves of Fig. 1 and that of Hoestra (2), SARD could also be a factor.

Growth of corn in 9 of the 20 soils (those not more than 100 ppm As) was closely correlated with total soil As content. We expected a lower "r" value for unfumigated soils because of the possible confounding of a soil pathogen with soil As in some soils, but not in others. Instead we found a better correlation but less growth in unfumigated soils. This was also true for apple and rye. It is difficult to explain the better correlation in

Table 4. Plant wt of peach trees planted in soils from an apple and an adjacent peach orchard with and without preplant treatment with biocides.

Source of soil[z]	Plant wt (g) by soil treatment: Methyl bromide	Chloropicrin	Control
Apple orchard	25.3	21.7	18.9
Peach orchard	26.6	27.9	19.9

LSD, 5% = 5.8; 1% = 7.8.

[z]Statistical significance between soils, P = 0.99 N.S.

the unfumigated soils. For rye we postulate that soil pathogens are present and that pathogenicity increases with increasing soil As and the two acting together result in a statistically significant "r" only in the unfumigated soil. This confounding may happen to a slight degree with apple but not with corn.

Non-specific plant pathogens appear to be present in most orchard soils. It is possible that several plant pathogens exist in these apple soils. Some pathogens attack grasses more aggressively than apple, but in most instances apple is most affected.

Peach and apple grew about equally in peach soil and both species responded similarly to preplant methyl bromide, indicating non-specific pathogens present. The growth of apple was severely depressed in apple soil, but the growth of peach was not, and in fumigated soils both species grew equally well (Table 3). The peach response to preplant fumigation in apple soil suggests a non-specific pathogen and the marked depression of growth by apple in apple soil suggests a specific plant pathogen. We believe the depressed growth of apple in apple soil and the curvilinear response by apple in mixed soils (Fig. 1) indicate the same factors are present in Washington soils as those responsible for SARD in Holland, England, and elsewhere (4).

It is clear there is a replant problem with apples planted in apple soils. We conclude soil As is a serious factor in growth retardation only in soils of very high As content, above 150 ppm. Soil fumigation with a general biocide restores the productivity of problem apple orchard soils of low to moderate As content.

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Nondestructive Sonic Resonance and the Texture of Apples[1]

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Abstract. **The sonic vibration characteristics of 5 major apple (*Malus domestica* Borkh.) cultivars were evaluated. The resonant frequency (f) and the mass (m) of individual intact apples were measured over 4 weekly harvests and again after 2½ and 5 months in storage. A nondestructive index of firmness, f^2m, for each apple was calculated and compared with other measures of fruit texture. The f^2m index was directly correlated with Magness-Taylor pressure test measurements of firmness and with sensory ratings of crispness, juiciness, and firmness, especially crispness. It was inversely related to mealiness. Correlations were affected by differences among cultivars; results were best and most consistent for 'Golden Delicious' and 'Rome Beauty'.**

Leaders in the apple industry recognize that high quality is of utmost importance to satisfy consumers and stimulate repeat sales (3). They urged the expansion of research to develop objective measurements of quality factors for use in grading and segregating fruit for storage or marketing. Texture is an important quality factor of apples. High quality apples are firm, crisp, and juicy (23). Devices are available to evaluate apple firmness and texture, but most are destructive and either damage or destroy the fruit (12).

Interest in nondestructive methods for the evaluation of the texture of horticultural commodities has been evident for many years. A nondestructive vibration technique to measure firmness of melons and pineapples was patented in 1942 (9). Virgin (30) developed a resonance technique to observe the effects of turgor pressure upon the rigidity of potato tissues. Nybom (26) constructed a nondestructive vibration device to test small fruits such as raspberries, and reported a significant correlation between firmness and the intensity of vibrations transmitted through the berries. Abbott et al. (1, 2) vibrated whole, intact apples and developed an expression, f^2m, which they designated as a "stiffness coefficient," or "index of firmness" of the fruit. In their expression, f is the frequency of one of the natural resonances of the fruit and m is the fruit wt or mass.

We examined relationships between f^2m and other indices of texture of 5 major apple cultivars. These cultivars account for over two-thirds of the apples produced in the U.S. (7).

Materials and Methods

Test fruit. Apples used in these studies were from commercial orchards in western Maryland. We tested 'McIntosh', 'Delicious' ('Red Spur'), and 'Stayman' in 1974 and 'Golden Delicious', 'Delicious' ('Miller Spur' and 'Red Spur'), and 'Rome Beauty' in 1975. 'Golden Delicious' apples were evaluated again in 1976. To obtain a range of maturities, we made 4 harvests of each cultivar at weekly intervals, beginning about 2 weeks before and ending about 1 week after the estimated optimum commercial harvest date. All fruits were hand harvested, placed in tray-packed corrugated cardboard boxes lined with perforated 1.5-mil polyethylene bags, and stored at 0°C. Texture measurements, both instrumental and sensory, were made after each harvest and again after 2½ and 5 months' storage at 0°. The same measurements were made on comparable samples after an additional 1 week of ripening at 18°.

Instrumental measurements. Sonic resonance measurements were made, as described (15), on 20 apples on the day after each harvest. Each apple was weighed to the nearest g and then placed on a vibration exciter. The vibration frequency was

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