GROWTH, LEAF AND ROOT COMPOSITION OF APPLE, CHERRY, AND PEACH TREES IN RELATION TO INJECTIONS OF METAL AND ALLOY POWDERS TO SUPPLY MINOR ELEMENTS

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By

VINCENT ALFRED AMATO

AN ABSTRACT

Submitted to the School of Graduate Studies of Michigan
State University of Agriculture and Applied Science
in partial fulfillment of the requirements
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MASTER OF SCIENCE

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1955

Approved A. L. Kenworthy

VINCENT ALFRED AMATO ABSTRACT

Greenhouse experiments with minor elements (Fe, Mn, Zn, B, Cu) in metal and alloy powder forms were conducted on apple, cherry and peach trees. The metal and alloy powders were injected in the trunks of the trees; major elements were supplied as nutrient solutions. Controls consisted of trees receiving a complete Hoagland solution and the same solution minus minor elements. Plants were grown in 12-inch clay pots painted with asphaltum and in a medium consisting of sterile No. 7 size white quartz gravel.

Linear growth and trunk diameters were recorded at the time of harvesting. Total dry weight increase was calculated for leaves, roots, shoots and trunk. Iron, manganese, zinc, copper and boron composition of leaves and fibrous roots were determined by spectrographic analysis.

Apple growth results were higher where 1.0 gram of the powder was used than where 0.5 grams were injected. A visible nutrient deficiency symptom appeared in the later growing period in the trees receiving no minor elements. However, differences in growth as measured by dry weights were not statistically significant.

The greatest total growth of cherry trees was obtained with the injection of powders impregnated with citric acid. Severe chlorosis, defoliation and shoot die-back occurred only in treatments where the minor elements were entirely omitted. This condition was not identified with chemical analysis. No deficiency symptoms were visually apparent in peach treatments, and the data show no significant growth differences between treatments.

Analyses of apple leaves showed that metal and alloy powders impregnated with citric acid significantly increased leaf manganese content over all other treatments. A similar response to citric acid was obtained for boron, but the highest response was registered where 0.5 grams were injected.

Analyses of cherry leaves showed manganese to be the only nutrient increased by citric acid impregnation of metal and alloy powders. Analyses of peach leaves showed a similar manganese increase with the citric acid impregnated materials.

Copper analyses of apple fibrous roots showed that an unexplainable accumulation of copper occurred in that treatment where minor elements were omitted from nutrient solutions. This accumulation was greater than that occurring in treatments receiving injected metal and alloy powders.

The absorption of manganese by cherry roots was found to be more significant in the complete nutrient solution than in the injected treatments or those where minor elements were omitted.

Definite increase in iron occurred in the fibrous roots of peach when the metal and alloy powders were impregnated with citric acid.

Internal wood injury occurred where metal and alloy powders were injected into the fruit trees.

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INTRODUCTION

Deficiencies or shortages of minor elements (Fe, Mn, B, Cu, Zn) have been successfully corrected by three general processes: soil application, trunk injections and sprays to foliage and bark. Under certain conditions, soil applications are not satisfactory, either because of their failure to correct the shortage or the hazard of toxicities. Sprays containing these minor elements may correct a shortage, but the correction usually lasts only one season. Injections of soluble salts of certain minor elements may correct a shortage with the injection being effective for one to six seasons.

Slowly soluble or relatively insoluble forms of minor elements have not received much attention as possible sources of nutrients injected into tree trunks. Investigation of injection of slowly soluble or relatively insoluble forms of minor elements into trunks of fruit trees to correct deficiencies has largely been neglected, with the possible exception of iron and zinc nails used to alleviate iron and zinc deficiency.

LITERATURE REVIEW

The importance of minor elements to plant growth and vigor has been firmly established. Deficiencies of iron, manganese, boron, copper and zinc have been reported in many areas of the world where fruit growing is of economic importance.

Whenever one or more minor elements are lacking, a decline in fruit production results. This decline has been reported by many investigators to be caused by various soil factors, such as biological condition, moisture, pH and chemical content. Numerous workers, Bennett (2), Chapman, Brown and Rayner (12), and Wann (49) have reported that these factors and not the lack of minor elements in the soil affect plant uptake of minor elements.

<u>Iron Deficiency</u>: Iron deficiency, according to Wallace (48), has been more commonly found in fruit plants than in any other agricultural crops. Injection of iron salts, he believed, may be used for commercial applications in curing chlorosis.

Bennett (2), Wallace (47), Starr (41) and Kemp Beare (26) used trunk injection of soluble iron salts and obtained better results correcting lime-induced chlorosis of fruit trees than were obtained with either soil or spray treatments. (Lime-induced chlorosis refers to instances of iron deficiency occurring on soils where the lime content is high). Bennett (2) found that the injection method was more practical, economical and results were more lasting than for other methods tried.

Hendrickson (23) investigating chlorotic conditions of pear trees, found that these conditions responded to treatments of iron salts. He found that trunk and limb injections of ferrous sulfate could correct extreme chlorotic conditions. A one or five per cent solution of iron sulfate sprayed on the foliage was not satisfactory, and the higher concentration caused severe leaf burning. Oserkowsky (33) similarly found that deficiency of chlorophyll in pear leaves was remedied by iron salts.

Southwick (40), using liquid solutions of ferrous sulfate injected under high pressure into citrus trees, reported that iron was evenly distributed throughout the tree, and corrected chlorosis for periods of two to four years. Dennis (14) injected ferrous citrate and found the injection lasted from six to seven years with no loss in commercial crop production. Finch *et al.* (40) found that placing ferric citrate in holes bored into tree trunks produced a rapid and permanent correction of chlorosis on citrus trees. They found that this response to injections was more striking than those of varying soil treatments tried. Moore (32) injected soluble ferric citrate into trunks and found that best results were obtained when the injections were made some time between March and August. Bennett (2), Starr (41), and Wallace (47) found that best results and less injury occurred when deciduous trees were treated during dormant season.

Crawford (13) found that under New Mexico conditions soil treatments were the most effective and permanent in control of chlorosis of fruit and grapes. He obtained successful results by using barnyard manure and other acid forming materials in combination with iron. Duggan (15) used a similar approach to cure chlorosis and reported that this method failed to cure the trouble.

Crawford (13) also tried trunk injection and spraying of iron salts and obtained only temporary relief from chlorosis. He also found that nails driven into trunks proved to be much slower than injection of iron salts, in bringing about control of chlorosis. Although iron nails driven into tree trunks were slower in controlling chlorosis, Burke _et al._ (6) recommended this treatment because of ease of application. Starr (41) recommended trunk injections of iron salts because of the striking and successful results obtained in correcting chlorosis of trees.

Zinc Deficiency: The characteristic symptom of zinc deficient fruit trees is the rosetting of the terminal leaves caused by the extreme reduction of internodal shoot growth. This is accompanied by many narrow and under-developed leaves showing extreme interveinal chlorosis, Kenworthy *et al.* (28), and Woodbridge (52). For years zinc deficiency of fruit trees has been corrected by regular and repeated bark and foliage sprays of zinc solutions. This method of correcting for zinc deficiency has not always given satisfactory, or lasting results. For some time investigators have been seeking a more practical and lasting method, either through the soil or tree injections. Soil conditions similar to those causing iron deficiency have been found by Chandler *et al.* (10), Woodbridge (52), Purvis (37), and Jensen (25) to be related to zinc deficiency. Finch (18) however, indicated that zinc deficiency is not related to the soluble zinc content or pH of the soil. By using trunk injections and foliar sprays of zinc salts, he was able to successfully arrest rosetting and shoot necrosis of pecan. He made no application of zinc or any other material to the soil during his experiment, assuming that zinc deficiency was associated with the above-ground plant parts and additions of zinc compounds to soil would be of no beneficial value.

Chandler *et al.* (10) injected zinc sulfate into trunks, using methods described by Bennett (2), and were able to get very satisfactory results in curing little-leaf or rosette of fruit trees. Some injury to sapwood and bark occurred around injection areas. Although some improvements were shown by both soil and spray treatment, the results were less striking and not as long lived as those produced by trunk injections. In a later experiment these same workers (11) drove pieces of zinc, e. g. glazer points, into trunks and branches of plants affected with rosette. Very good results were obtained for all deciduous fruit, grape and walnut trees receiving this treatment. Soil treatments proved to be too expensive and were not as effective as the trunk unjections.

Ridgeway (38) investigated rosette of apple in Virginia. He found that trunk treatments with zinc glazing points and injections of zinc sulfate crystals gave a much better response than soil applications or sprays of zinc salts, and that rosette was corrected for a few years, although there was some injury to the wood. McWhorter (31) reported similar results from Oregon.

Parker (35) was able to effectively correct mottle-leaf on lemon trees by using two to four grams of zinc sulfate crystals injected into trunk borings. Parker believed the crystal injection method would not be practical with citrus trees. Bould and co-workers (4) reported that although injections of solid zinc sulfate into trunks and branches will correct zinc deficiency, the method was very tedious and liable to cause local damage to plant tissues.

Ward (50) attempted to ascertain the best method for the application of zinc as a corrective measure of little-leaf of fruit trees He concluded that a dormant spray of five per cent zinc sulfate was the most satisfactory method for correcting this deficiency Applications of five pounds of zinc sulfate per tree broadcast over the soil produced beneficial effects only in the second and third years following treatments. Tree injections of zinc salt solutions, using the method of plant injection developed by Thomas and Roach (44) and Roach (39) were unsatisfactory. This method of correcting a deficiency appeared useful as a means of diagnosing deficiencies.

Manganese Deficiency: The symptom most common to manganese deficiency in fruit trees is chlorosis of the leaves. This chlorosis or yellowing of leaf tissue occurs in the interveinal and marginal areas. Manganese deficiency is often confused with symptoms of iron deficiency, but whereas iron deficiency generally appears on new tip leaves, those of manganese occur on older leaves of individual shoots, Wallace (48), and Woodbridge and McClarty (51). Manganese deficiency as found by Camp and Peech (8), occurring on citrus in Florida resembled symptoms of zinc deficiency as to leaf pattern, but was much less pronounced.

Investigations by Epstein and Lilleland (17), and Boynton *et al.* (5) showed that chlorosis of fruit trees was related to manganese content of the leaf. They were able to correct manganese chlorosis and increase the leaf content of manganese by the use of manganese salt injection techniques on fruit trees. Boynton *et al.* (5) observed that injections would control manganese deficiency for two growing seasons, whereas spraying lasted for only one season, and soil treatments resulted in erratic response in the trees the following year. Duggan (15), and Vanselow (46) showed that manganese deficiency could be corrected readily by using dry salt injections. Duggan found that spraying the foliage was not sufficient for practical purposes.

Copper Deficiency: Earlier literature considered copper deficiency to be a pathological condition and was called exanthema, wither-tip or die-back. This condition has been found on fruit trees in various parts of the world, Wallace (48). The first symptom of copper deficiency appears on the leaves. Deficient leaves develop a fine network of green veins accentuated by a light green background of leaf tissue between the veins, Camp *et al.* (9). Leaves thus affected appear distorted and malformed. When copper deficiency becomes acute, shoot die-back occurs on those shoots affected with defoliation and multiple bud formation, Bould *et al.* (3), and Dunne (16). Where the deficiency is very severe, gum exudes from cracks in the main branches and trunks This condition may lead eventually to the death of affected trees, Thomas (43), Anderssen (1), Oserkowsky and Thomas (34), and Bould *et al.* (3).

Copper deficiency in Florida citrus groves was first corrected, according to Camp *et al.* (9), by inserting crystals of bluestone under the bark of citrus trees. Thomas (43), and Oserkowsky and Thomas (34) reported that powdered copper sulfate injected during the dormant season into holes bored into tree trunks cured exanthema in deciduous fruit trees The beneficial effect lasted three seasons. A foliar spray of Bordeaux was similarly beneficial for one season. Soil treatments with copper sulfate crystals failed to decrease noticeably the symptoms of exanthema. Anderssen (1) was able to cure the chlorotic conditions of fruit trees caused by copper deficiency by using copper sulfate soil treatments, while all other methods that were tried failed to satisfactorily correct this condition.

Tixer (45) found that injections of copper sulfate into *Hevea brasiliensis* trees increased yields of rubber. He further found that a second and third injection at six-month intervals was neither detrimental to future yields of rubber nor injurious to bark and foliage.

Boron Deficiency: Boron deficiency usually affects the meristem or actively dividing tissues of affected plants. Symptoms of deficiency in apple trees are loss of some leaves followed by terminal rosetting. As the deficiency becomes severe, shoots die back with roughening and splitting of the bark. Fruits produced from such a tree are distorted, misshapen and lacking in flavor. The internal conditions of affected fruits are known as corky core, internal cork, or drought spot. Various treatments of boric acid and borax seem to prevent recurrence of these symptoms.

A deficiency of boron does not always mean a shortage of boron in the soil. Boron may be present in soil, but unavailable to the plant. Certain soil conditions, as drought and high lime content, can induce boron deficiency in plants, Gisiger (20) and Wallace (48).

The result of three years work by McLarty (30) showed that trunk injections of boric acid controlled corky core of apple. He reported no injury resulted from injections, except for the usual bark and wood injury around injection holes, as reported by many other workers using this technique. Magness *et al.* (29) found that boric acid crystals injected into trunks were beneficial in reducing internal cork of apples.

Gloyer (21) investigated drought spot of apples in New York. He reported severe injury resulted to all apple trees where injections of boric acid crystals were used.

Burrell (7) reported that injections of boric acid reduced the amount of internal cork of apples by over ninety-nine per cent where this condition was general in an orchard, and caused no foliage injury. He found that soil treatments of boron gave equally effective control of internal cork. He concluded that the injection method should not be used commercially because of bark injury.

Molybdenum Deficiency: Stewart and Leonard (42) were able to correct the molybdenum deficiency of citrus, commonly known as yellow spot, with foliar spray applications of sodium molybdate. Symptoms of molybdenum deficiency disappeared within three or four weeks after application. Trunk injections of one gram of sodium molybdate corrected deficient trees and returned the foliage to a healthy green color. Soil applications of molybdenum were found to be unsatisfactory for control of yellow spot.

MATERIALS AND METHODS

Ninety one-year-old trees (42 apple, 24 cherry, and 24 peach) to be grown in sand cultures, were carefully selected, uniformly pruned, weighed and planted in 12-inch clay pots that had been painted with three coats of asphaltum paint. The growing media was sterile white quartz gravel (No 7 grade).

After planting the trees were divided into groups of three trees for each treatment. The treatments were (1) injections of metal and alloy powders, plus nutrient solution without minor elements, (2) complete nutrient solution, and (3) nutrient solution without minor elements. Six metal and alloy powder mixtures were prepared by the Ferro Corporation, Cleveland, Ohio. The composition of these powders is given in Table 1.

Table 1. Nutrient Element Composition of the Metal and Alloy Powder Mixtures Injected into Trees.

Treatment No. *	Form	Composition (Per Cent)					
		Fe	Mn	Zn	B	Cu	Mo
1	Powder	38.4	38.4	7.7	2.9	7.7	1.1
2	Powder	23.4	23.4	23.4	2.9	23.4	1.0
3	Powder	19.6	33.5	33.5	2.5	6.7	0.8
4	Powder	14.8	7.3	36.6	2.8	36.6	0.9
5	Nail	42.0	15.0	19.0	3.7	19.2	0.8
6	Nail	42.0	15.0	19.0	3.7	19.2	0.8

*The materials as received from Ferro Corporation, Cleveland, Ohio were coded as follows: Treatment 1--562-1; Treatment 2--562-2; Treatment 3--562-3; Treatment 4--562-4; Treatment 5--No. 7 nail; and Treatment 6--No. 7 nail (impregnated with citric acid).

The trees were injected with the metal and alloy powders on February 1, 1955, before growth started (Figures 1 and 2). The injections were made by boring holes 3/16 inch in diameter and approximately 1/2 inch deep into the trunks. Gelatin capsules of No. 5 size, containing the powder mixtures were inserted into the holes. Each capsule contained 0.5 grams of the relatively insoluble powders containing minor elements. After inserting the capsules, the holes were sealed with latex sealing gauze. The powder mixture in nail form was inserted by making an incision with a knife and pressing the nail into the trunk with slip-joint pliers, after covering the jaws with rubber to prevent injuring the bark. One capsule, or nail, was injected into each tree, except that some apple trees received two capsules or nails (Tables 2, 5, 8).

The nutrient solutions were prepared according to Hoagland (24). His No. 2 solution was used to prevent changes to alkaline conditions. The pots were given one quart of solution every second day. When growth and day temperatures increased, two quarts per pot per day were used.

The experiment was terminated and trees harvested on June 21, 22, and 23, 1955, after recording linear growth and trunk diameters. Dry weights of leaves, roots, shoots and trunks were obtained

Figure 1. Nutrient element metal and alloy powders used for injections.

Upper row: No. 5 gelatin capsules containing powdered mixtures.

Lower row: Nail form of metal and alloy powders, series of four nails, lower left, are impregnated with citric acid.

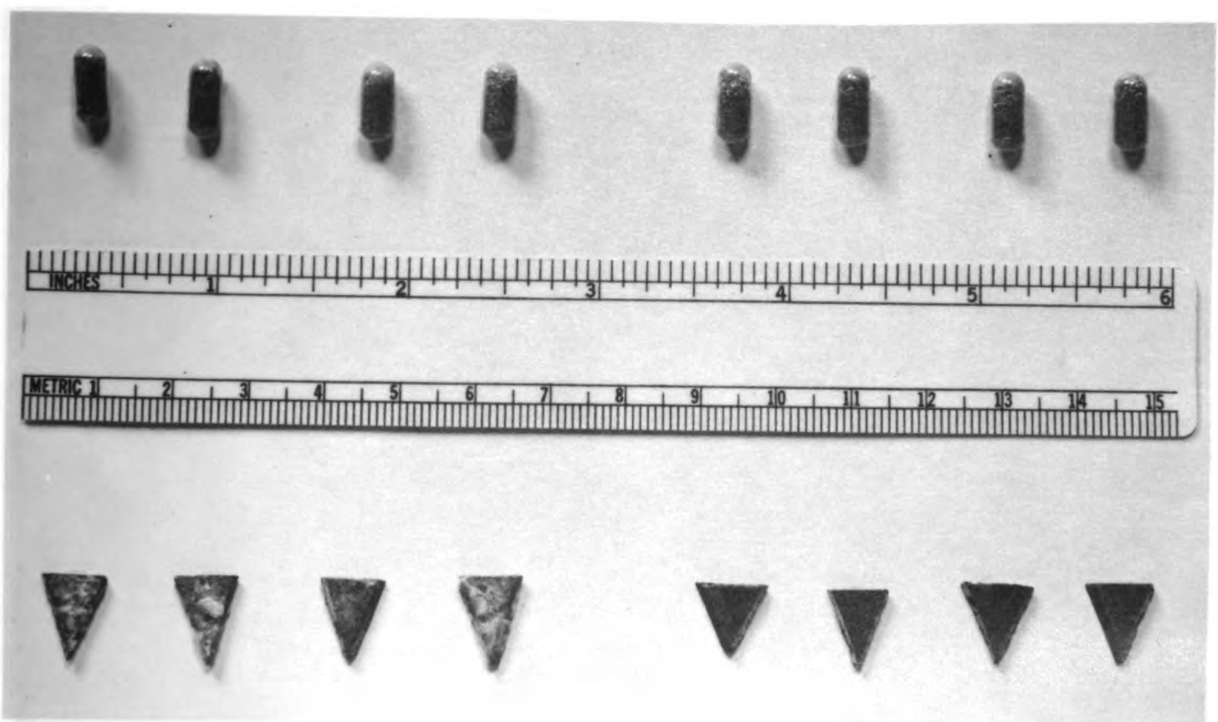
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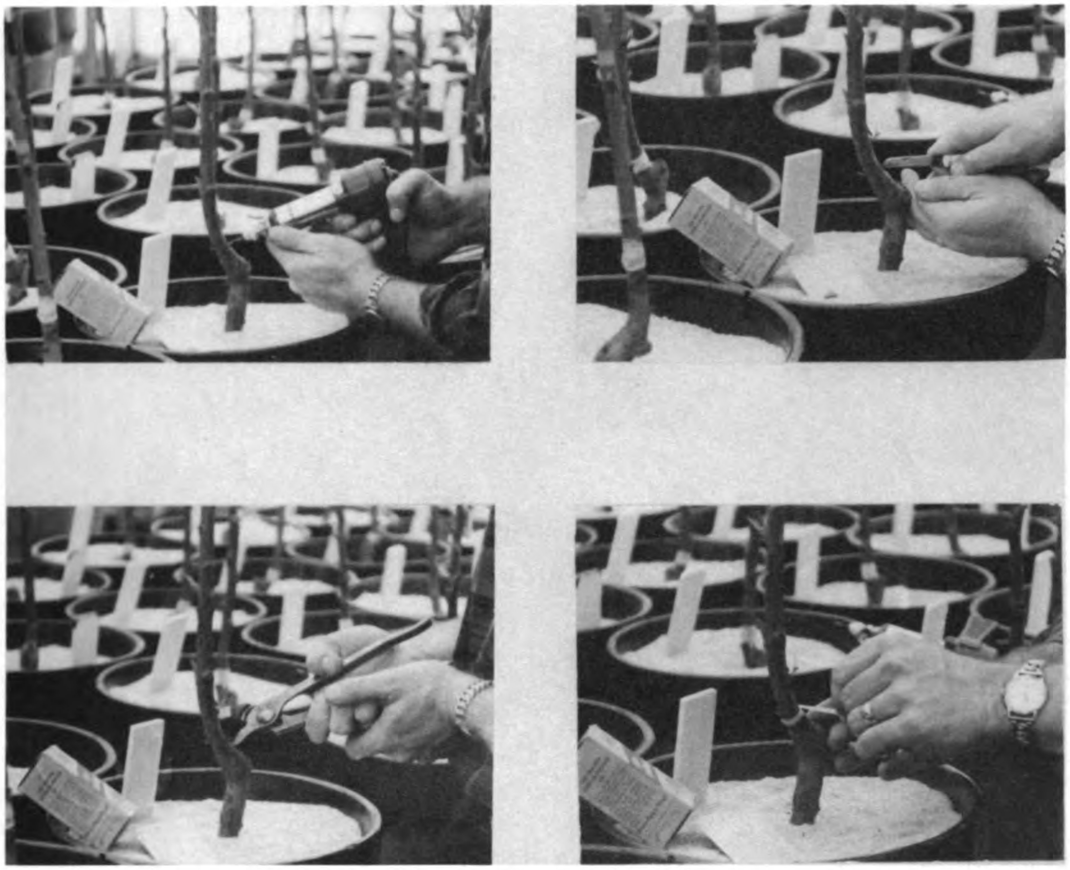
Figure 2. Methods used in injecting and sealing metal and alloy powders.

Upper left: drilling holes for injection of capsules.

Upper right: making incision with knife to insert powder mixture in nail form.

Lower left: pressing the nail into the trunk with slip-joint pliers, plier jaws covered with rubber.

Lower right: sealing injection openings with latex sealing gauze.



and the sums taken as total dry weights. Increase in growth was obtained by subtracting total dry weight after harvest from the calculated fresh weight before planting. Leaves and fibrous roots (separated from old roots) were prepared for spectrographic analyses and the analyses conducted in the laboratories of Agricultural Chemistry Department. Iron, manganese, zinc, copper, and boron were determined.

RESULTS

Growth in relation to the injection of metal and alloy powder mixtures is presented in Tables 2, 3, and 4. Tables 5, 6, and 7 present leaf composition resulting from the use of these materials. Fibrous root analysis as influenced by metal and alloy powder injections is shown in Tables 8, 9, and 10.

Growth

Apple: Increase in total growth was found to be somewhat higher for trees injected with 1.0 gram of powder than for trees injected with 0.5 gram (Table 2). All measurements of growth were higher for trees receiving minor elements as injected powders than was obtained for the trees that did not receive any minor elements. Neither omitting minor elements nor supplying minor elements as injected powders resulted in growth significantly different from that obtained when the trees were given a complete nutrient solution.

Visual growth differences, however, were observed at the time the trees were growing in the greenhouse. All treated plants showed good color and vigorous growth, whereas trees not receiving minor elements developed a symptom characteristic of nutrient deficiency in terminal shoot leaves.

Table 2. Growth of Delicious Apple Trees Injected with 0.5 and 1.0 Grams of Metal and Alloy Powders (Grams Dry Weight).

	Amount Injected	Treatments								L.S.D.*	
		1	2	3	4	5	6	Complete	Minus Minor Elements	5%	1%
Total growth	0.5	113.8	101.1	105.3	115.5	104.7	117.7	117.8	91.0	N.S.**	--
	1.0	123.1	108.7	111.0	129.6	115.6	118.6				
Leaves	0.5	30.3	27.4	27.6	31.3	28.7	27.3	31.7	24.6	N.S.	--
	1.0	30.0	23.8	30.1	32.8	29.9	27.8				
Shoots	0.5	25.5	21.3	20.3	34.8	23.6	23.3	27.8	19.4	N.S.	--
	1.0	24.4	19.4	22.3	26.9	23.8	25.0				
Fibrous roots	0.5	42.6	34.1	34.9	38.2	33.8	41.3	33.8	34.8	N.S.	--
	1.0	44.9	40.8	43.7	46.1	37.6	38.1				

*Least significant differences
**Differences not significant

<u>Cherry:</u> With the exception of fibrous root growth, statistical analysis showed that there were no significant differences in the growth of cherry trees injected with metal and alloy powders. As shown in Table 3, highest total growth resulted where metal and alloy powders were impregnated with citric acid. Fibrous root growth resulting from use of treatments 3, 5, and 6 was significantly greater than that made by trees that received no minor elements. During the period the plants were growing, check treatments from which minor elements were withheld developed a severe condition of chlorosis, defoliation and shoot die-back (Figure 3), while all other treatments maintained vigorous growth throughout the experiment.

<u>Peach:</u> Although the different measurements of growth showed no significant differences, trees that received injections of metal and alloy powders appeared equal to, or of better growth than those trees receiving no minor elements (Table 4). Peach trees given nutrient solutions not containing minor elements did not develop any foliar symptoms suggestive of nutrient deficiencies.

Table 3. Growth of Montmorency Cherry Trees Injected with 0.5 Grams of Metal and Alloy Powders (Grams Dry Weight).

	Treatments								L. S. D.*	
	1	2	3	4	5	6	Complete	Minus Minor Elements	5%	1%
Total growth	86.0	108.7	113.0	85.4	95.4	123.8	110.8	90.4	N. S.**	--
Leaves	23.6	31.6	30.8	24.0	23.9	29.7	31.4	31.4	N. S.	--
Shoots	15 2	20.5	23.1	15 5	12.9	19.6	22.1	19.2	N. S.	--
Fibrous roots	25.0	25.5	31.4	25.2	37.2	37.3	38.6	23.0	6.2	8.4

*Least significant differences

**Differences not significant

Figure 3. Symptoms of nutrient deficiency on Montmorency cherry trees.

Top: tree on left showing chlorosis, defoliation and shoot die-back, as it occurred when the minor elements were omitted from nutrient solutions. Tree on right, showing normal growth and color, received injections of metal and alloy powders.

Center: close-up of shoot die-back as it appeared on left tree, above.

Bottom: chlorotic leaves (right of scale) as they developed on trees where the minor elements were omitted in nutrient solution treatments. Normal leaf on left is from trees receiving injections of metal and alloy powders.

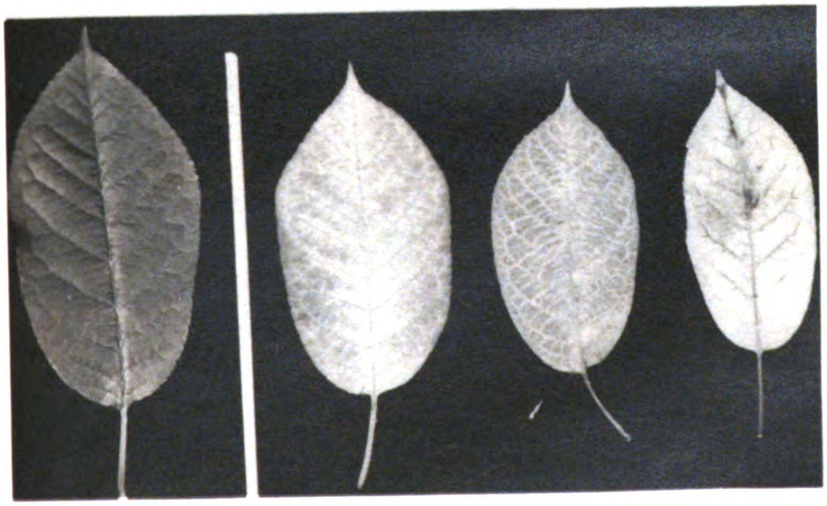


Table 4. Growth of Elberta Peach Trees Injected with 0.5 Grams of Metal and Alloy Powders (Grams Dry Weight).

	Treatments								L. S. D.*	
	1	2	3	4	5	6	Complete	Minus Minor Elements	5%	1%
Total growth	104 9	100.6	86.4	94.1	105.9	108.2	119.7	89.2	N. S.**	--
Leaves	45.7	47.9	40.4	44.8	39.5	45.1	53.9	41.2	N. S.	--
Shoots	19.5	21.4	15.8	18.2	16.4	17.5	26.5	16.3	N. S.	--
Fibrous roots	36.3	34.5	37.1	38.8	41.5	34.2	49.5	35.0	N. S.	--

*Least significant differences

**Differences not significant

Leaf Composition

Apple: Table 5 shows leaf composition of the leaves of trees from the various treatments. A significant reduction in leaf manganese and boron occurred when minor elements were omitted from the nutrient solution. All metal and alloy powders significantly increased leaf manganese above that obtained when solutions without minor elements were used. Injections of larger amounts of powder did not always increase the amount of manganese found in leaves. Impregnation of the powder with citric acid significantly increased leaf manganese. Boron content of leaves was significantly decreased when boron was omitted from the nutrient solution. An increase in leaf boron occurred when the trees were injected with metal and alloy powders. This increase was significant except for 0.5 gram injections of mixtures 1, 2, and 5. Injections of larger quantities of the powders with citric acid increased boron absorption. This increase was significant when 0.5 grams were injected, but not significant when 1.0 gram was injected.

There were no significant differences between the various treatments in regard to leaf composition for iron, copper and zinc.

Table 5. Composition of Apple Leaves in Relation to Injection of Metal and Alloy Powders (Per Cent Dry Weight).

Nutrient	Amount Injected	Treatments 1	2	3	4	5	6	Complete	Minus Minor Elements	L. S. D.* 5%	1%
Manganese	0.5	.0099	.0094	.0074	.0098	.0113	.0163	.0097	.0066	0023	0032
	1.0	.0084	.0093	.0083	.0077	.0164	.0314				
Iron	0.5	.033	.030	.020	.030	.030	.036	.026	033	N. S.**	--
	1.0	.029	.026	.026	.030	.032	.029				
Copper	0.5	.0022	.0019	.0016	.0018	.0017	.0020	.0017	.0021	N. S.	--
	1.0	.0012	.0014	.0020	.0012	.0014	.0015				
Boron	0.5	.0047	.0047	.0063	.0050	.0048	.0059	.0084	.0042	.0007	.0009
	1.0	.0064	.0081	.0086	.0060	.0054	.0062				
Zinc	0.5	.0026	.0033	.0030	.0034	.0025	.0038	.0027	.0024	N S.	--
	1.0	.0020	0019	.0019	.0018	.0018	.0017				

*Least significant differences

**Differences not significant

Cherry: Analyses of leaves from cherry trees are shown in Table 6. There was a significant difference in leaf manganese and leaf boron. This significance was as a result of lower leaf manganese and boron for treatments not receiving minor elements and/or receiving injections of metal and alloy powders not impregnated with citric acid. Injections of metal and alloy powders did not increase significantly leaf manganese above that found when minor elements were omitted, except when the powder was impregnated with citric acid. Boron content of leaves from trees injected with metal and alloy powders was not significantly different from that found in leaves from trees not receiving minor elements. There was no significant differences in the analyses for iron, copper and zinc.

Peach: There were significant differences in the manganese and boron content of peach leaves, Table 7. Both manganese and boron were significantly lower when minor elements were omitted from the nutrient solution. Injections of metal and alloy powders did not significantly increase leaf manganese, except when the powder was impregnated with citric acid. All injections of metal or alloy powders significantly increased leaf boron above that found when minor elements were omitted from the nutrient solution. Impregnating the powder with citric acid did not increase boron absorption. No significant differences were found for iron, copper and zinc analyses.

Table 6 Composition of Cherry Leaves (Per Cent in Dry Matter) in Relation to Injections of 0. 5 Grams of Metal and Alloy Powders.

Nutrient	Treatments								L. S. D.*	
	1	2	3	4	5	6	Complete	Minus Minor Elements	5%	1%
Manganese	.0038	.0029	.0027	.0036	.0027	.0110	.0058	0031	.0011	.0015
Iron	.021	.025	.018	.026	.019	.022	.024	.026	N. S.**	--
Copper	.0017	.0011	.0016	.0014	.0014	.0043	.0022	.0018	N. S.	--
Boron	.0043	.0041	.0040	.0037	.0037	.0035	.0054	.0040	.0006	.0008
Zinc	.0068	.0071	.0048	.0041	.0041	.0038	.0037	.0040	N. S.	--

*Least significant differences

**Differences not significant

Table 7. Composition of Peach Leaves (Per Cent in Dry Matter) in Relation to Injections of 0. 5 Grams Metal and Alloy Powders.

Nutrients	Treatments								L. S. D.*	
	1	2	3	4	5	6	Complete	Minus Minor Elements	5%	1%
Manganese	.0050	.0058	.0050	.0044	.0066	.0125	.0104	.0053	.0024	.0034
Iron	.029	.025	.022	.023	.027	.027	.027	.025	N. S.**	--
Copper	.0013	.0014	.0019	.0012	.0020	.0015	.0012	.0012	N. S	--
Boron	.0037	.0035	.0040	.0037	.0036	.0035	.0044	.0031	.0004	.0005
Zinc	.0027	.0033	.0032	.0033	.0031	.0035	.0042	.0027	N. S.	--

*Least significant differences

**Differences not significant

Root Composition

Apple: Analyses of fibrous roots of apple trees in relation to the various treatments are recorded in Table 8. Significant differences were found for copper, while all other elements showed no significant differences. Copper analysis showed an accumulation of copper in the fibrous roots when minor elements were omitted from the nutrient solution. The copper content of fibrous roots from trees injected with metal and alloy powder was significantly lower than that for trees not receiving minor elements.

Cherry: Table 9 records the data concerning the composition of fibrous roots in relation to injection of metal and alloy powders in cherry trees. Manganese was the only nutrient that varied significantly between treatments. Omitting minor elements from the nutrient solution and injection of metal and alloy powders resulted in a significantly lower mangnese content of fibrous roots than was found for the complete nutrient solution. Injection of powders used in treatments 1, 2, and 6 resulted in a manganese content of fibrous roots below that obtained when minor elements were omitted from the nutrient solution.

Table 8. Composition of Apple Roots in Relation to Injection of Metal and Alloy Powders (Per Cent Dry Weight).

Nutrient	Amount Injected	Treatments								L. S. D.*	
		1	2	3	4	5	6	Complete	Minus Minor Elements	5%	1%
Manganese	0.5	.0034	.0036	.0041	.0033	.0032	.0047	.0120	.0036	N S.**	--
	1.0	.0041	.0045	.0042	.0051	.0106	.0039				
Iron	0.5	.094	.091	.092	.079	.107	.158	.219	.138	N. S.	--
	1.0	070	.123	.191	.149	.201	.098				
Copper	0.5	.0030	.0047	.0047	.0043	.0036	.0043	.0042	.0063	0016	.0022
	1.0	.0040	0062	.0062	.0054	.0062	.0043				
Boron	0.5	.0034	.0051	.0044	.0044	.0038	.0045	.0054	.0048	N. S.	--
	1.0	.0041	.0046	.0050	.0037	.0042	.0044				
Zinc	0.5	.0014	.0011	.0015	.0008	.0017	.0014	.0010	.0008	N. S.	--
	1.0	.0011	0009	.0012	.0012	.0055	.0010				

*Least significant differences

**Differences not significant

Table 9. Composition of Cherry Roots in Relation to Injection of Metal and Alloy Powder (Per Cent Dry Weight)

Nutrients	Treatments								L. S. D.*	
	1	2	3	4	5	6	Complete	Minus Minor Elements	5%	1%
Manganese	.0028	.0034	.0053	.0054	.0055	.0040	.0146	.0053	.0013	.0017
Iron	.043	.045	.072	.071	.046	.085	.058	.051	N. S.**	--
Copper	.0021	.0056	.0025	.0042	.0021	.0089	.0045	.0021	N. S.	--
Boron	.0039	.0035	.0036	.0039	.0035	.0037	.0048	.0048	N. S.	--
Zinc	.0020	.0023	.0023	.0021	.0028	.0020	.0026	.0037	N. S.	--

*Least significant differences

**Differences not significant

Peach: The manganese and iron composition of fibrous peach roots was significantly influenced by the treatments, Table 10. Injections of metal and alloy powders did not significantly increase manganese content of fibrous roots and in all cases was much less than the manganese content of roots receiving the complete nutrient solution. The iron content of fibrous roots was significantly reduced when iron was omitted from the nutrient solution. The only significant increase in iron content of fibrous roots occurred when the powders were impregnated with citric acid. Analyses for copper, boron, and zinc showed no significant differences.

Table 10 Composition of Peach Roots in Relation to Injection of Metal and Alloy Powders (Per Cent Dry Weight.

Nutrients	Treatments								L. S. D. *	
	1	2	3	4	5	6	Complete	Minus Minor Elements	5%	1%
Manganese	.0040	.0052	.0049	.0043	.0046	.0053	.0220	.0050	.0043	.0060
Iron	.064	.072	.066	.065	.046	.104	.138	.046	.037	.045
Copper	.0043	.0038	.0023	.0028	.0027	.0037	.0029	.0034	N. S. **	--
Boron	.0042	.0045	.0042	.0041	0046	.0042	.0053	.0041	N. S.	--
Zinc	0014	.0008	.0017	.0012	.0027	.0015	.0031	.0013	N. S.	--

*Least significant differences

**Differences not significant

DISCUSSION

The results of this study indicate that fruit trees can absorb significant amounts of the minor elements from injected metal and alloy powders.

From the chemical analyses of leaves of apple, cherry and peach (Table 5, 6, and 7) it appears that minor elements were released from the injected materials impregnated with citric acid, and were absorbed in amounts significantly greater than when minor elements were added in nutrient solution, or omitted from nutrient solutions. Although not significant, total growth of cherry and peach (Tables 3 and 4) give similar responses where materials were impregnated with citric acid. This factor should not be overlooked because symptoms of severe chlorosis, defoliation and shoot die-back developed on trees which received no minor elements, whereas vigorous and healthy growth of cherry trees was sustained by all other treatments. This clearly indicates that some minor elements were being beneficially absorbed from all injected materials.

Comprehensive studies of other workers using leaf analyses as a means of determining chemical composition of leaves, reveals that leaf analyses values of this experiment do compare quite well with those percentages of elements reported by Goodall and Gregory (22) to be associated with normal growth.

Iron and manganese values attained by Proebsting and Kenworthy (36) were found to be the same as those reported in this experiment. Averages comparable to those established by Kenworthy (27) using spectrographic leaf analyses in determining percentages of iron, manganese, copper and boron, seem to be well borne out in this study of injected metal and alloy powders.

Employing different techniques with these metal and alloy powders may result in obtaining varying reactions in either plant growth or chemical responses.

Injury to internal wood tissues was sustained by the injections of metal and alloy powders (Figure 4). No signs of external injury resulting from injections were observed.

Figure 4 Internal wood injury of fruit trees as a result of metal and alloy powder injections.

Top: internal tissue injury characteristic to capsule injections.

Bottom: internal tissue injury characteristic to nail injections.

SUMMARY

Greenhouse experiments with minor elements (Fe, Mn, Zn, B, Cu) in metal and alloy powder forms were conducted on apple, cherry and peach trees. The metal and alloy powders were injected in the trunks of trees; major elements were supplied as nutrient solutions. Controls consisted of trees receiving a complete Hoagland solution, and the same solution minus minor elements. Plants were grown in 12-inch clay pots painted with asphaltum and in a medium consisting of sterile No. 7 size white quartz gravel.

Linear growth and trunk diameters were recorded at the time of harvesting. Total dry weight increase was calculated for leaves, roots, shoots and trunk. Iron, manganese, zinc, copper and boron composition of leaves and fibrous roots were determined by spectrographic analysis.

Apple growth results were higher where 1.0 gram of the powder was used than where 0.5 grams were injected. A visible nutrient deficiency symptom appeared in the later growing period in the trees receiving no minor elements. However, differences in growth as measured by dry weights, were not statistically significant.

The greatest total growth of cherry trees was obtained with injection of powders impregnated with citric acid. Severe chlorosis, defoliation and shoot die-back occurred only in treatments where the minor elements were entirely omitted. This condition was not identified with chemical analysis. No deficiency symptoms were visually apparent in peach treatments, and the data show no significant growth differences between treatments.

Analyses of apple leaves showed that metal and alloy powders impregnated with citric acid significantly increased leaf manganese content over all other treatments. A similar response to citric acid was obtained for boron, but the highest response was registered where 0.5 grams were injected.

Analyses of cherry leaves showed manganese to be the only nutrient increased by citric acid impregnation of metal and alloy powders. Analyses of peach leaves showed a similar manganese increase with the citric acid impregnated materials.

Copper analyses of apple fibrous roots showed an unexplainable accumulation of copper occurred in that treatment where minor elements were omitted from nutrient solutions. This accumulation was greater than that occurring in treatments receiving injected metal and alloy powders.

The absorption of manganese by cherry roots was found to be more significant in the complete nutrient solution than in the injected treatments, or those where minor elements were omitted. Definite increase in iron occurred in fibrous roots of peach when metal and alloy powders were impregnated with citric acid.

Internal wood injury occurred where metal and alloy powders were injected into the fruit trees.

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APPENDIX

A. Calculation of Increase in Growth

Since it was impossible to obtain dry weights of the trees at planting time, representative trees of each kind were dried, weighed, and the dry weights calculated as per cent of fresh weight, as follows:

Calculation of Dry Weight Per Cent of Fresh Weight

Kind of Tree	Weight of Tree--Gm Fresh	Weight of Tree--Gm Dry	Per Cent Dry Weight
Apple	122.0	65.0	53.0
Cherry	431.3	218.7	50.7
Peach	275.0	139.8	50.9

Dry weights of the trees at time of planting were then calculated in each case as the indicated per cent of the fresh weight. This calculated weight for each tree was subtracted from the total dry weight of the tree after harvest to obtain total growth in grams dry weight.

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