AN ABSTRACT OF THE THESIS OF

Scott Hill Robbins for the degree of Master of Science

in Horticulture presented on December 14, 1981

Title: Pressure Trunk Injections of Potassium as a Possible Short Term Corrective Measure for Potassium Deficiency in Sweet Cherry (Prunus avium L.) and Prune (Prunus domestica L.)

Abstract Approved: _____

M. H. Chaplin

The effect of pressure trunk injections of K_2HPO_4 and K_2SO_4 solutions on the mineral content, growth, yield and fruit quality of sweet cherry and mineral content of prune were investigated. A complimentary study presented in Appendix 1, was conducted to evaluate the short term effectiveness of K soil amendments, mulching and foliar K sprays for correcting K deficiency in sweet cherry and prune trees.

Potassium solutions were injected into sweet cherry trees at an average rate of 0.4 liter/min and into prune trees at an average rate of 0.06-0.08 liter/min using a pressure of 3.5-3.9 kg/cm^2.

Fall trunk injections of 200 g K in K_2SO_4 solution or up to 300 g K in K_2HPO_4 solution had no effect on sweet cherry midshoot leaf K the following August. Fall prune tree injections of up to 50 g K in K_2HPO_4 solution had no effect on midshoot leaf K the following August. One year, fall K_2HPO_4 (200 g K, 79.2 g P) injections of sweet cherry trees significantly increased the K content of spur tissues and the P content of buds in March and increased the P content of midshoot leaves in August.

Fruit set was significantly lower on sweet cherry trees injected

with 200 g K (K_2SO_4) and 300 g K (K_2HPO_4). Yield was significantly lower for all injection treatments but fruit quality was not affected.

Spring trunk injections of 12.5 g K in K_2SO_4 or K_2HPO_4 solution increased prune leaf K within four days and K levels remained higher than controls for at least 22 days with K_2SO_4. Leaf P was increased within four days by K_2HPO_4 injections and remained higher than controls in August.

Spring applications of 11.36 kg K_2SO_4 per tree by banding, placing in augered holes in the soil or injection into the soil had no effect on sweet cherry trees within two years but did significantly increase August midshoot leaf K in prune trees within one growing season. A heavy compost mulch applied in the fall increased August leaf K, N and fruit size on sweet cherry trees and August leaf K, N, Ca, Mn, Fe, Cu and B on prune trees within one growing season. Prune tree shoot growth and yield were increased by compost mulch applications the second growing season.

Trenches with backfill amendments of K_2SO_4, dolomite lime or a combination of the two had no effect on leaf K of sweet cherry trees within two growing seasons. Fruit size was reduced by all trenching treatments except trenching with K_2SO_4. Trenching with K_2SO_4 and K_2SO_4 plus lime increased August midshoot leaf K on prune trees to 2.06 and 1.94% respectfully within one growing season and trenching with lime only increased August leaf K the second season to 1.37%.

One percent K solutions of KNO_3 and K_2SO_4 sprayed on trees four times during the growing season did not affect leaf K levels of sweet cherry trees but did significantly increase August leaf K levels of prune trees.

Pressure Trunk Injections of Potassium as a Possible Short Term Corrective Measure For Potassium Deficiency in Sweet Cherry (*Prunus avium* L.) and Prune (*Prunus domestica* L.)

by

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A THESIS

submitted to

Oregon State University

in partial fulfillment of
the requirements for the
degree of
Master of Science

completed December 14, 1981

Commencement June 1982

APPROVED:

Professor of Horticulture in charge of major

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Date thesis is presented December 14, 1981

Typed by Karla Sorensen for Scott H. Robbins

Acknowledgements

I would like to sincerely thank the following:

Dr. M. H. Chaplin, Horticulture Department, Oregon State University, Corvallis, Oregon for confidence, guidance and critical review in this endeavor.

Dr. M. N. Westwood, Horticulture Department, Oregon State University, Corvallis, Oregon for serving on my graduate committee and always having an open office door.

Dr. T. L. Jackson, Soils Department, Oregon State University, Corvallis, Oregon for serving on my graduate committee.

Oregon Processed Prune and Plum Growers Commission for support and interest.

Mr. Don Meyer, Salem, Oregon for providing trees and equipment to work with and being a friend and excellent cooperator.

Mr. A. R. Dixon, Plant Analysis Laboratory, Oregon State University, Corvallis, Oregon for assistance and cooperation.

Mr. Don Henshaw, Forest Science Laboratory, Corvallis, Oregon for computer and statistical consultation.

I dedicate this thesis to my loving wife Patricia Ann Robbins for her patience and understanding.

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INTRODUCTION

Potassium deficiency is a serious problem in many fruit orchards in western Oregon. The losses incurred as a result of this problem range from inferior fruit quality as determined by fruit size, color and maturity, to reduced fruit yields, lack of tree vigor, tissue dieback and tree death. Problem orchards are typically non-irrigated and located in moderately acid clay loam or slity clay loam soil types on hillsides. Tree response to potassium fertilizers under these conditions is often very slow, sometimes taking several years. It would be desirable and of great benefit to the orchard industry to demonstrate postivie tree response to applied potassium in one growing season or less and then maintain a normal potassium nutritional status.

Pressure trunk injections have been successful in correcting Fe and Zn deficiencies in fruit trees. These treatments induced rapid complete recovery from deficiency symptoms and remained effective for one to four years.

The objectives of this study were the following:

1. To provide a thorough review of literature pertaining to all aspects of plant injection.
2. To evaluate the effectiveness of K trunk injections for correcting K deficiency in stone fruit trees.
3. To evaluate the short term effectiveness of K soil amendments, mulching and foliar K sprays for corrective K deficiency in stone fruit trees.

REVIEW OF LITERATURE

Plant Injection - History Techniques and Applications In Tree Mineral Nutrition

INTRODUCTION

Plant Injection is a process by which a substance is introduced into a plant by means of contacting severed plant tissue with the substance to be injected. This process can be achieved through active or passive methods. Active injection requires that an injection liquid be under pressure greater than atmospheric pressure. Passively injected liquids, under atmospheric pressure, are drawn into the plant system by xylem tension created by transpiration and/or cell diffusion and uptake. Solids can be passively injected but require dissolution by internal plant water before any distribution can occur.

Various plant injection techniques and their wide-ranging applications have been explored by several individuals throughout the world, particularly since the beginning of the twentieth century. The first two sections of this review will discuss these applications and techniques. An historical perspective will be presented which will provide a source of literature in plant injections for purposes other than mineral nutrition. The third section will focus on plant injection applications in tree mineral nutrition with special reference to treatment of mineral deficiencies in the field.

PLANT INJECTION HISTORY

Pre-Twentieth Century

Several twentieth century plant injection experimenters have reviewed the work of their predecessors before the turn of the century. Four reviews of this early work were presented by Rankin (56) in 1917, Rumbold (75) in 1920, Craighead and St. George (9) in 1938 and Roach (66) in 1939.

The earliest plant injections recorded according to Roach (66) were done by Ibn-Al-Awan in the twelfth century before 1158. Solid injection methods for spices such as musk, cloves and saffron were described and said to impart perfumes, flavors and medicinal qualities to fruits as well as colors to roses. Roach (66) also cites work by Leonardo de Vinci in the fifteenth century. This is the first recorded liquid injection of plants. Arsenic solutions were inserted in holes bored in trees resulting in poisoned fruit. An anonymous author in 1602 reported tree injections of various herbs and spices mixed in "fine" wine to flavor or color fruit and kill worms (Roach, 66).

Plant injection in the 1700's was used by various individuals to elucidate the nature of sap movement in trees and attempts were made to preserve wood. Magnol in 1709 cut stems and immersed the cut ends in dye solutions (Roach, 66; Rumbold, 75). This enabled him to trace the transpirational stream up through the stems and into the leaves and flowers. Further work on plant water movement was done by De la Baisse in 1733, Bonnet in 1754 and Buffon in 1755 (Craighead and St. George, 9). This same review reports that Hales in 1730 recommended putting wood tar in holes bored in trees for preservation. Roach (66)

reported that Wilson in 1765 wrote of mercury being injected into trees to kill insects. This was accomplished without apparent injury to the tree.

Injection work done in the early 1800's was mainly for purposes of killing insects, preserving wood and studying distribution of injected substances. Craighead and St. George (9) reported that Saussure in 1804 injected toxic solutions into trees and that Cotta in 1806 injected salt solutions. Meyer in 1808 injected dye by girdling and cutting as much of the trunk as possible to study distribution (Rankin, 56; Roach, 66). By 1840, Boucherie had a practical injection technique worked out for wood preservation that also showed distribution aspects of injected substances (Craighead and St. George, 9; Rankin, 56; Rumbold, 75). Roach (66) reported that Hartig in 1853 was the first to lead liquid from a reservior to an injection hole.

Several investigators were working with plant injection by the late 1800's. McNab in 1871 was the first to inject Li into trees (Rumbold, 75). Sachs in 1878 used $LiNO_3$ to study the ascent of sap (Rankin, 56). Later (1880-1886) he injected $FeSO_4$ and $FeCl_3$ to treat chlorosis (Roach, 66). Rumbold (75) reported other works published on injections in the 1880's and 1890's by Pfitzer in 1886, Pfeffer in 1886, Gaunersderfer in 1887, Wieler in 1888, Strosburger in 1891 and Shezyrez in 1894. These works helped establish that foreign substances could be safely conducted through plants and that large numbers of substances were poisonous.

Other injection studies published before 1900 include Roth in 1896, Goff in 1897 and Mangin in 1898 (Rankin, 56). These studies looked at nutrient and poison injections to cure physiological ailments

and inhibit pathogens and insects. In 1898 Nicolaeu-Tzygankov successfully treated chlorotic trees by solid injection of powdered $FeSO_4$ (Roach, 66).

Twentieth Century

From the early 1900's on, several researchers in many different countries studied a wide range of plant injection techniques and applications. Roach (66) discussed much of the work done in the early 1900's in Russia, France, Italy, Germany, England and America. Brief highlights of these varied applications will be discussed separately.

Pathology -- Studies on injections for purposes of wood preservation tapered off after 1900. Criaghead and St. George (9) in 1938 found $ZnCl_2$ to be good for wood preservation as well as insect control. A study reported in 1976 by Worley, et al. (95), showed that injected "osmose", a wood preservative, killed trees within ten days. The preservative effects of this technique are unknown.

The most work done in pathology with plant injections has been with fungicides. Rumbold (75, 76) carried out extensive experiments from 1912-1920 on injection of chemicals into American chestnut trees to study the effects on the chestnut blight fungus Endothia parasitica. She tried 26 inorganic compounds and 25 organic compounds. The effects of the various compounds on the fungus were inconclusive, however several observations showed various injection efficiency factors, chemical distribution and chemical effects on plant tissue. Roach (61) had variable results injecting $Na_2S_2O_3$ into apple trees to control mildew in 1931-1932. Some of his injections temporarily surpressed mildew infection, while other times they had no effect. In 1941,

Howard (28) reported that tree symptoms associated with infection by bleeding canker fungus, Phytophthora cactorum, were stopped after injection with a proven in vitro antidote to the toxin produced by the fungus, but did not suggest that it was a cure. Other work done before 1949 was reviewed by Stoddard and Dimond (87). They report successful treatments on other fungi species such as Verticillium sp. and Fusarium sp. that cause wilt diseases.

The access to systemic fungicidal compounds in recent years led to several successful injection treatments, particularly in the last decade. Helton and Rohrbach (24) studied translocation of 12 compounds in prune trees. They were seeking to control Cytospora sp. which penetrated deeply into stem tissues. Eight-quinolinol benzoate was the outstanding compound in their study. Injection of fungicides for control of Dutch elm disease caused by Ceratocystis uluri (Buism), Moreau, have been studied. Several authors have had success controlling this disease, especially when the treatment was preventative, by using the fungicide benomyl or a derivative of benomyl. The following workers have published on this subject since 1971: Gregory et. al. (19, 20), Prasad (54, 55), Van Alfen (92), Gibbs and Dickinson (16), Wilson, et. al. (94) and Campena (6).

Jones et. al. (31) in 1973 were able to partially control oak wilt disease and Jaynes and Van Alfen (29) demonstrated some control of chestnut blight with injections of solubilized benomyl. Preventative treatments were more effective than curative treatments. Pinkas, et. al. (52) studied the translocation of thiabendozole in apple trees with pressure trunk injections. Gregory, et. al. (19) reported initial trials of benomyl injections into elm, oak and maple trees and observed

injection efficiency factors, chemical distribution and chemical activity factors.

Early plant injections for studying or controlling diseases caused by bacteria and viruses were discussed in a comprehensive review by Stoddard and Dimond (87) in 1949. They found that up until that time many different materials had been successfully employed to control these diseases. Materials such as penicillin, streptomycin, $HgCl_2$, $ZnCl_2$, $CuSO_4$, $AgNO_3$ and 8-quinolinol sulfate, had been tried on X-disease of peach and bacterial diseases caused by Phytomonas sp., Corynebacterium sp., Xanthomonas sp. and Erwinia sp.

With the discovery of mycoplasmas in 1967 (Rogers, 73), the decade of the 1970's was a time when many investigators studied plant injection as a method to control mycoplasma caused diseases such as lethal yellowing of palm (McCoy, 44, 45, 46); young tree decline, sand hill decline and fruit greening of citrus (Leonard, 35; Schwarz, 81); decline in pear (Nyland, 51; Reil, 57) and X-disease in peach (Sands, 79). They injected antibiotics such as tetracycline-HCl, oxytetracycline-HCl (terramycin), streptomycin and penicillin. Techniques for antibiotic injection were discussed by these authors as well as others (Filer, 14; Rogers, 73 and Sachs, 78).

Entomology -- Potassium cyanide (KCN) was tried as an injection compound to control sap-sucking and wood-boring insects early in the twentieth century. Many of KCN's effects and distribution factors were studied by Elliott (12) in 1917. In 1938, Craighead and St. George (9) found $ZnCl_2$ and Beddard (1) found $CuSO_4$ to be effective in controlling insects when injected into trees. Morris (48) in 1951 attempted to control wood boring insects in birch trees by injection of nictotine sul-

fate, nicotine alkaloid, Na_2SeO_4 and KCN. Eighty-three formulations of 54 chemicals were pressure injected into orange trees infected with burrowing nematodes by Tarjan (88) from 1956-1958.

Systemic insecticides work well for injection into plants. In 1970, Merkel (47) reported 80-97% control of cone worms and seed worms in slash pine using four commercial systemic insecticides, dimethoate (Cygon®), oxydemetonmethyl (Meta-Systox-R®), dicrotophos (Bidrin®) and O, S-dimethyl phosphoramidithioate (Monitor®).

Kroll and Simmons (33) described a method in 1976 for labeling defoliating insects with phosphorus-32. They used tree root injection to label spruce budworm larvae feeding on balsam fir foliage and invertebrate predators of the budworms thereby tracing energy movement.

Physiology -- Injections have proven to be valuable in plant physiology studies both from a standpoint of plant science and plant management. Recent research has shown effective injection methods of herbicides to kill trees. Ferguson and Lawson (13) tried 2,4-D and picloram + 2,4-D for thinning pole-size hardwoods. One ml injected every 7.6 cm around the trunk killed most species when applied in the fall. Worley et. al. (95) found "osmose" (45.3% AS_2O_5, 19.3% CuO, 35.35% CrO_3), a wood preservative, to kill trees in ten days. Lagerstedt (34) found summer and late fall injections of undiluted 2,4-D, Tordon-212 and glyphosate were effective in preventing recurring root sprouts from cut off fruit and nut trees. Trees can be killed with an overdose of most chemicals, including the inorganic salts as well as countless organic compounds.

Injections have been used in studies on organic nutrition of plants. Gordon and Lipman (17) suggested in 1926 the injection of

starch into fruit trees to alter the C:N ratio in order to induce greater floral initiation. In 1940 Gayner (15) reported no fruit-set response in pear to glucose injections. Glucose injections were proposed in a review by Heffernan (27). It was suggested that the breaking of dormancy was hastened and that it could be used as a management tool to ensure correct timing of bloom for maximum pollination in Caprifig.

Injection of plant growth regulators allows control of the amount and placement of material as well as the timing of the treatment. Robitaille and Carlson (72) injected Gibberellic acid (GA) and Abscisic acid (ABA) into stems of dwarf apple trees and studied response to these injections. DeLange (10) in 1974 described an injection technique for growth regulators into tree trunks and studied the effects of injected GA_3 and 2,4-D on fruit set in citrus. He found injection to be more effective than foliar sprays. Brown, et. al. (5) pressure injected topped American elm trees with Maleic hydrazide (MH) and diaminozide (SADH) in June and found that subsequent sprout growth for two years was equivalent to one year's growth on untreated trees. Heffernan (27) suggested unspecified growth regulator injections for such management techniques as inducing abscission to aid harvest of tree crops and inducing efficient floral drop for easy cleanup in ornamental plantings.

Other uses of plant injections have been proposed and/or described for studying various aspects of plant physiology. In 1926, Gordon and Lipman (17) suggested without testing that trunk injection of electrolytes and non-electrolytes might be used to protect citrus trees against freezing. Graham (18) and Kroll and Simmons (33) described

techniques for introducing radioactive isotopes into trees. With labeled elements or compound introduced into the plant system, a wide range of physiological studies could follow.

PLANT INJECTION TECHNIQUES

Types

Passive, Solid Injection -- Injection of solids usually is accomplished by boring one or more holes (0.6-1.3 cm dia.) into a plant and inserting a water soluble substance. It is mainly a technique for tree trunks and large branches (Roach, 66). Wallace (93) recommended that these holes be slanted downward so that the powdered substance could easily be placed at the bottom. The holes should be drilled deep enough to reach functional xylem tissue, usually from 1.59-7.62 cm depending on the size of the stem (Duggan, 11). Injection holes should be cleanly drilled with a sharp wood bit, (Roach and Roberts, 69) and plugged flush to the cambium with wax (Chandler et. al., 7), cork (Duggan, 11; Roach, 68), wooden dowel (Neely, 49, 50) or a suitable tree wound dressing (Brown and Hildreth, 2).

The importance of not contacting the cambium with the injected substance is brought out by Roach and Roberts (69), who described a technique for inserting solid chemical tablets and a cork seal in one operation. Other workers have used gelatin capsules in drilled holes (Brown and Hildreth, 2; Neely, 49, 50). It was suggested that the capsule be punctured after insertion because of slow dissolution.

To inject an entire stem with this method, holes must be placed every 7.62-10.16 cm around the circumference (Chandler, et. al., 7; Roach and Roberts, 69; Brown and Hildreth, 2) or one hole for every 2.54 cm of stem diameter (Duggan, 11). These holes should be drilled in a spiral around the stem rather than a ring in order to prevent stem weakening (Brown and Hildreth, 2; Wallace, 93). This removes ten times as much wood as a comparable liquid injection (Roach and

Roberts, 69).

Another form of solid injection is accomplished by pounding a metal piece into a tree stem every 2.54 cm in a spiral around the circumference (Chandler et. al., 7; May, 43).

Passive, Liquid Injection -- The basic components of a passive liquid injection system consist of a liquid reservoir and some means of supplying the liquid to severed plant conductive tissue without leaking. The reservoir can be made from anything that can hold a liquid and be held in the proper place with the top open to the atmosphere. Placement can be at the injection site or some point above the injection site.

When the reservoir is placed at the site of injection it is usually done one of three ways: one) the hole itself is the reservoir (Schreiber, 80); two) an open sided reservoir is sealed around the injection site with wax or putty (Rankin, 56; Rumbold, 74, 77); or three) a severed plant part such as a leaf tip, leaf petiole, severed root or severed shoot is immersed in the reservoir of liquid (Roach, 66; Levy, 36). With the open sided reservoir method the injection hole can be made under the liquid thus excluding the air (Rumbold, 77) but this is not necessary (Collison, 8).

When the reservoir is placed above the injection site it must be connected by a suitable tube or hose. With this method a hole is usually drilled, punched, or cut into a tree stem and the reservoir tube has a fitting on the end that will seal into or onto the hole by a tight fitting made of glass, metal or plastic (Lipman and Gordon, 40; May, 43; McCoy, 46; Roach, 66; Rumbold, 74), a rubber gasket (Rumbold, 74) or a metal threaded fitting. The holes are essentially

the same as described for solid injections except some authors recommend drilling well into or through the heart wood (Collison, 8; Roach, 66). Another similar method is to severe a root or stem and connect the reservoir tubing onto the cut end (Collison, 8). Injection via a leaf vein incision is similar but with a different fitting arrangement (Roach, 66; Roach and Roberts, 69).

Based on these methods, different tree parts can be injected with solutions. In 1939, Roach (66) wrote a comprehensive review of these techniques that he had earlier described (Roach, 60, 61, 64). These techniques included interveinal leaf, leaf tip, leaf stalk (petiole), shoot tip, branch, branch-root and whole-tree (trunk) injections. He later improved the interveinal leaf and leaf petiole methods (Roach and Roberts, 69). His whole-tree injections were based on using large volumes of solution (1-10 1.) as are the whole-tree methods described by others (Collison, 8; Lipman and Gordon, 40; McCoy, 46; Schreiber, 80). Small volume passive injections are suitable for herbicide treatment and some are briefly described by Heffernan (27). Another small volume method is described by Graham (18) for injecting radioactive isotopes.

A whole-tree injection method for protecting lumber trees from bark beetle attack is described by Bedard (1). His saw-kerf, rubber collar method is done by making two parallel cuts three inches apart around the entire tree circumference just above the butt swell. The upper cut goes 0.64-1.27 cm into the wood for xylem exposure. The collar is put around this and the insecticide solution put into the collar. The entire new xylem tissue is exposed by this method. Because of the girdling this cannot be done for trees that are to remain

alive after treatment.

Active, Small Volume -- Many small volume pressure injectors have been developed for injecting trees with 60 ml or less of solutions containing plant growth regulators, pesticides or essential mineral elements. Typically these time efficient systems provide solution pressure from 0.7-7 kg/cm^2 and injection holes are relatively small (0.24-0.64 cm).

Brown (4), DeLange (10), Helburg, et. al. (23), Sterrett and Creager (86) and Wilson, et. al. (94) developed plant injectors after 1970 based on a medical syringe. In 1978 Brown (4) further described a system more suitable for commercial application. This apparatus used compressed air to develop 7 kg/cm^2 pressure in a 1.5 l solution tank and forced solution through stainless steel tube injectors. These 0.46 cm diameter injection tubes are hand forced with a twisting motion 1.27 cm into a drilled 0.56 cm diameter hole.

An attempted adaption of the multidose Jet Injectors used for human immunization is briefly described by Heffernan (27). The 105-350 kg/cm^2 pressure developed by this system had maintenance problems and "splash-back" of solution onto the operator. Mauget injectors consist of 8 ml plastic capsule reservoirs that are pressurized to 0.56-0.7 kg/cm^2 by hand squeezing the two capsule halves together into a locked position. The reservoir is then pushed onto a pre-inserted 0.32 cm diameter injection tube thereby rupturing the capsule and allowing the solution to be injected.

An injector for highly viscous solutions was developed by Marshall (42) before 1930. He modified a grease gun for rapid injection of 60 ml of material through hollow lag screw injectors.

Active, Large Volume -- The basic components of a large volume pressure injection system consist of a pressure source, solution reservoir, pressure regulator, supply hoses and injector heads. These usually operate in the 0.7-14 kg/cm^2 pressure range providing rapid injection of one or more liters of chemical solution. Southwick (85) described a basic pressure tree injector in 1945. Since that time equipment has been developed that greatly increases the efficiency of the operation thereby making this a commercially feasible management tool.

Pressure on the injected solution can be supplied by a non-flammable compressed gas such as air or nitrogen (Filer, 14; Gregory, et. al., 21; Himelick, 26; Jones, et. al., 30; Kondo, 32; Reil, 57; Southwick, 85; Tarjan, 88), by a hydraulic system (Brown and Bacheler, 3), or by a sprayer pump (Himelick, 26).

Solution reservoirs can be made from any tank able to hold liquids under pressure and receive proper fittings. Filer (14) used a 12 liter freon tank, Kondo (32) used a 45 liter plastic aspirator bottle and Southwick (85) used a 15 liter iron tank. With these reservoirs the liquid is usually forced directly to the injection sight, therefore a sight gauge or flow indicator is necessary to determine the amount injected. Other workers used a non-pressurized solution reservoir to feed a hydraulic cylinder that holds a prescribed dose. The hydraulic cylinder then pushes the solution into the tree. Brown and Bacheler (3) and Reil (57) have utilized this concept in developing practical machines for commercial field use. The pressurized part of the system usually has a pressure gauge installed.

Solution supply hoses are usually made with quick couple con-

nectors, at least at the injector end. When more than one injection point is desired, a manfold is installed in the supply line and hoses leading to injectors are connected to the manifold usually with a valve on each one. This manifold set up does not provide for equal distribution of material to the injection sites because of unequal flow resistance. A method of getting equal amounts to each injection site is clearly desirable. One way is to use a separate cylinder reservoir for each injection site (Brown and Bacheler, 3).

The most common type of injector head is the hollow lag screw type as described by Filer (14), Himelick (26), Reil (57), Southwick (85) and Tarjan (88). They commonly are 1.27 cm screws with a 0.32-0.64 cm bore and the head modified to fit a quick couple adapter. A 1.43 cm diameter by 5.08-7.62 cm deep hole is drilled into a tree and the injectors are screwed in just deep enough to seal.

Other injectors have been developed that allow the injected solution to be in contact with more of the functional xylem tissue than the lag screw method. Gibbs and Dickinson (16) developed injection lances that seal in a drilled hole when a wing nut is tightened and two rubber seals are squeezed against the walls of the hole creating a reservoir just inside the cambium. Gregory et. al. (21) used duplex nails to seal injectors against a gasket outside the injection hole.

A technique for large volume pressure injection of severed roots is described by Kondo (32). A pressure of 0.7 kg/cm^2 was utilized to force solutions through tubing connected to the ends of cut roots.

Performance

Since the first experiments with plant injection were conducted and observations recorded, investigators have noted various aspects of

performance. The particular performance of any given plant injection depends on several factors and can be evaluated in terms of the efficiency of the method, distribution of the injected substance and resulting plant response.

Efficiency -- The time and effort expended on plant injection are determined by the injection apparatus, injection pressure, injection site characteristics, substance characteristics, plant species characteristics, plant environment and persistence of the operator. Injection of one liter of solution can vary from less than 30 seconds to several hours or even days.

Important considerations when evaluating the efficiency of an injection apparatus include the set up time, ease of handling and the nature of the injector heads. When many injections are to be done, a system such as the one developed by Reil and Beutel (57) is useful. Repeated injections of a precise volume can be accomplished by operating one valve that controls filling the injection cylinder from the solution reservoir as well as the injection action of the cylinder.

The rate of injection is directly proportional to the pressure supplied to the solution (Brown and Bacheler, 3; Sachs, et. al., 78). The effect of increasing pressure was first noted with passive systems when it was found that raising the solution reservoir increased the injection rate (Lipman and Gordon, 40; Levy, 38). However, raising the reservoir more than 6.1 m. above the injection hole had no further effect on rate (Lipman and Gordon, 40). With pressure injection systems the rate does not significantly increase when more than 14 kg/cm^2 of pressure is applied (Himelick, 26; Reil, 49; Sachs, et. al. 78). Typical rates for pressure injection would be one liter in 30

seconds to ten minutes.

The placement of an injection hole in a tree so that functional xylem tissue is contacted is essential for fast solution absorption and the more sites used, the faster a given volume is injected (Himelick, 26; Reil, 59). Brown and Bachelor (3) and Sachs, et. al. (78) reported that the injection rate is increased by increasing the injection hole diameter and depth. Brown and Bacheler (3) also found that trees with holes cut cleanly by a sharp drill injected faster than trees with punched holes that had compressed vessels.

The kind, concentration and total amount of solution to be injected will influence the injection rate. Rumbold (75) in 1920 found with passive injection that solutions were absorbed faster than water and further that the greater the solution concentration the greater the absorption rate. This is in contrast with the findings of Collison, et. al. (8) in 1932 which showed that water was absorbed faster than solutions. Jones and Gregory (30) reported that solutions are absorbed faster than suspensions and Himelick (26) further noted that pressures of at least 14-21 kg/cm^2 are needed to inject suspensions into trees. Brown and Bacheler (3) found the rate of injection to be inversely proportional to the total amount injected when large volumes are injected.

Plant characteristics, particularly the structure of the vascular system, play an important role in injection efficiency. Sterrett and Creager (86) have stated that diffuse-porous species are more receptive to injection than ring-porous species. Filer (14) and Reil (59) have demonstrated that different tree species can be injected at different rates under similar conditions. Injection efficiency is also

influenced by the stage of the life cycle of the plant being injected. Injection rate is fastest when a plant is actively growing vegetatively in the spring, summer or early fall. The rate then decreases into late fall and is lowest in winter during dormancy (Jones and Gregory, 30; Reil, 59; Rumbold, 75). Injection rate is also proportional to tree size (Brown and Bachelor, 3; Collison, et. al., 8) and healthy trees are injected faster than unhealthy trees (Reil, 59).

Environmental conditions affect injection efficiency by influencing the internal water relations of the plant being injected. Reil and Beutel (57) report that injection is fastest when a tree is under slight water stress. They found it took longer to inject in the early morning or at night than in the afternoon and that cloudy humid days increased injection time.

Distribution -- The ability of an injected substance to perform a given role depends on the substance being distributed from the injection point to the sites of needed activity. Methods used to study this distribution include observed plant response, injection of suitable dyes followed by visual tissue inspection, and chemical analysis of plant tissue. Differential plant injury is often associated with plant injections indicating unequal chemical distribution within the plant. Brown, et. al. (5); Helton and Rohrbach (24) and Rumbold (76) used visual observation to evaluate the distribution of numerous substances. The use of dyes to elucidate distribution of other chemicals has been widely used by several investigators (Kondo, 32; Morris, 48; Roach, 66 and Sachs, et. al., 78). The value of this technique depends on the solubility and translocation characteristics being similar for the dyes and other chemicals injected. Despite limitations of extrapolating in-

formation from using dyes they have proven useful in studying distribution. The most accurate way to determine distribution of an injected substance is by chemical analysis. This has been done by DeLange (10) using growth regulators, Sands (79) using antibiotic bioassays, Sachs, et. al. (78) using radioactive antibiotics and Elliott (12), Rankin (56) and Southwick (85) using mineral analyses.

When a water soluble material or solution is injected into the xylem tissue of an angiosperm it enters the transpiration stream and is distributed upward and downward by mass flow to the plant parts directly connected with the severed xylem vessels in response to tension gradients (Roach, 66). Distribution also occurs by diffusion from injected xylem vessels to other vessels and phloem tissues, particularly at the injection site (Sachs, et. al. 78). This can result in further distribution and re-distribution of the injected material. Many workers report finding injected materials in the extremities of a tree within a few hours after trunk injection. Roach (66) reported that the upward rate varies but was around 1.27 cm per minute and circumferential movement round each annual ring of wood was about 0.13 cm per minute. Radial movement was slow and sometimes absent depending on the qualities of the heartwood. Initially distribution occurs faster when pressure is used because of the increased pressure gradient. Reil (59) stated that pressures below 7 kg/cm^2 caused limited distribution problems.

The injection site is particularly important in determining distribution. Injected chemicals can be restricted to various plant parts because of limited downward translocation. Roach (60, 66) demonstrated this with his interveinal leaf, leaf tip, leaf petiole, shoot

tip and branch injection methods. For whole-tree injections it is desirable that the injection holes contact as much functional xylem as possible. Effective translocation throughout whole trees has been accomplished by injection sites at severed roots (Kondo, 32), diametrically drilled holes through tree trunks (Roach, 66) and relatively shallow (1.9-7.62 cm) holes drilled radially (Collison et. al., 8; Reil, 59; Sachs et. al., 78) or tangentially (Brown, et. al., 5; Wilson, et. al, 94) into tree trunks. According to Reil (59) the injection holes should be placed directly under scaffold branches or every 15.2 cm of circumference for trees greater than 40.6 cm in diameter. This is in contrast with Roach's (66) work that shows the best distribution occurs from injecting under crotches so that conductive tissue of both scaffold branches are injected. Apparently both work for practical purposes since both authors report whole tree "cures" using their method.

Characteristics of the substance to be injected greatly influence distribution. Solubility is important for movement in the transpiration stream. Solutes are subject to being absorbed by cells or adsorbed onto cell walls as distribution occurs (Stoddard and Dimond, 87). Solution concentration can be important to distribution. Prasad and Trasnick (53) suggested higher concentrations of fungicides give better distribution and McCoy (46) reported that higher concentrations for a given dose of antibiotics translocated slower. Concentrations high enough to injure tissue reduces distribution (Collison, et. al., 8). Many authors have shown that the chemical characteristics of an injected chemical affects distribution (Collison, et. al., 8; Helton and Rohrbach, 24; Morris, 48; Rumbold, 76).

Plant characteristics, particularly vascular anatomy and physiology, must be considered in distribution of injected chemicals. Many workers have found various species differentially distribute injected substances (Collison, et. al., 8; Morris, 48; Rankin, 56; and Stoddard and Dimond, 87). Some plants have spiral grain (Morris, 48). The stage of a plant's life cycle, general plant health and vigor and location of dead tissue also affect distribution. When a tree is actively growing in the late spring and early summer distribution of injected chemicals is rapid. Injections in the fall result in more chemical translocation to the roots than spring or summer injections (Collison, et. al., 8; Gregory, 30; Rumbold, 76; Stoddard and Dimond, 87).

Environment can influence distribution, mainly by affecting transpiration and tension in the xylem. Conditions causing low or no transpiration would cause slower distribution of injected substances and allow more time for diffusion to take place, particularly close to the injection site. Roach (66) showed that injected solutions will distribute to roots growing in dry soil but not to ones in wet soil, reflecting respective differences in the tension gradient of the xylem. This would indicate significant downward movement in the xylem vessels.

Plant Injury -- A number of injuries can be associated with plant injection. These injuries arise from both the physical effects of the injection method and the chemical effects of the injected substance.

Leaf injection or small stem injections have a smaller physical injury impact than whole-tree injection techniques where holes are made in trunks. Injuries associated with boring holes in trees have been extensively studied (Brown, 4; Hepting, et. al., 25; Lorenz, 41; Rumbold, 76; Shigo, 82; Shigo and Campana, 83; Thomas and Haas, 89;

Toole and Gammage, 91). These investigators have all shown that wood discoloration occurs at least 30-60 cm., directly below and above an injection hole and that compartmentalization of tissues surrounding the hole occurs. This accounts for reports of not being able to re-use old injection holes or holes located directly above old ones (Collison, et. al., 8; Thomas and Haas, 91). Shigo and Campana (83) suggest later injection sites be located at least 46 cm above an old injection hole but not in the same longitudinal plant. The amount of discoloration varies with the tree species, the season of injection (Toole and Gammage, 91) and the material being injected (Shigo, 82).

Smaller holes heal faster than larger ones and associated discoloration and compartmentalization are likewise less (Brown, 4; Schreiber, 80; Toole and Gammage, 91). This healing process is noted by callus formation around and over the hole. Brown (4) found that small diameter force fit injector holes healed faster with a lower incidence of decay and internal compartmentalization than lag screw type injector holes. Shigo and Campana (83) suggested that injection holes be few, small as possible, shallow and clean-edged.

Decay resulting from these injuries is dependent on the amount of damaged tissue present, the presence of decay organisms and the plants genetic ability to suppress these organisms. Sterilizing equipment was suggested by Brown and Hildreth (2) as a means to reduce decay but was shown by Lorenz (41) to provide only a temporary effect. If heart rot fungi becomes established in the wound progressive decay can result for several years to come whereas sapwood rooting fungi will die after the injection hole calluses over (Lorenz, 41). Thus plugging holes with an antiseptic dressing can lower the incidence of heart rot in injected

trees (Lorenz, 41). Hepting, et. al. (25) reports that most diffuse-porous hardwoods are subject to developing cankers which can retard the healing for more than ten years. Most of the research has shown that these direct injuries remain local and have not led to loss of tree health and vigor.

Injury resulting from injected substances depends on the biological toxicity as well as the concentration and amount of the substance that is absorbed by living cells. When this injury occurs in the cambium close to a trunk injection site it can cause serious secondary injury due to pathogen invasion and the girdling effects of cambium loss (Elliott, 12).

Rumbold (76), Shigo (82) and Thomas and Roach (90) discuss injuries associated with inherent chemical qualities. Rumbold (76) found in general that heavy metals had detrimental effects and alkali metals did not. Shigo (82) noted differences in cambium injury from different materials. Thomas and Roach (90) studies injuries due to different nutrient salts.

Determining concentration and correct dosage for injected chemicals is important for avoiding unnecessary plant injury. Collison et. al. (8) found that the killing effects and speed of appearance were directly proportional to the solution concentration and that the extent of injury seemed to be a function of the osmotic properties of materials, equivalent quantities of salts giving about equivalent injury. Levy (37) reported that larger quantities of a nutrient can be injected in relatively dilute concentrations and further that 9-12 times as much solid can be injected than a corresponding liquid. Gregory, et. al. (20) and Rumbold (76) also recognized and discussed concentration

effects on plant injury.

Dosage determinations are difficult to make. Roach, (71, 66) used initial leaf injury symptoms as a signal that the maximum nutrient dose had been injected. Hearman, et. al. (22) showed that these indicator leaves should be the youngest fully expanded mature leaves. Levy (37) modified Roach's approach by adding a factor to account for differences in tree size as determined by cross sectional area of the trunk. By this method, maximum safe dosage of a complete nutrient (N-P-K) solution (0.5% total conc.) for some dwarf apple trees was found to be 0.5 g/cm^2 cross sectional trunk area. Gregory et. al. (20) also noted that larger trees could receive a greater chemical dose without sustaining injury.

TREE MINERAL NUTRITION

Plant injections have been used to study three aspects of tree mineral nutrition including basic research on mineral physiology, diagnosis of mineral deficiencies and treatment of mineral deficiencies in the field.

Basic Research

Basic research involves elucidation of the various roles and mechanisms of mineral elements in the metabolism of various plant tissues. To be of value as a tool for these kinds of studies plant injection must provide the means to accurately control mineral element levels in given plant tissue(s).

Two reviews have been written on this subject by Collison, et. al. (8) in 1932 and Roach (66) in 1939. The approach of Collison, et. al. (8) was to use passive liquid injections of whole trees or large branches. Roach also used these methods but in addition, developed more precise injection techniques on smaller portions of a tree. These injection methods included interveinal leaf, leaf tip, leaf petiole, shoot-tip, branch and branch root.

Collison et. al. (8) sampled and analyzed various tissues such as terminal leaves, spur leaves and wood for nitrogen in several injection trials and found large variations in nitrogen concentrations. This variability indicated the lack of precise control with their methods. Because of this and other factors such as not being able to use old injection holes, they concluded injection was not suitable for basic mineral nutrition research. Roach (66) did not report analytical data, therefore no conclusion can be made regarding control of tissue

nutrient levels resulting from his injection techniques.

In 1947, Singh (84) found branch injections of nitrogen, phosphorus and potassium had no effect on biennial bearing in apples trees.

Diagnosis

Plant injection can be a useful technique for diagnosing tree mineral deficiencies, however it has not been used for this purpose since the 1940's. A suspected deficient element is injected into a plant and leaf responses are detected visually. Improved growth or color of leaf tissues local to the injection site within 1-2 weeks would indicate that the element was deficient.

W. A. Roach of the East Malling Research Station, Kent, England was a proponent of this diagnostic technique during the 1930's and 1940's (Roach, 60, 61, 62, 64, 65, 66, 67, 68). All of his injection methods were used for diagnostic purposes but the interveinal leaf method was the best for diagnosis because the plant response was detected most rapidly (Roach and Roberts, 69). The leaf petiole method was by far the most generally used and thousands of diagnoses had been made by this method before 1945 (Roach and Roberts, 69). Both techniques allow more than one element to be tested on a single tree and four replications should be made of each treatment (Levy, 36; Roach and Roberts, 69). With either of these methods the injection process continued for several days or until a plant response was detected.

Roach and Roberts (69) suggested compounds and concentrations for diagnosis of several mineral deficiencies in trees (Table 1). Diagnoses of deficiencies of all these elements were achieved by plant injection.

TABLE 1

Compounds and Concentrations Used For

Mineral Deficiency Diagnosis Injections

Deficient Element	Compound	Solution Conc. (%)	Additives
Nitrogen	urea	1.0	--
Phosphorus	NaH_2PO_4	0.5	--
Potassium	KCl	1.0	--
Calcium	$CaCl_2$	1.0	--
Magnesium	$MgSO_4$	0.5	--
Iron	$FeSO_4$	0.025	0.025% H_2SO_4
Manganese	$MnSO_4$	0.025	0.025% H_2SO_4
Zinc	$ZnSO_4$	0.025	0.025% H_2SO_4
Copper	$CuSO_4$	0.025	0.025% H_2SO_4
Boron	H_3BO_3	0.1	--

Diagnosis of a single element deficiency has been accomplished by other experimenters. Duggan (11) used the shoot tip, leaf petiole and branch injection methods to diagnose Mn deficiency in cherry. Gayner (15) successfully diagnosed deficiencies of N, P, Mg, Fe, Zn and B in pear using leaf petiole injection of the compounds and concentrations presented in Table 1. Roach (62) successfully used twig tip injection of $FeCl_3$ and Fe tartrate to diagnose Fe deficiency in trees. Roach (64) also showed that concentrations of 0.1% $MnSO_4$ and $ZnSO_4$ could be used to diagnose Mn and Zn deficiency respectively in pear trees. Many workers have used injections for diagnosis of B deficiency in apple (Roach, 68).

Multiple mineral deficiencies have also been diagnosed using plant injection. Roach (68) reports successful diagnosis of Ca plus Mg deficiencies in potato, Mn, Fe and Zn deficiencies in fruit trees and other multiple trace element deficiencies. Roberts (70) used branch injection to diagnose K deficiency combined with Fe and/or Mn deficiency.

Treatment

Tree injections have been used as curative treatments for mineral deficiencies in trees. Macronutrient and micronutrient deficiencies can be temporarily corrected, some treatments remaining effective for a period of three years or more.

The success of any given mineral injection treatment can be evaluated in two ways. First the visual remission of deficiency symptoms resulting in improved leaf color, tree growth, and/or fruiting response can be observed. Second, mineral analysis of appropriate plant tissue(s) can be performed. The basic assumption of tissue analysis for determination of the mineral status of a plant is that levels of a particular element in a particular plant part at a particular stage of maturity can be quantitatively correlated with tree health. Current standard leaf analysis guidelines for temperate zone deciduous trees requires that the sample consist of the most recently mature leaves from current season's shoots during a period of minimal internal nutrient flux (mid-July through August).

Collison, et. al. (8) addressed the problems associated with tissue sampling and analysis after tree injections with nitrogen. They found analytical results to be highly variable and attributed the main factor causing these variations to differences in the stage of

maturity of the leaves and shoots being sampled. Current standard guidelines for leaf analysis can reduce this variation to a minimum. Another source of variation results from unequal distribution of the injected material and can be reduced by selecting a suitable whole-tree injection method.

Macronutrients -- In 1925 Lipman and Gordon (40) reported their results of passively injecting ten year old pear trees with various salts of Ca, Mg and K. Three liters of 0.3 N solutions were injected in early spring and observations were made throughout the growing season. Calcium salts of $Ca(NO_3)_2$, $CaHPO_4$, $CaCl_2$, and $CaSO_4$ were found to be somewhat toxic and reduced growth. Magnesium nitrate and $MgHPO_4$ injections were stimulating to tree growth, resulting in longer, greener leaves and flower buds of greater vigor than other treatments. The K salts, KNO_3, KH_2PO_4 and K_2HPO_4 were much more toxic than Mg salts and in no case stimulated tree growth. They felt that the concentration of the solutions of Ca and K were too high and that lower concentrations should stimulate tree growth. No mention was made of the nutrient status of the experimental trees.

Dosages of various macronutrient salts were investigated by Collison, et. al. (8) and reported in 1932. Working with 14 and 20 year old apple trees, three passive injection trials using $Ca(NO_3)$, $Mg(NO_3)_2$, KNO_3, $(NH_4)_2SO_4$, KH_2PO_4 and urea were conducted in spring and summer. These studies showed that trees could tolerate without visible injury, about one gram of salt per 2.54 cm of main limb circumference. Their work further showed that salts concentrated in injured tissues are apparently not absorbed later by uninjured tissue and that when injury was not visible, increases in tissue N could not

be detected following N compound injections.

In 1932, Roach (60) suggested that trunk injections of K could possibly be used to speed up the typically slow response to soil applied K fertilizers. This was followed by a KNO_3 injection of a 15 year old apple tree with potassium deficiency (Roach, 61). Ten liters of 1% KNO_3 solution were passively injected in the early part of the growing season.. The following day leaf scorch was visible on the fully expanded leaves, particularly on branches above the injection hole but leaves expanding after this time were undamaged. After one month these leaves were darker green, thicker, larger and apparently more healthy than before. By autumn strong healthy shoot growth was evident, exceeding previous year's growth by 50-70%. The branches that showed the most damage from injection had the greatest amount of shoot growth.

Roach (63) described a test of the tree injection of nutrients on a larger scale in 1939. Eight 21 year old apple trees were passively injected with a solution containing 0.25% K_2HPO_4 plus 0.25% urea in June. The trees absorbed this solution until the first signs of leaf injury were visible, thus variable amounts were absorbed ranging from 15-75g per tree of each substance. Shoot growth increased and was positively correlated with the amount of material injected. Number of prunings from injected trees was 1.9 times more than from uninjected trees. The injected trees also showed the best looking foliage as well as lower infestations of leaf hopper insects and red spider mites. No effect was measured on crop size; however fruit from injected trees had inferior color and finish to those from control trees. This may have been due to differences in maturity resulting from relatively high

N. It was noted that the tree branches were uniformly invigorated.

In 1937, Levy (39) injected K deficient six year old dwarf apple trees in mid-summer with a nutrient solution containing 0.125% urea, 0.125% K_2SO_4 and 0.25% KH_2PO_4 by Roach's branch injection method. The dosage administered was 0.5 g of total salt per one centimeter of trunk cross-sectional area. The same growing season "incipient" flower buds were stimulated into vegetative growth. Levy did not think this was due to defoliation injury because no correlation between the number of new shoots and incidence of injury could be found. The following spring, decreased branch dieback, leaf scorch, number of "ghost blossoms" and number of flower buds were observed on injected trees. No increases in shoot growth or cropping were detected.

Successful spring time solid injections of K salts alone or in combination with Fe or Mn salts were described by Roberts and Landau (71) in 1947. Potassium sulfate and K_2HPO_4 were injected into apple trees at the rate of 6-12 g per 2.54 cm of trunk diameter depending on tree size, although it was found that maximum safe doses were 24-144 g for K_2SO_4 and 18-108 g for K_2HPO_4. Ferrous sulfate and $MnSO_4$ were injected at the rate of 2-4 g of salt per 2.54 cm of trunk diameter. In general, trees injected with iron had deeper green foliage than untreated trees. All trees injected with K plus Fe were even deeper green than the Fe injected trees. Midshoot leaves of current season's growth were sampled in the summer and analyzed for K to determine the effects of injections at four different sites. These data showed that in experiments where a definite improvement in foliage appearance occurred the average midsummer leaf K levels were 0.8% for control trees, 1.01% for K injected trees, 1.14% for trace element injected trees and

1.07% for K plus trace element injected trees. Potassium leaf levels of 1.0-1.14% are still low however the significant increase probably contributed to improved color along with increased leaf Fe content.

Worley, et. al. (95) reported in 1976 that early spring pressure injection of up to 64 g per tree of $MgSO_4 \cdot 7H_2O$ caused no visual damage on pecan trees ranging in circumference from 142-257 cm.

Micronutrients -- Chlorosis caused by Fe deficiency was eliminated with $FeSO_4$ injections by Lipman and Gordon (40) and reported in 1925. Injections of 0.1-7 g of $FeSO_4$ produced green foliage and renewed shoot growth in lemon trees that had been chlorotic for some time prior to treatment. The remission of chlorosis, leaf veins turning green first followed by leaf mesophyll cells, took about three weeks.

Temporary elimination of chlorosis in orange trees was achieved in 1928 by passive injection of solutions containing 3-7 g of $FeSO_4$ or 1-2 g of Fe tartrate (Thomas and Hass, 89). They found re-treatment necessary with each new cycle of tree growth.

Chandler, et. al. (7) reported in 1933 that they had obtained remission of Zn deficiency symptoms for two growing seasons in fruit trees from solid injections of either $ZnSO_4$, ZnO or Zn dust. Drilled holes, 0.96 cm in diameter and 3.81 cm deep, spaced 7.62-10.16 cm apart around the tree trunk were filled with the Zn material. New growth on trees did not display "little leaf" or "rosette" symptoms typically associated with Zn deficiency of fruit trees. Zinc coated nails pounded 2.54 cm apart in a spiral around the trunk was also an effective treatment.

In 1934, W. A. Roach (62) reported that whole-tree injection of 0.05% $FeCl_2$ solution for two days during the growing season cured

chlorosis in a peach tree within two weeks without any ill effects.

Wallace (93) in 1935 reviewed results of solid injections of iron compounds performed earlier by J. P. Bennett and also reported some of his own experiments with solid injections to control lime induced chlorosis in fruit trees. Bennett had corrected chlorotic pear trees with dormant season injections of powdered ferrous citrate and ferric citrate and claimed that by 1933 about 75,000 pear trees had already been successfully treated by growers themselves. Wallace presented Bennett's table of iron salt dosages which ranged, from 2.8-57 g per tree for trees 2.54-50.8 cm in diameter. These recommendations were followed by Wallace and resulted in totally successful remission of chlorosis in apple, pear and plum trees ranging in age from 5-50 years. In some cases this treatment was effective up to three years.

Manganese deficiency in cherry trees was effectively treated with solid $MnSO_4$ injections by Duggan (11) and reported in 1943. One centimeter diameter holes spaced 2.54 cm apart around the trunk were filled with 2-5 g of $MnSO_4$ in early spring. This treatment resulted in complete remission of chlorosis and an increase in tree growth and cropping without apparent tree injury. Duggan expected this treatment to last at least four years.

Southwick (85) used pressure injection to effectively treat Fe deficiency in 15 year old orange trees. He reported in 1945 that 3.5-4.2 kg/cm^2 of pressure was employed to inject trees with solutions containing 30-200 g of $FeSO_4$. All treatments corrected chlorosis and were effective for 2-4 years. Because of injury assoicated with dosages above 100 g the resulting recommended dosage range was 50-100 g. Some injury of small shoots was associated with injections of 70-100 g

of $FeSO_4$ but rapid recovery with normal foliage, shoot growth and cropping was observed.

Water insoluble FeO was effective as a solid injection compound for correcting lime induced chlorosis of several ornamental trees (Brown and Hildreth, 2). Drilled holes, 0.9 cm in diameter and 5.1 cm deep, spaced 7.6-10.2 cm around the trunk in a spiral were filled with FeO. Response to this treatment was reported to be nearly as rapid as with water soluble iron salts and lasted nearly three times longer.

Neely (49, 50) working with Fe deficient pin oak trees in 1971 tested trunk implantation of gelatin capsules containing various Fe compounds. Nursery trees ten centimeters diameter were implanted with one #3 gelatin capsule in each of two drilled holes from April to June. Iron citrate and Fe ammonium citrate were the most effective treatments. Foliage became green after 2-4 weeks from treatment without apparent plant injury and lasted 1-2 years.

Worley, et. al. (95) in 1976 reported their preliminary results of pressure injecting Zn compounds into pecan trees. Pressures of 2.1-2.5 kg/cm^2 were used to inject eight liters of solution into the tree trunk. Injection of 2270 g per tree of $ZnSO_4$ killed all first flush leaves and stem tips in a tree 201 cm in circumference. A larger tree of 270 cm in circumference had some uninjured small limbs. Damaged foliage contained over 5000 ppm Zn and within three weeks new shoots emerged with normal foliage. Replicated trials showed that injection of one gram of $ZnSO_4$ per 2.54 cm of trunk circumference in April increased midshoot leaflet Zn levels from 38 ppm to 100 ppm in mid-August. Trunk injection of 11 g of Zn as N-Zn also significantly increased leaflet Zn levels in August.

In 1978, Reil, et. al. (58) reported successful results with pressure injection of Fe and Zn compounds into trees. Pressure of 14 kg/cm^2 was used to inject pear trees with Fe and Zn sulfates and Fe and Zinc chelates. The sulfates were more effective than the chelates in correcting Fe and Zn deficiencies. A volume of 0.95 liter of 1% or 2% $FeSO_4$ solution corrected severe chlorosis in mature trees for at least one year. Larger trees were not injured by 1.9 liters of 2% $FeSO_4$ solution and remained free of chlorosis for two years. An injection of 0.95 liter of 1% $ZnSO_4$ solution controlled Zn deficiency for at least one year.

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The Effect of Pressure Trunk Injections of Potassium on the Mineral Content, Growth, Yield and Fruit Quality of Sweet Cherry (Prunus avium L.) and Mineral Content of Prune (Prunus domestica L.)

Key words: Plant Analysis, Mineral Nutrition

ABSTRACT

Fall trunk injections of 200 g K in K_2SO_4 solution or up to 300 g K in K_2HPO_4 solution had no effect on sweet cherry midshoot leaf K in August. Phosphorus content was significantly increased in buds in March and midshoot leaves in August one year by fall injection of K_2HPO_4 (79.2 g P).

Spring trunk injections of 12.5 g K (K_2SO_4 or K_2HPO_4) in prune increased leaf K within four days and K levels remained higher than controls for at least 22 days with K_2SO_4. Leaf P was increased within four days by K_2HPO_4 and was higher than controls in August.

Fruit set in sweet cherry was significantly lower on trees injected with 200 g K (K_2SO_4) and 300 g K (K_2HPO_4). Yield was significantly lower for all injection treatments and was probably caused at least in part by reduced fruit set. Fruit quality was not affected by K injections.

INTRODUCTION

Potassium deficiency can be difficult to correct in established, non-irrigated sweet cherry (Prunus avium L.) and prune (Prunus domestica L.) trees growing in the moderately acid clay loam and silty clay loam hill soils of western Oregon. Tree responses to applied K fertilizers can be slow because of adsorption and fixation of K by clay minerals, unavailability of K in dry soil and lack of root growth in heavy, compacted soils by trees with poor vigor.

Essential minerals have been injected into trees for curative purposes since the 1880's (12). Most successful treatments have been for deficiencies of Fe (4,5,6,8,14,16) and Zn (1,8,17) but have also included N and K (3,9,11,13). These treatments provided a rapid (one growing season or less) but temporary (1-4 years) correction of the mineral deficiency problem.

Roach (9) suggested that K trunk injections could possibly be used to speed up the typically slow response to soil applied K fertilizers. He injected apple trees in late spring with varying concentrations (up to 38.7 g K) of either KNO_3 (10) or K_2HPO_4 plus urea (11) and found that the trees had healthier foliage and uniformly increased shoot growth which correlated with the amount of material injected. These responses could have been from the injected K and/or N. Roberts and Landau (13) increased leaf K from .8 to 1% in apple trees by placing solid K_2SO_4 and K_2HPO_4 into drilled holes in the trunks at the rate of 6-12 g/2.54 cm trunk diameter in the spring.

Passive (gravity flow) injection methods for mineral solutions such as Roach's (9,12) frequently require apparatus to be connected to trees for several days during the early - mid growing season allow-

ing large volumes of ten or more liters of dilute (0.5-1.0%) salt solutions to enter tree conductive tissues. A pressure injection system such as the one described by Reil and Beutel (7) is more time efficient, allows injection over a wider range of the seasons, including dormancy and can be used effectively on a commercial scale. They report injections of 0.95 liters of fluid in less than one minute using a pressure of 14 kg/cm^2.

The purpose of this study was to explore the possibilities of using pressure injection techniques for one-time treatments resulting in short term correction of K deficiency in established sweet cherry and prune orchards.

MATERIALS AND METHODS

Test plots of 'Royal Ann' sweet cherry and 'Italian' prune were established in non-irrigated, non-cultivated commercial orchards west of Salem, Oregon in October, 1977. The sweet cherry plot consisted of 19 year old trees, spaced 10.7 m by 10.7 m with an average trunk diameter of 36 cm. August 1976 midshoot leaf K was 0.73% (normal 1.5%). The prune plot consisted of 13 year old trees, spaced 3.4 m by 6.7 m with an average trunk diameter of 15 cm. August 1976 midshoot leaf K was 0.55% (normal 1.5%).

Solutions were injected by forcing fluid through threaded injector heads (No. 24 X 7.6 cm wood screw with quick coupler and 0.3 cm bore) into three 0.6 cm diameter, 3.8 cm deep drilled holes, each located directly beneath a main scaffold branch, under 3.5-3.9 kg/cm^2 pressure. The injection apparatus consisted of an 11.4 liter metal solution reservoir with a bolt down cover and gasket, sight gauge, pressure gauge, pressure regulator, safety valve, threaded air inlet and threaded solution outlet; compressed nitrogen tank with regulator and air hose; 9.2 m of 1.5 cm diameter rubber-nylon solution hose connected via a shut-off valve and two tees to three 0.6 cm diameter plastic lines each with a quick coupler end that connects to the injector heads.

Fall injection times averaged 2.5 min./liter for both H_2O and K solutions in sweet cherry trees while prune tree injection times averaged 12 min./liter for H_2O and 16.5 min./liter for K solutions. Spring injection times for prune trees averaged 12 min./liter for H_2O and K solutions.

All tissue samples were chemically analyzed by spark emission

spectroscopy for % d.w. K and P (2).

Fall Injections

In October, 1977 a completely randomized design experiment with four treatments and five replications was established in the sweet cherry plot. Treatments consisted of 1.0 liter distilled H_2O, 0.5 liter, 1.0 liter and 2.0 liters of 10% K solution containing 291.5 g of analytical grade $K_2HPO_4 \cdot 3H_2O$/liter.

Twenty spurs with buds were collected 3/17/78, all leaves from 20 spurs were collected 5/17/78 and 20 midshoot leaves were collected 8/9/78 and 8/2/79. Leaf element content for all samples was statistically analyzed using analysis of variance (ANOVA) (15). Treatments were compared to the control by the Least Significant Difference (LSD) Method when F values were significant.

In October, 1978 a randomized block design experiment with five treatments and eight replications was established in the sweet cherry plot. Treatments consisted of a no injection control and injections of 3.0 liters distilled H_2O, 2.0 liters and 3.0 liters of a 10% K solution of K_2HPO_4 and 4.0 liters of a 5% K solution containing 111.43 g of analytical grade K_2SO_4/liter.

Midshoot leaf samples consisting of 20 leaves were collected from each tree on 8/9/78 and 8/2/79. Percent fruit set in 1979 was estimated (except H_2O inj.) by counting the fruits resulting from 200-400 blossoms on each of four branches per tree. Trunk cross-sectional areas were measured 2/78 and 9/79. Yields were measured in 7/79 and 100 fruits (without stems), randomly selected from each tree's yield, were weighed and the volume measured by water displacement. Juice from ten of these fruits was mixed and soluble solids (SS)

determined with a refractometer. The data were statistically analyzed by ANOVA.

A completely randomized design experiment with five treatments and five replications was established in the prune plot in October, 1977. Treatments consisted of a no injection control and injections of 0. 12.5, 25 and 50 g K using a 5% K solution containing 145.7 g K_2HPO_4 $3H_2O$/liter. Midshoot leaves were sampled 8/9/78, chemically analyzed and the K data statistically analyzed using ANOVA.

Spring Injections

Non replicated injections in June indicated that 100 g K (K_2HPO_4 solution) produced severe leaf toxicity symptoms on some branches in sweet cherry trees and that the maximum dosage without sustaining substantial leaf injury in prune trees was 12.5 g K for both K_2SO_4 and K_2HPO_4 solutions.

A randomized block design experiment with six treatments and seven replications was established in the prune plot in June, 1978. Treatments consisted of a no-injection control plus 1.0 liter injections of distilled H_2O, K_2HPO_4 solutions containing 6.3 g K and 12.5 g K and K_2SO_4 solutions containing 6.3 g K and 12.5 g K. Leaf samples consisting of ten midshoot leaves on each of the three main scaffold branches or leaders on each tree (except no-inj.) were taken 6/23/78 before treatment, 6/27/78, 7/15/78 and 8/10/78. Whole tree leaf samples consisting of 20 leaves per tree were taken on all trees on 8/10/78 and 8/7/79. Leaf samples were chemically analyzed and the data statistically analyzed using ANOVA.

RESULTS AND DISCUSSION

Fall Injections

Slight leaf toxicity was observed on a few sweet cherry branches in both K_2SO_4 and K_2HPO_4 200 g K treatments. This injury occurred within two days and appeared as dry dull-green areas in the interveinal parts of the leaf. Trees injected with 300 g K had toxicity symptoms on 34-50% of their leaves. Buds were not injured in any instance and treatments of 100 g K or less were not visiably injurious to either tree species.

In 3/78 spur tissues from trees injected with 200 g K had a significantly higher K content and buds had a significantly higher P content than controls (Table 2). In 5/78 trees treated with 200 g K had significantly higher leaf K levels but not in 8/78 when the trees in all treatment groups were deficient ($<$1.2%) or below normal (1.2-1.5%) in K (Table 2). Leaves sampled in 8/78 from trees injected with 200 g K (79.2 g P) had higher P levels than controls (Table 2) but all treatments had normal P ($>$.13%). In 8/79 no nutrient content differences were found between any treatments and all had deficient K levels.

Potassium injections of sweet cherry trees in 10/78 had no significant effect on leaf mineral content in 8/79 when all treatments had below normal K. Before treatment in 8/78, these trees had below normal K and marginally normal P. Fruit set in 1979 was significantly lower than the control in the K_2SO_4 200 g K and K_2HPO_4 300 g K treatments and could have resulted from toxic effects of treatment (Table 3). Yield was lower for all treatments than for the control (Table 3) and apparently resulted from less fruit set and/or random

tree selection. Other factors were not significantly affected by treatment (Table 3).

Prune tree injections of up to 50 g K in 10/77 had no effect on 8/78 midshoot leaf K levels. All treatments had normal K levels (1.5-3%) however these levels were high due to lack of cropping in 1978.

Although relatively large doses of K can be injected into trees in the fall without serious permanent injury, it does not appear to be an effective corrective measure for trees with below normal K nutrition. The effect of these treatments on severely deficient trees is not known and could possibly be of some benefit.

Spring Injections

Potassium sulfate was more toxic than K_2HPO_4, the K_2SO_4 12.5 g K injections resulting in some leaf toxicity on one or two leaders in all replications. Potassium levels in prune leaves were significantly increased within four days by both 12.5 g K treatments and this difference was maintained for at least 22 days by the K_2SO_4 treatment (Table 4). Leaf K levels in 8/78 were not affected and all treatment groups had normal K ($\geq$1.5%) (Table 4). Leaf K levels in 8/79 were all deficient ($<$1.3%) and unaffected by treatment (Table 4). Leaf P levels were increased by both the low (2.5 g P) and high (4.9 g P) dose of K_2HPO_4 within four days and this increase was maintained into August with the high K_2HPO_4 dose (Table 4). All other treatments had below normal ($<$.13%) P levels (Table 4). Mineral contents of August whole tree samples agree quite well with the averages of individual tree leader samples and also indicate significantly higher P levels in the leaves of trees injected with 4.9 g P (Table 4).

The toxic effects of pressure injecting large doses of K salts in spring prevents this approach from being a feasible short term corrective measure. However, where P is a limiting factor, this method could prove to be effective.

Table 2. Effect of Fall[z] Trunk Injections of K_2HPO_4 on the K and P Content of Sweet Cherry (Prunus avium L.)

Treatment	3/17/78				5/17/78	8/9/78	
	Buds		Spurs		Leaves[y]	Leaves[x]	
	% K	% P	% K	% P	% K	% K	% P
H_2O	1.20	.39	.29	.09	1.09	.97	.14
50 g K	1.19	.39	.30	.09	1.25	1.12	.15
100 g K	1.22	.41	.32	.10	1.16	1.00	.14
200 g K	1.28	.46	.42	.11	1.41	1.34	.19
LSD_{05}	NS	.05	.05	NS	.15	NS	.02

[z] 10/15/77

[y] spur leaves

[x] midshoot leaves

Table 3. Effect of Fall[z] K Trunk Injections on the Fruit Set, Yield, Fruit Quality and Growth of Sweet Cherry (Prunus avium L.)

Treatment	1979 Fruit set (%)	1979 Yield per tree (kg)	Fruit wt. (g)	Fruit vol. (cm^3)	Fruit SS (%)	Change[y] trunk x-sec. area (cm^2)
Control	15.1	103	7.6	7.2	17.8	106
H_2O	-	78	7.6	7.2	18.8	63
200 g K (K_2HPO_4)	12.6	77	7.8	7.3	19.2	75
300 g K (K_2HPO_4)	8.5	71	7.9	7.4	18.5	122
200 g K (K_2SO_4)	8.9	59	7.7	7.2	18.4	106
LSD_{05}	4.1	24	NS	NS	NS	NS

[z]10/22/78

[y]2/78-9/79

Table 4. Effect of Spring[z] K Trunk Injections on the K and P Content in Midshoot Leaves of Prune (Prunus domestica L.)

Treatment	6/23/78 - Pre		6/27/78		7/15/78		8/10/78		8/10/78 whole tree	
	% K	% P	% K	% P	% K	% P	% K	% P	% K	% P
NO INJ. CONTROL	-	-	-	-	-	-	-	-	1.54	.11
H_2O CONTROL	1.20	.17	1.20	.16	1.26	.15	1.42	.12	1.35	.12
6.25 g K (K_2HPO_4)	1.25	.17	1.32	.22	1.47	.15	1.58	.12	1.59	.12
12.5 g K (K_2HPO_4)	1.18	.17	1.50	.27	1.48	.20	1.66	.14	1.67	.14
6.25 g K (K_2SO_4)	1.08	.16	1.31	.15	1.38	.13	1.52	.12	1.49	.11
12.5 g K (K_2SO_4)	1.27	.16	1.61	.15	1.61	.14	1.67	.11	1.65	.11
LSD_{05}	NS	NS	.30	.04	.31	.04	NS	.02	NS	.025

[z]6/23/78

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APPENDICES

Appendix 1 consists of additional experiments presented in journal paper format designed to evaluate the effectiveness of K soil amendments and foliar sprays for correcting K deficiency in sweet cherry and prune trees. This work is complimentary to the trunk injection work and together provide more complete information on short and long term correction of K deficiency.

Appendicies 2-7 provide additional data not presented in either the main body of the thesis or appendix 1.

Appendix 1.

The Effect of Potassium Soil Amendments, Trenching and Foliar Sprays on the Mineral Content, Growth, Yield and Fruit Quality of Sweet Cherry (Prunus avium L.) and Prune (Prunus domestica L.)

Key words: Plant Analysis, Mineral Nutrition

ABSTRACT

Potassium sulfate was applied to established, non-irrigated, K deficient trees on fine textured soil by three methods, banding, placing in augered holes and injecting into the soil. Additional trees received a heavy compost mulch in early fall. Trenches were dug in the fall beside trees to break roots and then were backfilled with K_2SO_4, dolomite lime or a combination of the two. One percent K solutions of KNO_3 or K_2SO_4 were sprayed on trees four times during the growing season.

Sweet cherry trees only responded to compost mulch applications within two years. August midshoot leaf K, leaf N and fruit size were increased within one year however tree growth and yield were not affected. Fruit size and shoot growth were partially dependent on August leaf K level.

August midshoot leaf K of prune trees was increased within one growing season by all treatments except trench plus lime. Trees receiving compost also had increased levels of leaf N, P, Ca, Mn, Fe, Cu and B. Yield and shoot growth were increased only by compost mulch applications. Fruit size was partially dependent on August leaf K levels.

INTRODUCTION

Potassium deficiency in stone fruit trees results in losses including inferior fruit quality as determined by fruit size, color and maturity, reduced yields, lack of tree vigor, tissue dieback and in extreme cases tree death. Although this deficiency is generally corrected by application of an adequate amount of soluble K fertilizer, K deficiency is prevalent in non-irrigated sweet cherry and prune orchards in western Oregon and has been a persistent problem for many years (9).

Current recommendations for K soil amendments indicate that 2-6 kg K/tree, applied near the tree dripline in a concentrated band and preferably placed 15-20 cm deep, is necessary to correct K deficient trees (5,15,16). Foliar sprays of a 1% K solution of KNO_3 applied four, six, eight and ten weeks after full bloom have also been suggested as a possible supplement to soil applications of K for prune, peach and almond (5). Heavy mulching with organic or inorganic materials has been effective in correcting K deficiency of fruit trees in one growing season (1,2,6,7,20). Tree responses to mulch applications were due to increased available K, extended time of favorable soil moisture and/or increased growth of feeder roots (2,8,18). These recommended K soil amendments have not been effective in some cases in western Oregon hillside orchards and foliar K sprays and heavy mulching have not been tested.

A recent study was done of the soil characteristics in typical stone fruit orchards with K deficiency in the Willamette Valley of Oregon (14). In general these soils are fine textured, moderately acid and have extremely low native K contents particularly in the

subsoil. Liming these low base saturated soils did not result in more exchangable K, in contrast with results of other work (3,4), but base saturation in the soil A horizon was significantly correlated with tree leaf K. Applied K did move down into the soil profile when the ion exchange complex was saturated; however, no consistent relationship was found between available soil K and the K nutrition status of trees (14).

The purpose of this study was to determine the effectiveness of various soil amendment and foliar spray treatments for correcting K deficiency in sweet cherry and prune trees growing in soils on western Oregon hillsides.

MATERIALS AND METHODS

Test plots selected in February, 1978 were located in two established, non-irrigated, non-cultivated orchards west of Salem, Oregon. Sweet cherry (var. Royal Ann/Mazzard rootstock) trees were 19 years old, spaced 10.7 m X 10.7 m, averaged 36 cm in trunk diameter and August 1976 midshoot leaf K was 0.73%. Prune (var. Italian/myro 29-C rootstock) trees were 13 years old, spaced 3.4 m X 6.7 m, averaged 15 cm in diameter and August 1976 midshoot leaf K was 0.55%. Normal K content is 1.5 - 3.0%. Both plots were on Jory clay loam soils with pH of 5.4 - 5.8, K content of .37 - .64 meq/100 g soil in the A horizon, K content of .06 - .41 meq/100 g soil in the B horizon and base saturation of 30 - 40%.

Soil amendment tests. Treatments applied to sweet cherry and prune trees in March, 1978 with the exception of compost which was applied in October, 1978 were as follows:

1) Untreated control.
2) Band K: 11.36 kg granular K_2SO_4 in a 30 cm band encircling tree at .67 the distance from trunk to dripline.
3) Auger K: 11.36 kg granular K_2SO_4 in eight evenly spaced 5.1 cm diameter by 35 cm deep holes encircling tree at the same radius as in band K.
4) Soil injection K: 11.36 kg finely ground K_2SO_4 dissolved in 189 liters water and pressure injected into soil at a depth of 30 cm at 12 evenly spaced points encircling tree at same radius as in band K.
5) Compost: Mushroom production compost containing 2.28 kg K/m^3 was applied at the rate of 7.6 m^3 on sweet cherry and 1.3 m^3

on prune.

6) Soil + trunk injection K: Prune only. Soil injection as in 4) above was combined with a June, 1978 pressure trunk injection on 12.5 g K (K_2HPO_4) by the method of Robbins (12).

Trenching tests. In October, 1978 trenches 15 cm wide and 30-45 cm deep were dug 7.6 m long at .67 the distance from the trunk to the dripline in sweet cherry and 3.4 m long at the dripline in prune. The trenches were then backfilled with one of the following amendments added:

1) Untreated control.

2) Trench only.

3) K_2SO_4: 11.36 kg/tree.

4) Dolomite lime: 11.36 kg/sweet cherry tree; 5.68 kg/prune tree.

5) K_2SO_4 + Dolomite lime: as in 2) and 3) above.

Foliar spray tests. One percent K sprays were applied with a hand gun to the drip point (30-34 liter/sweet cherry tree, 11-15 liter/prune tree) at 30, 40, 50 and 60 days post bloom as follows:

1) Untreated control.

2) KNO_2: 9.6 g/liter.

3) K_2SO_4: 8.4 g/liter.

Samples consisting of 20 random mid-shoot leaves were collected from soil amendment test trees in 8/78, all test trees in 8/79 and all except foliar spray test trees in 8/80. Samples consisting of 20 random non-fruiting spur leaves were collected in the foliar spray tests before treatment at 30 and 50 days post bloom. Samples were analyzed for N by automatic Kjeldahl (13) and K, P, Ca, Mg, Mn, Fe,

Cu, B, Zn and Al by spark emission spectroscopy (10).

Growth of trees in the sweet cherry soil amendment and trenching tests and prune soil amendment test was estimated by measuring the change in trunk cross sectional area (19) from 2/78 to 9/80 and by measuring the length of ten random one year old shoots in 2/81.

Yields were measured in the sweet cherry tests in 1979 and 1980. Prune yields in the soil amendment test were measured in 1980. Fruit (without stems) weight and volume were measured by weighing and water displacement of 100 fruits. Juice from ten of these fruits was mixed and soluble solids (SS) determined with a refractometer.

All tests were randomized block designs with eight single tree replications. Data were analyzed by the appropriate analysis of variance (17) and least significant difference (LSD) values were calculated only when F values were significant. All treatments were compared to the untreated control. Linear regression analyses (11) were performed on all measured variables with leaf K content as the independent variable in each case.

RESULTS AND DISCUSSION

Soil amendment test: Band K, auger K and soil injection K in sweet cherry had no effect on leaf K during the two years of the study (Table 5). All treatment means indicated deficient (1.2%) or below normal (1.2-1.5%) K. Cherry trees receiving compost had normal leaf K levels (1.5-3.0%) the year following and two years following application (Table 5).

In 1979, the year following treatment, cherry trees receiving compost had a significantly higher leaf N content than the controls (2.23 vs. 2.04%); however, this level was below normal (2.3%). Leaf Mg levels were significantly lower but normal in trees receiving compost (.31 vs. .48%) indicating soil and/or plant cations anatagonisms. All other minerals were present at normal levels.

In August, 1980, leaf N was below normal for all soil amendment treatments in cherry and other minerals were present at normal levels.

Sweet cherry tree growth and crop yield were not significantly increased within two years of treatment by any soil amendment (Table 6). Fruit weight was significantly greater in 1980 and fruit volume was significantly greater in 1979 and 1980 on trees receiving compost (Table 6). Fruit SS were unaffected by treatment (Table 6).

Band K, Auger K, soil injection K and soil plus trunk injection K significantly increased leaf K in prune trees the year of treatment and remained effective two years after treatment (Table 7). Control trees had normal leaf K (1.5-3.0%) in 1978 because of poor cropping and had deficient K (1.3%) the following two years (Table 7). Prune trees receiving compost had above normal leaf K the year following treatment and normal K two years following treatment (Table 7).

The year following treatment, prune trees receiving compost had normal leaf P (.16%) and leaf B (36 ppm) when all other treatment groups had below normal P (.10-.13%) and below normal (30-35 ppm) or deficient (<30 ppm) B. Other minerals were present in normal amounts for all soil amendment treatments; however, trees receiving compost had significantly higher leaf N (2.23 vs. 1.96%), Ca (2.53 vs. 1.37%), Mn (127 vs. 80 ppm), Fe (99 vs. 57 ppm) and Cu (11 vs. 6 ppm) and lower leaf Mg (.40 vs. .56%) than the controls. In 1980, two years following treatment all soil amendment treatment groups in the prune tree test had normal leaf N, P, Ca, Mg, Mn, Fe, Cu, B and Zn. Trees receiving compost had significantly higher leaf N (2.34 vs. 1.86%), P (.17 vs. .15%), Ca (2.38 vs. 2.14%), Mn (140 vs. 119 ppm) and Cu (10 vs. 8 ppm) and lower leaf Mg (.48 vs. .63%) than the controls.

Prune tree trunk cross sectional area increase from 2/78 to 9/80 was not affected by soil amendment treatment (Table 8). Shoot growth was 54% greater and crop yield was 112% greater in trees receiving compost while fruit weight, volume and SS were unaffected (Table 8).

Trenching tests. Trench only, trench + K, trench + lime and trench + K + lime had no effect on sweet cherry leaf K the year following treatment or two years following treatment (Table 5) when all groups were deficient in K. All trenching treatment groups had below normal leaf N and normal leaf P, Ca, Mg, Mn, Fe, Cu, B and Zn in 1979 and 1980.

Trunk area increase of sweet cherry trees was not affected by any trenching treatment; however, 1980 shoot growth and 1979 crop yield were significantly lower in trench + lime and trench + K + lime groups (Table 6). Fruit size was affected in 1980 when trench only,

trench + lime and trench + K + lime had significantly smaller fruit than controls. Soluble solids in cherry fruits were not affected by treatment.

Leaf K in prune was significantly increased to a normal level one and two years following treatment by trench + K and trench + K + lime (Table 7). Trench + lime treated trees had significantly higher but below normal leaf K levels two years following treatment (Table 7). All trenching treatment groups had below normal leaf P in 1979 and 1980, deficient B in 1979 and normal Ca, Mg, Mn, Fe, Cu, and Zn in 1979 and 1980. Trenching + lime treated trees had below normal leaf N in 1979 and 1980 while other treatment groups had normal N levels.

Foliar spray tests. Foliar KNO_3 and K_2SO_4 sprays had no effect on leaf K in sweet cherry (Table 9).

In prune trees, leaf K levels were maintained during the growing season by KNO_3 and K_2SO_4 foliar sprays resulting in normal August leaf K levels that were significantly higher than the K deficient controls (Table 9). Some mild spray toxicity (spot burn) was observed on leaves of KNO_3 sprayed trees before the third spray was applied.

Linear regression analyses of 1979 and 1980 sweet cherry soil amendment and trenching test data and 1980 prune soil amendment test data showed that fruit weight and volume were partially dependent on August midshoot leaf K levels (Table 10). These analyses indicate that in sweet cherry 17-20% of the variability in fruit weight and 21-23% of the variability in fruit volume could be accounted for by variations in leaf K. In prune, 14% of the variability in fruit weight and 11% of the variability in fruit volume could be accounted

for by variations in leaf K.

Shoot growth of sweet cherry trees in 1980 was partially dependent on August midshoot leaf K levels (Table 10). An R^2 value of .344 indicated that 34% of the variation in shoot growth could be explained by variations in leaf K content.

In general, prune trees responded better to K treatments than sweet cherry trees. In sweet cherry, only the compost mulch treatment was able to induce a positive response in terms of increased leaf K and fruit size; however, in two years this treatment had not increased tree vigor or yield. Prune trees responded with increased leaf K to all treatments but only the compost mulched trees had significantly more vigor and yield.

Potassium is moving into the rooting zone with all the K treatments. The success of the mulch treatments particularly in the sweet cherry tests suggest that unmulched trees are not getting the necessary feeder root growth in the zones of high soil K at the necessary time and that this is probably due to lack of soil moisture in these zones. Other factors possibly limiting root growth are soil compaction and generally low vigor in some trees. This general low vigor could be due to virus infections and not a direct result of a mineral deficiency.

Further observations are necessary to establish whether trees with improved leaf K content will exhibit a complete recovery from K deficiency.

Table 5. Effect of K Soil Amendments on Mid-Shoot Leaf K Content in Sweet Cherry (Prunus avium L.)

Treatment	Date of Sampling		
	8/78	8/79	8/80
	% K	% K	% K
Control	1.24	1.20	.86
Band K[z]	1.33	1.25	1.05
Auger K[z]	1.04	1.01	.97
Soil Inj. K[z]	1.22	1.20	1.05
Compost[y]	1.32	2.00	1.69
LSD_{05}	NS	.29	.29
Trench[x]	-	.88	.86
Trench + K[x]	-	1.00	.90
Trench + L[x]	-	.91	.89
Trench + K + L[x]	-	1.04	.94
LSD_{05}	-	NS	NS

[z] 11.36 kg K_2SO_4, applied 3/78.

[y] 7.6 m^3, applied 10/78.

[x] applied 10/78, K = 11.36 kg K_2SO_4, L = 11.36 kg dolomite.

Table 6. Effect of K Soil Amendments on Growth, Yield, and Fruit Quality Factors in Sweet Cherry (Prunus avium L.)

Treatment	Change[z] trunk x-sect area (cm^2)	1980 shoot growth (cm)	Yield/tree		Fruit wt.		Fruit vol.		Fruit SS	
			1979 (kg)	1980 (kg)	1979 (g)	1980 (g)	1979 (cm^3)	1980 (cm^3)	1979 (%)	1980 (%)
Control	158	16.7	103	61	7.6	7.3	7.2	6.8	17.8	19.3
Band K[y]	202	15.2	76	45	8.0	7.1	7.5	6.7	18.7	19.4
Auger K[y]	122	10.4	88	61	7.7	7.0	7.2	6.5	18.7	19.5
Soil Inj. K[y]	115	14.6	77	56	7.7	7.1	7.2	6.6	18.7	19.4
Compost[x]	133	17.8	77	65	8.4	7.9	8.0	7.5	18.6	18.4
LSD_{05}	NS	5.4	NS	NS	NS	.6	.5	.6	NS	NS
Trench[w]	155	13.3	84	61	7.1	6.6	6.7	6.2	18.3	18.5
Trench + K[w]	96	11.8	93	46	7.4	6.8	7.0	6.4	18.5	19.1
Trench + L[w]	100	8.4	72	46	7.3	6.6	6.9	6.0	19.2	18.2
Trench + K + L[w]	212	11.2	74	46	7.4	6.3	6.9	6.0	18.0	18.3
LSD_{05}	NS	5.4	22	NS	NS	.6	NS	.6	NS	NS

[z]2/78-9/80; [y]11.36 kg K_2SO_4, applied 3/78; [x]7.6 m^3, applied 10/78; [w]applied 10/78, K = 11.36 kg K_2SO_4, L = 11.36 kg dolomite.

Table 7. Effect of K Soil Amendments on Mid-Shoot Leaf K Content in Prune (Prunus domestica L.)

Treatment	Date of Sampling		
	8/78	8/79	8/80
	% K	% K	% K
Control	1.54	1.07	1.17
Band K[z]	2.42	2.23	2.39
Auger K[z]	1.85	1.77	1.99
Soil Inj. K[z]	2.45	2.25	2.06
Soil + Trunk Inj. K[z]	2.63	2.07	2.18
Compost[y]	-	3.01	2.28
LSD_{05}	.30	.26	.23
Trench[x]	-	.96	.95
Trench + K[x]	-	2.06	2.11
Trench + L[x]	-	1.26	1.37
Trench + K + L[x]	-	1.94	2.07
LSD_{05}	-	.36	.11

[z] 11.36 kg K_2SO_4, applied 3/78.

[y] 1.3 m^3, applied 10/78.

[x] applied 10/78, K = 11.36 kg K_2SO_4, L = 5.68 kg dolomite.

Table 8. Effect of K Soil Amendments on Growth, Yield and Fruit Quality Factors in Prune (*Prunus domestica* L.)

Treatment	Change[z] trunk x-sect area (cm^2)	1980 Shoot growth (cm)	1980 Yield/ tree (kg)	1980 Fruit wt. (g)	1980 Fruit vol. (cm^3)	1980 Fruit SS (%)
Control	56	16.1	49	30.4	29.4	19.8
Band K[y]	53	18.2	52	34.4	32.8	21.6
Auger K[y]	55	16.6	60	33.1	31.7	21.3
Soil Inj. K[y]	54	18.2	58	30.6	29.0	19.6
Soil + Trunk Inj. K[x]	55	16.6	58	32.9	31.2	21.0
Compost[w]	-	24.8	104	33.0	31.0	19.6
LSD_{05}	NS	4.2	18	NS	NS	NS

[z] 2/78-9/80.

[y] 11.36 kg K_2SO_4, applied 3/78.

[x] Soil = 11.36 kg K_2SO_4 applied 3/78, trunk = 12.5 g K (K_2HPO_4) applied 6/78.

[w] 1.3 m^3 applied 10/78.

Table 9.. Effect of Foliar K on Leaf K Content in Sweet Cherry (Prunus avium L.) and Prune (Prunus domestica L.)

Crop	Treatment	Date of Sampling		
		5/79[z]	6/79[z]	8/79[y]
		% K	% K	% K
Sweet Cherry	Control	1.67	1.31	1.20
	KNO_3[x]	1.60	1.41	1.14
	K_2SO_4[x]	1.56	1.34	1.15
	LSD_{05}	NS	NS	NS
Prune	Control	1.78	1.41	1.20
	KNO_3[x]	1.59	1.58	1.63
	K_2SO_4[x]	1.70	1.70	1.79
	LSD_{05}	NS	NS	.36

[z]Non-fruiting spur leaves.

[y]Mid-shoot leaves.

[x]1% K solutions applied at 30, 40, 50 and 60 days post bloom.

Table 10. The Relationships between Leaf K Levels and Fruit Size and Shoot Growth in Sweet Cherry and Prune

Plot	Dependent Variable	Ent. F	Regression Equation	R^2
1979 Cherry Soil Tmts.	Fruit wt. (g)	**	$\hat{y} = .63(\%K) + 7.02$	.184
	Fruit vol. (cm^3)	**	$\hat{y} = .64(\%K) + 6.55$	.215
1979 Cherry Trench tmts.	Fruit wt. (g)	**	$\hat{y} = .75(\%K) + 6.63$	.167
	Fruit vol. (cm^3)	**	$\hat{y} = .77(\%K) + 6.14$	.206
1980 Cherry Soil and Trench tmts.	Fruit wt. (g)	**	$\hat{y} = 1.04(\%K) + 5.93$	.214
	Fruit vol. (cm^3)	**	$\hat{y} = 1.02(\%K) + 5.50$	.233
	Shoot length (cm)	**	$\hat{y} = 9.77(\%K) + 3.78$	.344
1980 Prune Soil Tmts.	Fruit wt. (g)	**	$\hat{y} = 3.32(\%K) + 25.96$	.144
	Fruit vol. (cm^3)	**	$\hat{y} = 2.72(\%K) + 25.51$	.110

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Appendix 2.

Analysis of Mushroom Compost

Compost from commercial mushroom production consisted basically of race track manure, grass hays and straws with amendments of grape pumice, wheat bran, $CaSO_4$, N, P, and K. Ground limestone ($CaCO_3$) was added to adjust initial pH to 7.5. Bulk density and dry weight were measured and mineral content was determined by spark emission spectroscopy (Table 12).

TABLE 11

The Bulk Density, Dry Weight and Mineral Content of Commercial Mushroom Production Compost Used in this Study

Bulk density (wet): 0.482 g/cm^3

Dry weight (%): 29.4

Mineral Content

% d.w.	ppm d.w.
N - 1.50	Mn - 231
K - 1.61	Fe - 743
P - .34	Cu - 12
Ca - 4.10	B - 12
Mg - .27	Zn - 55
	Al - 2678

Appendix 3.

Effect of Foliar K Sprays on Yield and Fruit Quality of Sweet Cherry

Four foliar sprays of KNO_3 (1% K) or K_2SO_4 (1% K) solutions during the growing season had no effect on fruit weight, fruit volume or soluble solids of sweet cherry but yield was significantly greater in control trees (Table 13). Yield differences were probably due to tree selection because no toxic spray effects were observed and excessive fruit drop did not occur on sprayed trees.

TABLE 12

Effect of 1979 Foliar K Sprays on 1979 Yield and Fruit Quality Factors of Sweet Cherry

Treatment	Yield (kg)	Fruit Wt. (g)	Fruit Vol. (cm^3)	SS (%)
Control	103	7.64	7.19	17.8
KNO_3[z]	63	7.49	7.2	19.7
K_2SO_4[z]	77	7.63	7.17	19.1
LSD_{05}	19	NS	NS	NS

[z]1% K solutions sprayed to drip point at 30, 40, 50 and 60 days post full bloom.

Appendix 4.

Effect of K Trunk Injections on Leaf Mineral Content of Sweet Cherry and Prune

Fall trunk injection of K_2HPO_4 (200 g K) significantly increased bud K content 16 days after treatment (Table 14).

TABLE 13

Effect of 10/15/77 K_2HPO_4 Trunk Injections on 7 and 16 Day Post Treatment K Content of Sweet Cherry Leaves and Buds

	Leaves			Buds		
	10/15	10/22	10/31	10/15	10/22	10/31
Treatment	% K	% K	% K	% K	% K	% K
H_2O	.52	.45	.35	.48	.46	.45
50 g K	.46	.49	.37	.43	.49	.46
100 g K	.53	.46	.43	.45	.47	.45
200 g K	.63	.72	.51	.49	.54	.55
LSD_{05}	NS	NS	NS	.03	NS	.04

Fall trunk injection of K_2SO_4 (200 g K) significantly lowered August leaf Mg and Mn and K_2HPO_4 (300 g K) injection reduced leaf Mn in sweet cherry however all were normal concentrations (Table 15). Other leaf nutrient levels were not affected by fall injections (Table 15).

TABLE 14

Effect of 10/78 K Trunk Injections on 8/79 Leaf Mineral Content of Sweet Cherry

Treatment	% d.w.					ppm d.w.					
	N	K	P	Ca	Mg	Mn	Fe	Cu	B	Z	Al
Control	2.04	1.20	.17	1.26	.48	104	153	10	65	13	116
H_2O	2.05	1.05	.17	1.29	.49	70	104	8	68	16	73
200 g K (K_2SO_4)	2.10	1.39	.18	1.10	.38	66	131	10	62	14	95
200 g K (K_2HPO_4)	2.20	1.27	.27	1.41	.51	92	163	10	68	17	126
300 g K (K_2HPO_4)	2.05	1.42	.23	1.31	.42	74	138	10	68	18	95
LSD_{05}	NS	NS	NS	NS	.08	26	NS	NS	NS	NS	NS

Late spring trunk injections of K_2SO_4 or K_2HPO_4 solutions containing up to 12.5 g K had no effect on prune leaf mineral content the year of treatment (Table 16) or the year following (Table 17).

TABLE 15

Effect of 6/78 K Trunk Injections on 8/78

Leaf Mineral Content of Prune

Treatment	% d.w.		ppm d.w.					
	Ca	Mg	Mn	Fe	Cu	B	An	Al
Control	1.41	.48	65	48	7	40	21	28
Dist. H_2O	1.34	.47	75	52	8	42	20	30
6.25 g K (KH_2PO_4)	1.22	.41	65	59	8	41	21	23
12.5 g K (KH_2PO_4)	1.31	.45	64	46	6	44	21	28
6.25 g K (K_2SO_4)	1.38	.46	75	65	8	43	19	33
12.5 g K (K_2SO_4)	1.36	.41	63	131	8	39	20	34
LSD_{05}	NS	NS	NS	NS	NS	NS	NS	NS

TABLE 16

Effect of 6/78 K Trunk Injections on 8/79

Leaf Mineral Content of Prune

Treatment	% d.w.					ppm d.w.					
	N	K	P	Ca	Mg	Mn	Fe	Cu	B	Zn	Al
Control	1.96	1.07	.12	1.37	.56	80	57	6	29	22	43
Dist. H_2O	1.79	1.03	.13	1.30	.50	74	58	7	31	24	47
6.25 g K (K_2HPO_4)	1.92	1.07	.13	1.39	.49	78	60	7	35	23	52
12.5 g K (K_2HPO_4)	2.01	1.26	.13	1.45	.53	85	70	7	31	20	62
6.25 g K (K_2SO_4)	1.91	1.05	.12	1.34	.46	72	55	6	33	21	50
12.5 g K (K_2SO_4)	1.89	1.13	.13	1.39	.49	78	56	8	31	21	39
LSD_{05}	NS	NS	NS	NS	NS	NS	NS	NS	3	NS	14

Non-replicated trunk injections of 12.5-100 g K to prune trees in June indicated that 12.5 g K was the maximum dose that could be used without sustaining substantial tree injury. Some injury occurred in all cases. Three leaf samples of ten leaves each were obtained from each tree three days after treatment and consisted of 1) affected leaves on affected branch, 2) non-affected leaves on affected branch and 3) non-affected leaves on non-affected branch. These samples were analyzed for K and P content (Table 18). Potassium sulfate was generally more toxic than K_2HPO_4 at a given dosage.

TABLE 17

Effects of 6/16/78 Non-replicated K Trunk Injections on the Three Day Post Treatment K and P Content of Midshoot Leaves of Prune

Treatment	6/16/78-Pre		Affected leaves on affected branch		Non-affected leaves on affected branch		Non-affected leaves on non-affected branch	
	% K	% P	% K	% P	% K	% P	% K	% P
12.5 g K (K_2HPO_4)	1.55	.14	2.14	.67	1.57	.23	1.54	.15
12.5 g K (K_2SO_4)	1.79	.16	1.93	.17	1.53	.14	1.60	.17
25 g K (K_2HPO_4)	1.09	.15	1.73	.55	1.19	.38	1.10	.17
25 g K (K_2SO_4)	1.51	.17	2.11	.14	1.62[z]	.17[z]	2.07[y]	.16[y]
50 g K (K_2HPO_4)	1.42	.16	3.90	1.43	1.62[z]	.40[z]	1.37	.15
50 g K (K_2SO_4)	1.79	.15	2.84	.14	2.89[z]	.99[z]	1.78[y]	.16[y]
100 g K (K_2HPO_4)	1.76	.18	1.97	.17	1.55	.23	1.90	.33

[z]mildly affected leaves.

[y]non-affected leaves on affected branch.

Appendix 5.

Effect of K Soil Amendments on Leaf Mineral Content of Sweet Cherry and Prune

Applications of 11.36 kg K_2SO_4 in March to sweet cherry trees by banding, augered holes or soil injection did not affect leaf nutrient content the year of treatment (Table 19). The growing season following treatment, compost mulch raised leaf N while leaf Mg was lowered (Table 20). Two years following treatment leaf Ca levels were significantly greater in trees with banded K and leaf Mg was lower for all treatments (Table 21). All K soil amendment treatments resulted in higher leaf levels of B and Zn (Table 21).

TABLE 18

Effect of 3/78 K Soil Amendments on 8/78 Leaf Mineral Content of Sweet Cherry

Treatment	% d.w.			ppm d.w.					
	P	Ca	Mg	Mn	Fe	Cu	B	Zn	Al
Control	.14	1.08	.32	76	108	7	65	10	73
Band K	.15	1.11	.33	70	97	11	69	12	62
Auger K	.14	1.20	.37	70	94	7	67	14	63
Soil inj. K	.15	1.09	.33	69	96	7	66	11	61
Compost[z]	.15	1.19	.32	61	87	6	66	11	59
LSD_{05}	NS	NS	NS	NS	NS	NS	NS	NS	NS

[z]Applied 10/78.

TABLE 19

Effect of 8/78 K Soil Amendments on 8/79 Leaf Mineral Content of Sweet Cherry

Treatment	% d.w.				ppm d.w.					
	N	P	Ca	Mg	Mn	Fe	Cu	B	Zn	Al
Control	2.04	.17	1.26	.48	104	153	10	65	13	116
Band K	2.13	.19	1.32	.44	84	134	9	67	16	96
Auger K	2.04	.16	1.29	.47	78	99	9	67	17	74
Soil inj. K	1.97	.17	1.21	.48	74	126	9	64	16	89
Compost[z]	2.23	.17	1.23	.31	82	101	9	66	13	60
LSD_{05}	.16	NS	NS	.09	NS	NS	NS	NS	NS	NS

[z]Applied 10/78.

TABLE 20

Effect of 3/78 Soil Amendments on 8/80 Leaf Mineral Content in Sweet Cherry

Treatment	% d.w.				ppm d.w.					
	N	P	Ca	Mg	Mn	Fe	Cu	B	Zn	Al
Control	2.08	.13	1.12	.46	64	107	7	44	38	73
Band K	2.08	.15	1.24	.42	70	123	10	50	45	86
Auger K	2.02	.16	1.16	.39	67	118	9	60	60	89
Soil inj. K	2.20	.15	1.08	.41	63	103	9	51	45	72
Compost	2.21	.15	1.11	.34	71	109	10	50	43	70
LSD_{05}	NS	NS	.07	.02	NS	NS	NS	3	5	NS

Potassium soil amendment treatments of prune trees had no effect on leaf mineral content the year of treatment (Table 22). The year following treatment leaf N, P, Ca, Mn, Fe, Cu, B and Al were increased by compost mulch while leaf Mg was reduced (Table 23). Trees with banded K had lower leaf Mg and Zn levels than controls and trees with augered K had greater leaf Ca, Mn and Cu and lower leaf Mg (Table 23). Trees with soil injected K had greater leaf Mn, Fe and Cu and lower leaf Mg and Zn than controls (Table 23).

Two years following treatment of prune trees leaf levels of N, P, Ca, Mg, Mn and Cu were affected (Table 24). Leaf N was greater in trees with soil injection and compost treatments than in control trees.

Phosphorus was lower in leaves from trees with augered K and soil injected K and higher in trees receiving compost. Leaf Ca was lower in trees with augered K and higher in trees receiving compost. Magnesium levels were reduced in leaves by all treatments and leaf Cu was greater in all treatment groups except the soil plus trunk injection group. Leaf Mn was greater in trees with banded K, soil injected K and compost treatments but lower in trees with soil plus trunk injected K.

TABLE 21

Effect of 3/78 K Soil Amendments on 8/78 Leaf Mineral Content of Prune

Treatment	% d.w.			ppm d.w.					
	P	Ca	Mg	Mn	Fe	Cu	B	Zn	Al
Control	.11	1.41	.48	65	48	7	40	21	28
Band K	.09	1.13	.33	68	66	8	35	16	31
Aguer K	.12	1.40	.47	76	65	8	45	20	34
Soil Inj. K	.11	1.56	.39	90	85	8	40	19	33
Soil & Trunk Inj. K[z]	.13	1.51	.44	90	70	8	42	16	36
LSD_{05}	NS	NS	NS	NS	NS	NS	NS	NS	NS

[z]Trunk inj. applied 6/78.

TABLE 22

Effect of 3/78 K Soil Amendments on 8/79 Leaf Mineral Content of Prune

Treatment	% d.w.				ppm d.w.					
	N	P	Ca	Mg	Mn	Fe	Cu	B	Zn	Al
Control	1.96	.12	1.37	.56	80	57	6	29	22	43
Band K	1.91	.12	1.65	.40	92	66	6	31	16	50
Auger K	1.93	.13	1.83	.44	97	68	7	32	21	55
Soil Inj. K	1.83	.13	1.55	.43	100	75	8	30	18	53
Soil & Trunk Inj. K[z]	1.90	.12	1.45	.40	86	66	7	28	16	46
Compost[y]	2.23	.16	2.53	.40	127	99	11	36	22	76
LSD_{05}	.17	.02	.33	.06	14	12	1	4	4	12

[z]Trunk inj. applied 6/78.

[y]Applied 10/78.

TABLE 23

Effect of 3/78 K Soil Amendments on 8/80 Leaf Mineral Content of Prune

Treatment	% d.w.				ppm d.w.					
	N	P	Ca	Mg	Mn	Fe	Cu	B	Zn	Al
Control	1.86	.15	2.14	.63	119	108	8	38	26	91
Band K	1.86	.15	2.12	.46	123	117	9	38	24	108
Auger K	1.87	.14	1.98	.51	120	108	9	34	20	93
Soil Inj. K	2.11	.14	2.09	.50	133	137	9	33	21	120
Soil & Trunk Inj. K[z]	1.95	.14	2.14	.51	114	105	8	34	22	92
Compost[y]	2.34	.17	2.38	.48	140	120	10	37	25	101
LSD_{05}	.04	.01	.06	.02	4	NS	1	NS	NS	NS

[z]Trunk inj. applied 6/78.

[y]Applied 10/78.

Appendix 6.

Effect of Trenching Treatments on Leaf Mineral Content of Sweet Cherry and Prune

Trenching treatments had no effect on sweet cherry leaf mineral content the year following treatment (Table 25). Two years following treatment leaf Ca, Mg, B and Zn were significantly greater than the control for all trenching treatments regardless of accompanying amendment (Table 26).

TABLE 24

Effect of 10/78 Trenching Treatments on 8/79 Leaf Mineral Content of Sweet Cherry

Treatment	% d.w.				ppm d.w.					
	N	P	Ca	Mg	Mn	Fe	Cu	B	Zn	Al
Control	2.04	.17	1.26	.48	104	153	10	65	13	116
Trench only	2.17	.16	1.24	.51	77	121	9	58	23	88
Trench + K[z]	1.99	.16	1.31	.51	72	127	9	65	14	89
Trench + lime[y]	2.01	.16	1.24	.50	68	100	9	59	13	74
Trench + K + lime	2.05	.15	1.29	.47	73	109	9	59	13	76
LSD_{05}	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

[z]11.36 kg K_2SO_4.

[y]11.36 kg dolomite.

TABLE 25

Effect of 10/78 Trenching Treatments on 8/80 Leaf Mineral Content of Sweet Cherry

Treatment	% d.w.				ppm d.w.					
	N	P	Ca	Mg	Mn	Fe	Cu	B	Zn	Al
Control	2.08	.13	1.12	.46	64	107	7	44	38	73
Trench only	2.21	.15	1.39	.52	75	126	15	53	57	91
Trench + K	2.14	.15	1.50	.49	78	119	9	55	71	73
Trench + lime[z]	2.07	.15	1.40	.53	75	117	10	52	47	89
Trench + K + lime[y]	2.22	.15	1.51	.56	84	127	13	52	56	85
LSD_{05}	NS	NS	.07	.02	NS	NS	NS	3	5	NS

[z]11.36 kg K_2SO_4.

[y]11.36 kg dolomite.

Prune trees were affected by trenching treatments the year following treatment (Table 27). Leaf Mg and Zn were lower for all trenching treatments while leaf Fe and Al were greater. Leaf Ca and Cu were greater in trenched trees receiving an amendment of K plus dolomite lime.

TABLE 26

Effect of 10/78 Trenching Treatments on 8/79

Leaf Mineral Content of Prune

Treatment	% d.w.				ppm d.w.					
	N	P	Ca	Mg	Mn	Fe	Cu	B	Zn	Al
Control	1.96	.12	1.37	.56	80	57	6	29	22	43
Trench only	1.90	.10	1.24	.50	81	89	6	29	16	85
Trench + K[z]	2.03	.11	1.40	.42	90	84	6	28	14	69
Trench + lime[y]	1.84	.12	1.33	.47	83	87	6	30	17	88
Trench + K + lime	1.99	.11	1.60	.46	92	77	8	30	16	62
LSD_{05}	NS	NS	.21	.06	NS	16	1	NS	3	16

[z]11.36 kg K_2SO_4.

[y]5.68 kg dolomite.

Two years after treatment of prune trees, leaf N was higher and leaf P and Ca were lower for all trenching treatments (Table 28). Leaf Mg was lower in trenched trees with K or lime amendments and leaf Mn was lower in trenched trees with lime only added (Table 28). Leaf Cu was lower for all trenching treatments except for trees receiving both K and lime where leaf Cu was higher (Table 28).

TABLE 27

Effect of 10/78 Trenching Treatments on 8/80

Leaf Mineral Content of Prune

Treatment	% d.w.				ppm d.w.					
	N	P	Ca	Mg	Mn	Fe	Cu	B	Zn	Al
Control	1.86	.15	2.14	.63	119	108	8	38	26	91
Trench only	1.97	.11	1.73	.63	118	109	7	36	27	78
Trench + K[z]	1.99	.12	1.90	.49	121	111	7	34	22	91
Trench + lime[y]	1.84	.12	1.91	.60	105	84	7	37	24	66
Trench + K + lime	2.09	.13	2.02	.53	120	118	9	33	20	83
LSD_{05}	.04	.01	.06	.02	4	NS	1	NS	NS	NS

[z]11.36 kg K_2SO_4.

[y]5.68 kg dolomite.

Appendix 7.

Effect of K Foliar Sprays on Leaf Mineral Content of Sweet Cherry and Prune

Foliar sprays of KNO_3 (1% K) or K_2SO_4 (1%) at 30, 40, 50 and 60 days post full bloom had no effect on the August leaf mineral content of sweet cherry (Table 29).

TABLE 28

Effect of 1979 Foliar K Sprays on 8/79 Leaf Mineral Content of Sweet Cherry

	% d.w.				ppm d.w.					
Treatment	N	P	Ca	Mg	Mn	Fe	Cu	B	Zn	Al
Control	2.04	.17	1.26	.48	104	153	10	65	13	116
KNO_3 [z]	2.08	.18	1.19	.44	60	114	11	67	15	86
K_2SO_4 [z]	2.07	.16	1.27	.45	66	121	8	66	23	86
LSD_{05}	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

[z] 1% K solutions sprayed to drip point at 30, 40, 50 and 60 days post full bloom.

Iron levels in leaves of prune trees sprayed with KNO_3 or K_2SO_4 solutions were significantly higher than the control (Table 30). Leaf Cu was lower in trees receiving K_2SO_4 sprays and leaf levels of all other minerals were not affected by treatment (Table 30).

TABLE 29

Effect of 1979 K Foliar Sprays on 8/79 Leaf Mineral Content of Prune

Treatment	% d.w.				ppm d.w.					
	N	P	Ca	Mg	Mn	Fe	Cu	B	Zn	Al
Control	1.84	.12	1.46	.46	71	50	7	28	17	40
KNO_3[z]	2.00	.13	1.44	.48	78	61	7	30	21	44
K_2SO_4[z]	1.88	.13	1.63	.41	82	59	5	30	21	44
LSD_{05}	NS	NS	NS	NS	NS	8	1	NS	NS	NS

[z]1% K solutions sprayed to drip point at 30, 40, 50 and 60 days post full bloom.