Phosphate Starter Fertilizer Temporarily Enhances Soil Arsenic Uptake by Apple Trees Grown under Field Conditions

F.J. Peryea

Tree Fruit Research and Extension Center, Washington State University, 1100 North Western Avenue, Wenatchee, WA 98801

Additional index words. *Malus × domestica*, phytotoxicity, lead, heavy metal, replant

Abstract. Monoammonium phosphate (MAP) is a popular starter fertilizer in Pacific Northwest tree fruit orchards; however, its use on soils contaminated with lead arsenate pesticide residues can enhance As solubility, thereby increasing As phytoavailability. 'Fuji'/EMLA.26 apple trees (*Malus × domestica* Borkh.) were planted in Mar. 1992 on a lead arsenate-contaminated Cashmont gravelly sandy loam soil (HCl-extractable soil As range: 60–222 mg·kg⁻¹) using in-hole starter fertilizer application of either MAP or ammonium sulfate at equivalent N and anion rates. In ensuing years, all trees received identical applications of ammonium nitrate only. Relative trunk cross-sectional area was inversely related to soil As concentration in the year of planting but not in subsequent years, and was independent of starter fertilizer treatment. Leaf and fruit As were positively related to soil As in all years. Leaf As was initially higher in the MAP-treated trees; however, this effect diminished over time and disappeared by 1995. Fruit As was independent of starter fertilizer treatment, and was substantially lower than the tolerance established for As in fresh produce. The experimental results indicate that MAP starter fertilizer can increase soil As phytoavailability to apple trees grown under field conditions; however, the effects on tree growth and food safety are insignificant.

Acid lead arsenate (PbHAsO₄) was the most commonly used insecticide in deciduous fruit tree orchards before the introduction of synthetic organic insecticides during the late 1940s (Shepard, 1951). Frequent applications at high rates led to substantial Pb and As accumulation in orchard topsoils throughout the world (Peryea and Kammereck, 1997). Lead in these soils is not appreciably phytoavailable or phytotoxic (Creger and Peryea, 1994; Keaton, 1937; Moulton, 1977; Vandecaveye et al., 1936); however, the soil As is phytoavailable (Creger and Peryea, 1992, 1994) and can be phytotoxic at relatively low concentrations (Benson, 1976).

Use of PO₄-containing starter fertilizers in Washington and British Columbia orchards has increased in popularity since Slykhuis and Li (1985) reported enhanced growth of apple seedlings planted in monoammonium phosphate (MAP, NH₄H₂PO₄)-amended soil in con-

tainers. Although the effects of MAP starter fertilizer placed in the tree planting hole are inconsistent under field conditions (Nielsen et al., 1994) and pose risk of tree injury or death caused by transient soil salinization (Peryea, 1990), this practice and other methods of applying P at planting time are now frequently used in commercial orchards.

Phosphate addition to lead arsenate-contaminated soil enhances release of adsorbed As to the solution phase through the process of competitive anion exchange, thereby increasing solubility (Peryea, 1991), mobility (Peryea and Kammereck, 1997) and phytoavailability (Creger and Peryea, 1994) of As. The last-mentioned study was conducted in a closed-pot system using soil recently amended with lead arsenate, where the nature of PO₄-As-plant interactions probably differ from field situations where the insecticide has equilibrated with soil for decades and where leaching can occur. The effect on plant growth of adding PO₄ to high As-soil is inconsistent; yields or biomass have been reported to decrease, remain unchanged, or increase (see discussion in Creger and Peryea, 1994).

The current study was conducted to determine the nature and magnitude of the effect of MAP starter fertilizer on soil As phytoavailability to apple trees under field conditions.

Materials and Methods

A mixed 'Fuji'/EMLA.26 and 'Gala'/EMLA.26 apple orchard was planted in Mar.

1992 on a Cashmont gravelly sandy loam soil (coarse-loamy, mixed, mixed mesic Aridic Haploxeroll), which was contaminated with Pb and As from use of lead arsenate insecticide. The land was previously used for apple production and therefore was fumigated with metam sodium in Oct. 1991 to control possible replant disease (Benson et al., 1978). The liquid fumigant was applied by boom sprayer in a strip 2.44 m wide over the future tree rows while a hand-line irrigation system was operating to incorporate the product. Dolomite (4.5 Mg·ha⁻¹) was surface-broadcast on 6 Mar. 1992. On 15–18 Mar., the metam sodium-sprayed areas were rototilled and 46-cm-diameter tree holes were augered to a depth of 38 cm. The tree spacing was 2 m in-row and 4.6 m between rows.

The starter fertilizer treatments were applied on 19, 20, or 24 Mar. 1992 by sprinkling an appropriate amount of each product on the ring-shaped mound of excavated soil around each augered hole. This fertilizer-amended soil was then shoveled back into the hole while the tree was held in place. Immediately after planting, four soil samples were collected from the top 46 cm of the planting hole soil at a 15-cm distance from each tree trunk using a soil sampling tube, and were composited by tree. The trees then were individually hand-watered from a nurse tank. Portable hand-lines with high-pressure impact sprinklers were used to irrigate the trees until installation of a microjet irrigation system was completed in mid-April.

An additional 4.5 Mg·ha⁻¹ magnesian calcite lime was surface-broadcast on 9 Apr. 1993. In Spring 1994, foliar sprays of zinc and copper chelates were applied at the half-inch (1.25-cm) green bud stage and boron was applied postbloom. Insecticide and fungicide sprays were applied following Washington State Univ. guidelines (Beers, 1997).

The experimental treatments were applied to 10 randomly selected pairs of adjacent 'Fuji' apple trees located in the two outermost rows of the orchard. One tree of each pair was randomly selected to receive 12.38 g of N as monoammonium phosphate (MAP, NH₄H₂PO₄) directly in the planting hole upon planting followed 4 weeks later by a surface application of 9.62 g of N as NH₄NO₃ broadcast within the tree dripline. The second tree of each pair received 12.38 g of N as (NH₄)₂SO₄ directly in the planting hole upon planting followed 4 weeks later by a surface application of 9.62 g of N as NH₄NO₃ broadcast within the tree dripline. Phosphorus and S were therefore applied at equivalent mole per tree rates in the two treatments. In early May of ensuing years, all trees received identical surface applications of NH₄NO₃ at per-tree rates of 22, 44, and 66 g of N in 1993, 1994, and 1995, respectively.

Tree growth was assessed by measuring scion trunk diameter at a marked location above the graft union parallel and perpendicular to the tree row, at planting and in late Oct. 1992–95, and was used to calculate trunk cross-sectional area (TCSA). Relative TCSA (TCSA_r) for each year was calculated by di-

Received for publication 26 Sept. 1997. Accepted for publication 6 Feb. 1998. Dept. of Crop and Soil Sciences Paper 9708-01. This research was conducted under Project WNP00954, College of Agriculture and Home Economics, Washington State Univ., Pullman, and Western Regional Research Project W-184, CSREES, U.S. Dept. of Agriculture, Washington, D.C. I thank Rudi Kammereck, Glen Williams, and Rhoda Burrows for their technical 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.

viding TCSA after each growing season by TCSA at planting.

Twenty leaves were randomly sampled from each experimental tree in late July 1992–95, oven-dried at 85 °C, ground in a mill, and analyzed for As, N, P, K, Ca, Mg, S, Fe, Zn, Cu, B, and Na. Three fruits (or as many as were present up to three) were randomly sampled from each experimental tree at commercial harvest (mid- to late October) in 1994 and 1995. Each fruit was cut longitudinally into quarters, and seeds and stems were removed. Two opposing quarters were weighed, freeze-dried, reweighed, ground in an agate mortar, and analyzed for As. All plant tissue samples were washed in 0.5% Liquinox solution (Alconox, New York), followed by tap water and distilled water rinses, prior to analysis. Leaf and fruit samples were analyzed for As by wet digestion in sulphomonoperacid [1.6:1 (v/v) concentrated H₂SO₄ : 30% H₂O₂] followed by assay using arsine generation-atomic absorption spectrophotometry. Leaf N was determined by total Kjeldahl analysis and other mineral elements by dry-ashing, followed by assay using inductively coupled plasma emission spectroscopy.

The composite soil samples collected from each experimental tree planting hole were analyzed for pH (1:1, distilled water) and for concentrated HCl-extractable As (Peryea and Kammereck, 1997), which is used commercially as the index for soil As contamination in Washington orchards. This technique recovers between 92% and 97% of total As in this Cashmont soil (Peryea, 1997). Additional soil samples (0- to 15-cm depth) were collected throughout the entire orchard at planting and analyzed for pertinent physical and chemical properties using standard techniques (Page et al., 1982) except for Pb, which was analyzed using the procedure described in Peryea and Kammereck (1997).

The experiment was established using a randomized paired comparison design with treatments of MAP vs. (NH₄)₂SO₄ starter fertilizer (Steel and Torrie, 1980). The data for one pair of trees were excluded because the MAP-treatment tree died from root damage caused by rodents during Winter 1992–93; hence, the statistical analysis was based on nine pairs of trees. The data were also analyzed using tests for comparison of regression lines (Weisberg, 1985), with soil As at planting time used as the independent predictor for tree responses. The test for TCSA_i response to soil As compared a Model 4 response [coincident MAP and (NH₄)₂SO₄ regression lines] with a Model 1 most general response [the slope and intercept values for the MAP and (NH₄)₂SO₄ regression lines are different]. This comparison makes no a priori assumptions regarding the differential effects of the PO₄ vs. SO₄ counter-ions in the starter fertilizer on TCSA_i response. The test for plant tissue As concentration response to soil As compared a Model 4 response [coincident MAP and (NH₄)₂SO₄ regression lines] with a Model 3 concurrent response [the intercept values for the MAP and (NH₄)₂SO₄ regression lines are identical but the slopes are different]. This comparison

assumes that plant tissue As concentrations will be identical (and theoretically zero) in a soil containing no As regardless of starter fertilizer treatment because there is no soil As to become differentially phytoavailable, and that the MAP and (NH₄)₂SO₄ may have differential effects on plant As when soil As is present. Statistical significance for both data analysis approaches was defined as $P \leq 0.05$.

Results and Discussion

HCl-extractable soil As concentrations in the experimental tree planting holes ranged from 60 to 222 mg·kg⁻¹. Natural background concentrations in central Washington orchard soils typically are <10 mg·kg⁻¹ (Peryea and Creger, 1994). Existing standards indicate that apple tree growth will be significantly reduced at soil As concentrations >50 mg·kg⁻¹ and that tree death may be expected at soil As concentrations >100 mg·kg⁻¹ (Dow et al., 1983); however, none of the experimental trees died except for the rodent-damaged tree. The lack of tree mortality suggests that the standards, which were established about 1968, may now

be invalid and should be adjusted to reflect reduced As phytotoxicity resulting from continued transformation of soil As to less phytoavailable forms (Merry et al., 1986).

Soil chemical properties in the orchard site were generally suitable for apple trees. Soil pH in the experimental tree planting holes ranged from 6.2 to 7.0. Soil chemical properties averaged across the entire orchard (top 15 cm) at planting time were: 1 M NH₄OAc (pH 7)-exchangeable Ca 715, Mg 167, K 58, and Na 24 meq·g⁻¹; hot water-extractable B 0.56 mg·kg⁻¹; DTPA-TEA-CaCl₂-extractable Zn 6.3, Mn 15.0, and Cu <1.0 mg·kg⁻¹; and HCl-extractable Pb 1066 mg·kg⁻¹. One-half molar NaHCO₃-extractable soil P averaged 27 mg·kg⁻¹, an amount considered high enough to preclude P fertilizer use on nontree crops (Dow et al., 1976). Soil P test standards for fruit trees in Washington have not been established because tree responses are poorly related to soil P tests (Tukey et al., 1984).

The paired *t* test analyses indicated that starter fertilizer treatment had no effect on TCSA_i (Table 1). Leaf As was initially higher in the MAP-treated trees, with the magnitude

Table 1. The *t* statistics for comparison of responses of paired 'Fuji' apple trees to monoammonium phosphate (MAP) or ammonium sulfate starter fertilizer.

Response variable	<i>t</i> statistic ²			
	Year			
	1992	1993	1994	1995
TCSA _i ¹	1.577 ^{ns}	0.367 ^{ns}	0.319 ^{ns}	-0.272 ^{ns}
Fruit As concentration	---	---	1.448 ^{ns}	---
Leaf concentration				
As	5.445***	2.932*	2.744*	0.310 ^{ns}
P	2.428*	1.214 ^{ns}	0.800 ^{ns}	0.000 ^{ns}
S	2.036 ^{ns}	1.596 ^{ns}	1.644 ^{ns}	-0.217 ^{ns}
N	1.516 ^{ns}	0.349 ^{ns}	-0.654 ^{ns}	1.494 ^{ns}
K	0.079 ^{ns}	2.147 ^{ns}	-1.221 ^{ns}	0.167 ^{ns}
Ca	1.402 ^{ns}	1.015 ^{ns}	2.869*	0.974 ^{ns}
Mn	1.135 ^{ns}	-0.195 ^{ns}	1.788 ^{ns}	0.357 ^{ns}
Fe	2.367 ^{ns}	0.830 ^{ns}	-0.669 ^{ns}	-2.114 ^{ns}
Cu	-1.772 ^{ns}	-1.116 ^{ns}	-2.324*	-1.945 ^{ns}

¹The *t* statistic was calculated using the MAP minus the ammonium sulfate response for each pair of trees; hence, positive values indicate greater overall magnitude for the MAP-treated trees relative to ammonium sulfate-treated trees. Degrees of freedom = 8 for all response variables ($t_{0.05} = 2.31$; $t_{0.01} = 3.36$; $t_{0.001} = 5.04$).

²TCSA_i = relative trunk cross-sectional area.

^{ns}, *, ***, Nonsignificant or significant at $P \leq 0.05$ or 0.001, respectively.

Table 2. The *F* statistics for tests comparing the influence of starter fertilizer treatment [monoammonium phosphate- (MAP) vs. ammonium sulfate] on regression lines relating relative trunk cross-sectional area, leaf As and fruit As of 'Fuji' apple trees to soil As concentration at planting.

Response variable ¹	<i>F</i> statistic			
	Year			
	1992	1993	1994	1995
TCSA _i ² · <i>x</i>	1.639 ^{ns}	0.102 ^{ns}	0.045 ^{ns}	0.022 ^{ns}
Leaf As ³	18.748***	3.959*	7.459**	0.245 ^{ns}
Fruit As ³	---	---	1.805 ^{ns}	0.696 ^{ns}

¹The regression model under evaluation is $Response\ variable = A_i + B_i (Soil\ As)$ for case *i*, where *i* represents starter fertilizer composition (MAP or ammonium sulfate).

²TCSA_i = trunk cross-sectional area at year's end, relative to TCSA at planting.

³The *F* statistic for TCSA_i is for comparison of a coincident regression model (i.e., the TCSA_i X soil As regression lines are identical for both MAP and ammonium sulfate starter fertilizer) with the most general model (i.e., the TCSA_i X soil As regression lines for the MAP and ammonium sulfate starter fertilizer have different slopes and intercepts). For TCSA_i (all years), $F_{0.05} = 3.68$ (df = 2, 15).

⁴The *F* statistics for fruit and leaf As are for comparison of a coincident regression model (i.e., the fruit As or leaf As X soil As regression lines are identical for both MAP and ammonium sulfate starter fertilizer) with a concurrent model (i.e., the fruit As or leaf As X soil As regression lines for the MAP and ammonium sulfate starter fertilizer have different slopes and the same intercept). For leaf As (all years) and fruit As (1994), $F_{0.05} = 4.49$, $F_{0.01} = 8.53$, $F_{0.001} = 16.12$ (df = 1, 16). For fruit As (1995), $F_{0.05} = 3.46$ (df = 1, 8).

^{ns}, *, ***, Nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively.

of the effect diminishing over time until it disappeared by the 4th year after planting. Unlike leaf As, fruit As in 1994 was independent of starter fertilizer treatment. Under Washington conditions, 'Fuji' apple trees are highly prone to alternate-bearing. The experimental trees in 1995 were in the "off-year," with some trees not setting any fruit and thereby precluding a paired *t* test analysis. The MAP-treated trees had higher leaf P in the year of planting but not in succeeding years. In contrast, leaf S was not affected by starter fertilizer treatment. Leaf N, K, Ca, Mn, Fe, and Cu were independent of starter fertilizer treatment except for Ca and Cu in 1994, but these are interpreted as random statistical effects with no horticultural significance.

The comparative regression line analyses indicated that, in all years, a single coincident regression line representing both the MAP and ammonium sulfate data described the TCSA_r relationship with soil As as well as two separate regression lines, one for each fertilizer source (Table 2, Fig. 1). The TCSA_r was inversely related to soil As in the year of planting ($Y = 1.713 - 0.00235X$; $r^2 = 0.255^*$, $n = 19$); however, the slopes were not different from zero in succeeding years. The rate of increase in TCSA_r slowed in 1994 because the trees were allowed to fruit that year. Failure of MAP to improve tree growth may reflect the already adequate P status of the soil. The relationship between apple tree biomass or TCSA and soil As qualitatively conforms to a monotonic function that decreases at a decreasing rate with increasing soil As (Benson, 1976; Benson et al., 1978; Merwin et al., 1994). The flat tree growth response in the current experiment appears to correspond with the asymptotic portion of this relationship; hence, TCSA_r probably would have been substantially greater if soil As concentrations had been <60 mg·kg⁻¹.

The relationship between leaf As and soil As for 1992, 1993, and 1994 was better described using separate regression lines for MAP and ammonium sulfate starter fertilizer than with a single coincident line (Table 2; Fig. 2). Leaf As was positively related to soil As in all years. Separation of the starter fertilizer curves became weaker after the first year and disappeared by 1995, consistent with the result found using the paired *t*-test analysis. Leaf As concentrations were elevated compared to values reported for other plants (Woolson, 1983); however, soil As concentrations in the experimental orchard also were higher than those listed by Woolson.

The structure of comparative regression line analysis permits evaluation of the fruit As response in 1995. Starter fertilizer treatment had no influence on the relationship between fruit As and soil As in either 1994 or 1995 (Table 2; Fig. 3). Fruit As was positively related to soil As in both years. The maximum fruit As concentration measured was 107 µg·kg⁻¹ fresh mass, substantially lower than the 2650 µg·kg⁻¹ fresh mass tolerance for As in raw agricultural commodities that was used until it was abolished as unnecessary by the U.S. Environmental Protection Agency (1991).

Fig. 1. Influence of starter fertilizer composition {monoammonium phosphate [MAP] = closed symbols, solid lines; ammonium sulfate [(NH₄)₂SO₄] = open symbols, dotted lines} and soil As at planting on relative trunk cross-sectional area (TCSA_r) of 'Fuji' apple trees at the end of growing seasons 1992–95.

Fig. 2. Influence of starter fertilizer composition {monoammonium phosphate [MAP] = closed symbols, solid lines; ammonium sulfate [(NH₄)₂SO₄] = open symbols, dotted lines} and soil As at planting on leaf As concentration of 'Fuji' apple trees in 1992–95.

Fig. 3. Influence of starter fertilizer composition {monoammonium phosphate [MAP] = closed symbols, solid lines; ammonium sulfate $[(\text{NH}_4)_2\text{SO}_4]$ = open symbols, dotted lines} and soil As at planting on fruit As concentration of 'Fuji' apple trees in 1994–95.

The EPA argued that fruits and vegetables harvested from arsenate-treated fields are expected to contain inconsequential amounts of arsenic, a position supported by the current experiment. The As concentrations measured in the 'Fuji' fruit of the current experiment were very similar to those observed in 'Gala' apples (Creger and Peryea, 1992).

Fruit mass averaged 254 g in 1994 and 226 g in 1995; hence, As content per whole fruit averaged 20.7 and 16.8 μg in 1994 and 1995, respectively. Although the internal distribution of As within fruit has not been reported, analogy with P suggests that a significant proportion of fruit As would reside in the core (Perring and Pearson, 1984).

The concentration of As in fruit was substantially lower than that in dried leaf tissue, averaging 12.3 times lower when fruit As was expressed on a dry mass basis and 67 times lower when it was expressed on a fresh mass basis. The As concentration in both leaves and fruit for a particular year was inversely related to the rate of TSCA_r increase, suggesting a sensitivity to tree biomass accumulation.

Conclusions

In-hole application of MAP starter fertilizer for apple trees planted in lead arsenate-contaminated soil temporarily enhanced soil As phytoavailability under field conditions. The effect was strongest in the year of planting and diminished with time. The increase in tree As status was insufficient to impair tree growth when initial soil As concentration was greater than 60 $\text{mg}\cdot\text{kg}^{-1}$, which was the lowest concentration observed in the experimental or-

chard. Fruit As concentrations were less than four percent of the EPA tolerance for As in fresh produce and were not enhanced by MAP starter fertilizer, probably because the stimulatory effects of the added PO_4 had effectively disappeared by the time the trees came into bearing. The results of the current experiment indicate that use of MAP starter fertilizer (and, by inference, probably all other PO_4 fertilizer formulations) on apple trees planted in lead arsenate-contaminated soils has no deleterious effect on horticultural performance or food safety.

Literature Cited

- Beers, E.H. 1997. 1997 crop protection guide for tree fruits in Washington. Washington State Univ. Coop. Ext. Bul. EB0419.
- Benson, N.R. 1976. Retardation of apple tree growth by soil arsenic residues. *J. Amer. Soc. Hort. Sci.* 101:251–253.
- Benson, N.R., R.P. Covey, Jr., and W. Haglund. 1978. The apple replant problem in Washington State. *J. Amer. Soc. Hort. Sci.* 103:156–158.
- Creger, T.L. and F.J. Peryea. 1992. Lead and arsenic in two apricot cultivars and in 'Gala' apples grown in lead arsenate-contaminated soils. *HortScience* 27:1277–1278.
- Creger, T.L. and F.J. Peryea. 1994. Phosphate fertilizer enhances arsenic uptake by apricot liners grown in lead-arsenate-enriched soil. *HortScience* 29:88–92.
- Dow, A.I., A.R. Halvorsen, and R.B. Tukey. 1983. Fertilizer guide: Special orchard soil tests. Washington State Univ. Coop. Ext. Bul. FG-28d.
- Dow, A.I., R.B. Tukey, and A.R. Halvorsen. 1976. Fertilizer guide: Orchard cover crops and sods. Washington State Univ. Coop. Ext. Bul. FG-28b.

- Keaton, C.M. 1937. The influence of lead compounds on the growth of barley. *Soil Sci.* 43:401–411.
- Merry, R.H., K.G. Tiller, and A.M. Alston. 1986. The effects of soil contamination with copper, lead and arsenic on the growth and composition of plants: II. Effects of source of contamination, varying soil pH, and prior waterlogging. *Plant Soil* 95:255–269.
- Merwin, I., P.T. Pruyne, J.G. Ebel, Jr., K.L. Manzell, and D.J. Lisk. 1994. Persistence, phytotoxicity, and management of arsenic, lead and mercury residues in old orchard soils of New York state. *Chemosphere* 29:1361–1367.
- Moulton, G.A. 1977. The response of apple seedlings with mycorrhizal fungi to arsenic contaminated soils. MS Thesis, Dept. of Horticulture, Washington State Univ., Pullman.
- Neilsen, G.H., J. Beulah, E.J. Hogue, and R. Utkhede. 1994. Planting-hole amendments modify growth and fruiting of apples on replant sites. *HortScience* 29:82–84.
- Page, A.L., R.H. Miller, and D.R. Keeney (eds.). 1982. Methods of soil analysis, Part 2. 2nd ed. Agron. Monogr. 9, Amer. Soc. Agron., Madison, Wis.
- Perring, M.A. and K. Pearson. 1984. The distribution of calcium, magnesium and phosphorus in Cox's Orange Pippin and Spartan apple fruit. *J. Sci. Food Agr.* 35:897–899.
- Peryea, F.J. 1990. Phosphate fertilizer-induced salt toxicity of newly planted apple trees. *Soil Sci. Soc. Amer. J.* 54:1778–1783.
- Peryea, F.J. 1991. Phosphate-induced release of arsenic from soils contaminated with lead arsenate. *Soil Sci. Soc. Amer. J.* 55:1301–1306.
- Peryea, F.J. 1997. Evaluation of soil tests for predicting growth of and arsenic uptake by apple trees planted in lead arsenate-contaminated soil. Extended Abstr., 4th Intl. Conf. Biogeochemistry of Trace Elements, Berkeley, Calif., 23–26 June 1997.
- Peryea, F.J. and T.L. Creger. 1994. Vertical distribution of lead and arsenic in soils contaminated with lead arsenate pesticide residues. *Water Air Soil Pollut.* 78:297–306.
- Peryea, F.J. and R. Kammereck. 1997. Phosphate-enhanced movement of arsenic out of lead arsenate-contaminated topsoil and through uncontaminated subsoil. *Water Air Soil Pollut.* 93:243–254.
- Shepard, H.H. 1951. The chemistry and action of insecticides. 1st ed. McGraw-Hill, New York.
- Slykhuis, J.T. and T.S.C. Li. 1985. Responses of apple seedlings to biocides and phosphate fertilizers in orchard soils in British Columbia. *Can. J. Plant Pathol.* 7:294–301.
- Steel, R.G.D. and J.H. Torrie. 1980. Principles and procedures of statistics. 2nd ed. McGraw-Hill, New York.
- Tukey, R.B., A.I. Dow, and A.R. Halvorsen. 1984. Fertilizer guide: Fruit trees for the entire state. Washington State Univ. Coop. Ext. Bul. FG-28a.
- U.S. Environmental Protection Agency. 1991. Calcium arsenate; revocation of tolerances. *Congr. Fed. Register* 56:13594–13595.
- Vandecaveye, S.C., G.M. Horner, and C.M. Keaton. 1936. Unproductiveness of certain orchard soils as related to lead arsenate spray accumulations. *Soil Sci.* 42:203–213.
- Weisberg, S. 1985. Applied linear regression. Wiley, New York.
- Woolson, E.A. 1983. Emissions, cycling and effects of arsenic in soil ecosystems, p. 51–139. In: B.A. Fowler (ed.). Biological and environmental effects of arsenic. Elsevier, New York.