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Title: "Instant Orchard": Technique for the Production of Ready-to-Bear Temperate Zone Fruit Trees

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Techniques for producing "ready-to-bear" fruit trees for planting new orchards and as replacements in existing orchards are presented. A preliminary study determined the feasibility of producing trees in a 100% Douglas-fir bark medium. Three plant species and conventional chemical fertilizers were used. In an additional study, 'Newtown Pipin' apple trees on Malling Merton (MM 106) rootstock were planted into plastic lined wooden containers, with two different volumes (0.2 m^3 and 0.4 m^3) of Douglas-fir bark and three different fertilizer rates. Half the trees were planted with a small volume (7.6 liters) of soil surrounding the root system in order to determine the

effect soil would produce in a bark media. All of these factors significantly influenced growth.

In the 0.2 m^3 bark volume, total shoot growth was less than in the 0.4 m^3 volume. No differences were observed between trees grown in the two lower fertilizer levels, but total shoot growth was reduced by the high fertilizer level. The addition of soil to the media decreased total shoot growth because of water logged conditions and collar rot (*Phytophthora cactorum*). Growth was greatest in the larger medium volume without soil, with both the low and middle fertilizer rates.

"Instant Orchard": Technique for the Production of Ready-to-Bear Temperate Zone Fruit Trees

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"INSTANT ORCHARD": TECHNIQUE FOR THE PRODUCTION OF READY-TO-BEAR TEMPERATE ZONE FRUIT TREES

1. INTRODUCTION

The present economics of fruit production in Hood River County provides motivation to develop a method for producing movable ready-to-bear fruit trees. Unimproved land in the county suitable for orchards sells for $10,000 per acre. With interest rates at 10-15%, any delay in bringing a new orchard into production is extremely costly. It is also costly to remove and replant old orchards, yet this must be done if the fruit industry is to remain competitive.[1]

The current practice for replacing old orchards is to interplant one-year-old nursery whips between the old trees in the row. Once the new trees are established and growing, the older trees are pruned back, and eventually removed. Often as a result of excessive shading, weed competition, disease problems attributed to the older infected trees, damage from harvest equipment, and improper irrigation and fertilization, these newly planted trees either die, or grow slowly and are

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[1] Grant proposal, Dr. R. L. Stebbins, Department of Horticulture, Oregon State University, Corvallis, 1982.

poorly shaped. Since many older orchards have improper tree spacing for the best land utilization, interplanting can result in a repeat of previous mistakes (87).

The purpose of this research is to develop a technically feasible method of producing container grown ready-to-bear fruit trees for later orchard transplant. Producing trees for the home-owner market could be another application of this technique. It is believed that a sizable market exists for the "ready-to-bear" fruit trees.[1,2]

Ideally, an orchardist would be able to utilize this technique with conventional nursery stock, equipment normally available in orchards, and on land that is not suitable for orchards. The flexibility of the container system allows the grower to take advantage of alternative sites. The use of inexpensive containers, along with conventional fertilizers and lime instead of slow-release formulations may be desired. Another feature that sets this approach apart from other experimental methods is the complete elimination of

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[1] Personal Communication, Carlton Nursery, Dayton, Oregon, 1981.

[2] Grant proposal, Dr. R. L. Stebbins, Department of Horticulture, Oregon State University, Corvallis, Oregon, 1982.

of root pruning (45, 55, 57, 58, 78, 88, 89). To accomplish this large volumes of growing media are needed. Hence, the success of this idea depends on finding an abundant, relatively inexpensive source of growing medium.

II. LITERATURE REVIEW

Production of Large Caliper Trees: Past, Present Research, and Future

Past

Producing and transplanting mature trees is not a new idea; it has been practiced for centuries (49, 78). As early as the sixteenth century, gardens in Europe were filled with container-grown plants. Some trees spent the duration of their lives in the pots, while others were later transplanted into the field (8). The well known treatise by Agricola (2) shows many pictures of large fruiting trees in pots and he briefly discusses transplanting them. Part of his experiments involve using pots for propagating lemons.

During the Victorian era, large trees were commonly moved by hand. A large, square root or soil mass was dug and the tree moved to its new site by rolling it on logs (86). James Johnson, Scotland's Secretary of State in the early eighteenth century, was well known for his skill in successfully transplanting large trees during the hottest months of the summer (41).

In the past, nurseries have been growing large "specimen" trees to be balled and burlapped, for landscape use. Large trees from natural forest settings into man-made landscapes have been transplanted. In 1951, three Scotch Pines approximately 18 m high, with a spread of 12 m, and a diameter of 0.7 m, were moved 33 miles and replanted. The total cost of the operation was $78,000 and twenty-five years later, the trees are still thriving in their new location -- Akron, Ohio (59).

Over the last 10 years the use of the powered tree spade has increased. The machine consists of a frame, a base, and four hydraulically driven, water lubricated blades, which push into the soil, envelope a tree's root system with the surrounding soil, and lift the tree roots, soil and all, from the ground. It can also be used to dig the new hole which will receive the tree (83).

In New Zealand a 98% survival rate of shade trees was reported with the tree spade. In the city of Lansing, Michigan, spade dug street trees had a survival rate of 99% as opposed to 59% for bare-rooted trees (24, 83). The tree spade has also been used to move fruit and nut trees (78, 83, 91). In one instance, hazelnut trees, *Corylus avellana* moved by a tree spade later suffered injury or died because of heat stress. How well these trees will produce in the future remains to be seen (78).

Three limitations of the tree spade have been reported: 1) weather constraints; 2) availability of trees within a reasonable hauling distance; and 3) loss of root system (24, 75). The tree spade cannot be used if the weather is too hot. Heavy rains or snowfall will limit the machine's mobility and subsequently its use (24). Cost of machine time may be an economic limitation relative to the distance trees may be moved. Trees with no advanced root pruning will lose as much as 75% or more of their root systems (78), in which case the tops should be severely pruned. Pruning young, non-bearing trees delays the onset of bearing and reduces the quality of fruit produced in the early years (77, 85).

Present Research

Because of costs involved in producing and moving semi-mature trees, several researchers have focused on making this process more economically feasible. Presently, almost all efforts to produce large caliper trees are concentrated in the shade tree industry. The strategy usually includes some type of root pruning and a potting system. The following approaches have been tried:

but continuation of root growth is prevented by the oxygen deficient water.

Other advantages of the buried container were the elimination of both winter injury to roots and toppling of trees in heavy winds.

2. At Oklahoma State University a different approach to root pruning and tree production was developed (88, 89). The tree seedlings were grown in open bottomed containers which were placed on wire benches. The containers were filled with a 2-1-1 mixture of ground pine bark, peat, and perlite. The tap root of a seedling will grow until it makes contact with the air, which kills the root tip, stimulating branching and ultimately resulting in a fibrous, compact root system.

   The air pruned trees were transplanted into flat bottomed, all wire baskets (61 cm top diameter, 51 cm base diameter, and 36 cm deep). Black 6 mil polyethylene was cut to cover the bottom of the basket to prevent root penetration below the basket. Lastly, holes were augered and the baskets were placed in the ground.

Handles on the baskets facilitated harvest. The trees were quickly harvested, resulting in a savings of time and labor compared to preparing balled and burlapped trees. Trees grown under this method were equal or superior to trees planted in the same field without the wire baskets. During harvest, additional root pruning occurs when the baskets are dug. If trees were grown for more than two years utilizing this method, a large amount of root pruning might be required for harvesting.

3. The "Clemson Method" (55) also incorporates the use of wire baskets. Trees are first balled and burlapped and then placed in wire baskets which will be planted into the ground. The holes into which the trees are to be planted are lined with a woven synthetic material that is water-permeable to allow adequate drainage, but restricts root growth out of the root ball. Drainage tile was also installed at the bottom of a row of holes.

   After one year, the root system of the trees in the baskets were compared with those of trees freshly dug from the field. The trees grown under the "Clemson method" had a more fibrous, well developed root system, with no reduction in top growth.

4. The "Wooster Tube Method" (45) was developed to eliminate some of the inherent problems of containerized trees and shrubs. Under this system the plants are grown in the field until they reach a salable size. Then a hollow Wooster Tube (#26-gauge with a 20 cm diameter, 23 cm high, and approximately 7.6 liter capacity) is placed over the plant and driven into the ground until the top is about even with the ground surface. The insertion of the tube prunes side roots which stimulates the formation of a denser, more compact root system.

   After 6-12 months (from spring to fall, from fall to spring, or spring to next spring) the tube, along with the soil/root ball is removed and placed in a container or plastic wrapping for transportation.

   The advantages of this method include: a) A smaller soil/root ball than commercial balled-and-burlapped plants is produced. It is easier to handle and reduces transportation costs; b) It results in a denser root system than that developed by balled and burlapped plants; and c) Since plants are grown in the field, it eliminates over-wintering costs and problems. However, future use depends on the development of machines to drive the tube into the ground and later to lift the tube.

Future

The idea of growing trees in a water culture is not new. Nutritional studies were conducted in 1940 at East Malling Research Station (England) with apple trees planted into covered earthenware containers which were filled with water. Since apples are sensitive to water logged conditions, the water solution had to be continuously aerated. The trees were started in rain water, but later, nutrient solutions were used and changed each week (56).

Trees in water culture made significantly more growth than those in the field, but this was attributed to the longer growing period and higher temperatures in the greenhouse where they were grown (56). Perhaps this approach can be refined to accommodate the production of large caliper trees.

A new Israeli agricultural system called "aeroponics", could be adopted for the purpose of producing large caliper trees. With aeroponics, plant root systems grow in sealed chambers where the exposed roots receive a nutrient-enriched mist from a computer controlled spray system. This practice of aeroponics results in less water and fertilizer usage, with experimental yields 34-200% higher than those achieved under soil farming (72).

In spite of these promising results, the initial cost of production is still very high, especially for small scale use.

When producing semi-mature trees in containers, it is important to avoid root circling within the container as this can be detrimental to subsequent growth. This can be accomplished by either root pruning or large volumes of a planting medium. Root pruning methods utilize specialized equipment and containers, making them more complicated.

The proposed technique uses large volumes of planting media. Bark was chosen because: ample quantities are available in the Pacific Northwest, it is relatively inexpensive, it has a low bulk density, and it has good inherent growth characteristics.

Bark Production and Use in Horticulture

Nearly five million tons of tree bark were produced as waste in 1966 from the Pacific Northwest wood products industry. More than two thirds of this bark came from Oregon and Washington. Douglas-fir (*Pseudotsuga menziesii* represented 48% of that fraction (9).

In 1966 only 10% of the total bark produced was used for agricultural purposes. At that time tree bark had relatively little economic value, and presented a major disposal problem for the industry. Most of the bark was buried in trenches and landfills, or more commonly, burned. This latter practice resulted in a significant source of air pollution (6, 9).

Presently, bark is employed as a landscape mulch, a soil amendment, a soil mix for containers, and a compost material (9, 53).

Douglas-fir Bark as Growth Medium in Containers

Physical Structure

As long as there is adequate aeration, it is desirable to use materials that have a high water holding capacity. Aeration is important for respiration by the roots. The required free porosity after drainage (loss of water by gravity) normally varies from 2% to 20% or more, Douglas-fir bark has a free porosity range of 31.5% to 54.7% (30, 42). The bark's relatively large particle size 6.4 to 13.0 mm is the major reason for its high porosity and excellent drainage capabilities (9, 74).

Another very important feature of bark is that it is slow to decompose (4, 9, 18, 42, 62). Lignin, a structural component of bark, is responsible for the slow decomposition (4, 9, 11). Lignin must first be metabolized before the cellulose can be attacked by cellulolytic organisms and other enzymes. Since Lignin metabolizers act slowly, the cellulose is protected and decomposition is retarded (9). For that reason, there is very little available carbon which results in a wide C:N ratio (12) and accounts for the low nitrogen demand (4, 9, 12, 18, 42). Fresh bark has the most consistent C:N ratio and has the lowest demand for nitrogen (14).

Water Retention

Water retention capacity in volume percent is 15-38 (Water Retention = Total Porosity - Free Porosity). This means that in a volume of 100 liters of bark, 15-38 liters of water would be retained depending on particle size. The larger the size, the less water is adsorbed (42). If the particle size is too large, the medium will have little water retention (18).

Bulk Density

Bark has a bulk density of 178 Kg/m^3 when dry and 320 kg/m^3 hen wet. Typical clay loams have bulk densities of 899 kg/m^3 and 1424 kg/m^3 (15,42). An advantage of a low bulk density is light weight, this contributes to the ease of handling and reduces shipping costs.

Mineral Content of Bark

Ash (mineral content) is highest in tree leaves or needles, followed by bark, branches, and wood. Nutrient content of bark varies with species, tree age, environmental factors, and growing site. The minor element content especially varies with growing site. But though bark ranks second to leaves in ash content, it contains almost no available plant nutrients. Both nitrogen and mineral content in bark is low, however, calcium content is high when compared to other essential elements (9). The major plant nutrient content of Douglas-fir bark, expressed as percent dry matter, is as follows: nitrogen 0.12, phosphorus 0.011, potassium 0.11, calcium 0.52, and magnesium 0.01 (9, 53).

Since bark is slow to decompose and low in nutrient value, fertilizers must be added to obtain good growth. Fortunately, bark has a cation exchange capacity of 39.7 to 44.8 meq/100 g, which is ten times that of sand (by volume) (9, 17). The range is due to particle size, with smaller sizes having the greatest CEC (9). The high CEC minimizes the loss of cations by leaching (53).

pH

The majority of barks have an acidic pH due to polyphenols (9, 53). Douglas-fir has a pH of around 4.0, which is one of the lowest pHs of all wood residues (53).

The acidic nature of bark begins to subside 4 - 5 months after initial potting. Possibly this can be attributed to an increase in the cation exchange capacity resulting from decomposition (34, 47). The low pH of bark makes it essential to add lime if a neutral pH is desired (17). It is recommended 2.9 kg of lime be added to neutralize one cubic meter of fir bark (26).

Economics

Compared to perlite ($36.25/cubic meter) and peat ($75/cubic meter), bark at $15.83/cubic meter is still relatively inexpensive to use as a growth medium (19). However, in Corvallis, Oregon, due to mill shutdowns and the rising popularity of bark as a mulch in landscapes, the price in 1983 has increased to 16 dollars per cubic meter.[1] Sometimes away from large residential areas, bark can still be purchased for 4 dollars per cubic meter.[2] This price may be lower still, if bought directly from the mill.

Other Advantages

Compared to soil, bark decreased the occurrence of root rot and suppressed nematodes (81).

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[1] Personal communication, Corvallis Cabinet Supply, Corvallis, Oregon, 1982.

[2] Personal communication, Dr. R.L. Stebbins, Department of Horticulture, Oregon State University, Corvallis, Oregon, 1982.

Potential Problems

1. When bark is moist and stored in piles, it may become compacted to the point where air is eliminated from the center of the pile. If this develops, anaerobic micro-organisms produce various organic acids and heat. Temperatures may reach a point high enough to inactivate all microbial life. This highly heated area within the pile undergoes charring and destructive distillation, which results in the production of pyrologenous acid that contains acetic acid and smaller amounts of fatty acids, as well as, methanol, formaldehyde, ketones, phenols and other compounds that can be harmful to plant life (13).

   These products of decomposition also produce a persistent and occasionally strong acid odor in the charred and adjacent bark. Such an odor provides an excellent warning that the bark is unsuitable for use with plants. This simple pH test may be used to indicate the suitability of the bark for plant culture.

   > Mix one part bark with 10 parts distilled water, let mixture stand for a few minutes. Strain and test the pH of the liquid. A pH below 3.5 indicates the material is probably unsafe for plant use (13).

2. Logs that have been stored or transported in salt water can have a salt content as high as 3.5%. The percent of sodium chloride found in bark from salt water-floated Douglas-fir logs ranged from 0.75 to 1.94. Salt content depends on bark moisture, extent of exposure to salt water, dilution of sea water by fresh water, bark thickness, flotation pattern of the log, scuff marks, dead knots, and the extent of marine borer action (10).

   If salt is leached by rainfall or irrigation into the rhizosphere, water absorption can be reduced. Factors which determine the possibility of salt reaching toxic levels include: initial salt content of the bark, bark particle size and amount, distribution of rain or irrigation water, soil type, and age of plant (10).

3. Prior to recent research, it was falsely believed that tannins, resins, and other wood extracts had a toxic effect on plants when added to the soil. Instead, restricted plant growth was caused by nitrogen deficiency, which can easily be corrected by proper fertilization (4, 9, 26, 53). However, monoterpenes in fresh bark have been found to be toxic or inhibitory to higher plants when in the

vapor phase. But, if bark is stockpiled where themophylic bacteria can increase the internal temperature in excess of 50° C, and this temperature is maintained for 6 weeks, monoterpenes can be reduced to safe levels (1).

4. Since softwood barks are initially difficult to wet, several surfactants have been used to facilitate this process (62). But, in the Pacific Northwest most bark is moistened by rains while stockpiled.

Soil as Growth Medium in Containers

Soils in containers can be differentiated from the same soil in situ by two important characteristics: soils in containers have smaller volumes and shallower depths. The small volume results in inadequate storage of water and nutrients, while the shallow depths result in excess soil water content and poor aeration (73, 74, 75). Excess soil water remains because there is little pressure for the water to drain. "As a general rule, the deeper the soil in the container, the smaller its surface and average water content following watering and drainage" (70). This illustrates why most soils are unsatisfactory when used in containers. Many soils remain saturated following irrigation, creating anaerobic conditions which result in poor growth or death of plants (53, 70, 75).

An additional disadvantage of using soil as a container medium is its high bulk density. This increases both transportation costs and the difficulty of handling the containers.

Root Growth

To fully comprehend the impact of using large volumes of bark to produce trees in containers, it is essential to understand several variables which affect root growth.

Seasonal Periodicity of Root Growth

Tree roots may grow any time that conditions are favorable (35, 40, 63, 87), and the growth rates are varied throughout the year. There are two main periods of root growth, one in the spring before shoot growth begins, and another in the fall after shoot growth has terminated (64, 65). Variations during these two periods are most likely due to temperature and moisture fluctuations. Therefore, based on the periodicity of root growth, the ideal time to transplant is before root growth resumes in spring. If the winters are mild like those in the Willamette Valley, the best time to transplant is February through March as roots are quite hardy at this time (90). The success of a newly transplanted tree depends largely on root acclimation to the new environment. This can best be aided by allowing new root growth to occur prior to the initiation of shoot growth.

Many researchers in the past (7, 64, 65, 67) have reported declines in root growth during mid-summer as being caused by a decrease in available moisture. Current research, however, has demonstrated the cause to be competition for photosynthate, which is a source-sink relationship (31, 50, 52). A sink, when rapidly growing or metabolizing can attract photosynthate at the expense of other competing plant parts (50, 61). When vigorous sinks are located near the site of photosynthesis as in Red Pine, only a small quantity of photosynthate is translocated to the roots. But translocation more than doubled to the roots after the cessation of shoot growth (69).

Additional evidence has shown that when apple and pear trees were pruned, vegetative growth was stimulated and root growth was reduced (37, 67). Large increases in root growth occurred during period of inactive shoot growth, and with little or no root growth occurring during periods of intense shoot growth (67). The practice of undercutting trees during transplanting necessitates severe top pruning, which in turn reduces root growth following transplanting. The proposed system keeps roots intact during transplanting, and thus eliminates the need for severe top pruning.

The end result will be a tree which reaches bearing size sooner.

Root Distribution of Apple Trees

The main roots in apple trees are called scaffolding or extension roots. They are primarily horizontal and in mature apple trees, are located at a soil depth between 25-50 cm (63, 66, 67). Most root growth occurs in the upper .26 m for one-year- old trees and at a depth of 1.2 - 2.5 m for mature trees (84). Since extension root spread *in situ* can be expected to exceed that of branches by 1.5 to 3.0 times (63, 64, 66, 67), trees not root pruned will require a large volume of medium to prevent root circling and the ensuing "pot-bound" dwarfing effect. This natural tendency for roots to spread explains why a large percentage of the root system is lost with the powered tree spade. The spade prunes off all roots located outside a radius of 60 cm from the trunk (78).

The sinker roots, whose main function is to anchor the plant, typically grow to a depth of 1.2 - 1.5 m in mature apple trees (66), but can reach depths of as much as 2.74 m (67). A one-year-old root system of MIV stock grown in sand penetrated to 60 cm and in two years to a depth of 76.4 cm (82). This demonstrates the necessity of restricting the downward growth of trees used in an instant orchard scheme.

Factors Affecting Root Growth

A. Temperature. Root growth fluctuates throughout the season following temperature changes (65). It is generally accepted that root growth is greatest when the soil is both moist and warm. Maximum growth is realized at about 15.6° C, while very little or no root growth occurs below 7.2° C (20, 64, 65, 66). Low soil temperatures can limit or even completely impede water and mineral absorption by roots (60).

Roots of young apple trees in some trials (66) were not injured by long durations of soil temperatures as high as 32° C. This agrees with other results which indicated that temperatures as high as 40 - 45° C were necessary for root injury to occur in five different container grown plant species. However, it is possible for these high temperatures to develop within container media and this may account for root loss (93).

B. Oxygen and Anaerobiosis. Poor drainage in containers can lead to anaerobic conditions which may result in a variety of root growth problems. An improper balance between oxygen and carbon dioxide can slow down and in extreme cases can completely stop root growth (22, 60). The nature of injury due to anaerobic conditions are as follows (39, 68):

1. Root growth is restricted, with new roots occurring above the zone of saturation. There are few rootlets formed and some dieback of extremities within the zone. Roots will be black as opposed to a normal brown color.
2. Leaves tend to be small and chlorotic.
3. Severe injury can be observed on hot days. Leaves appear toasted, stippled, or burned or in severe cases, necrotic, as opposed to the crisp green color found on drought-stressed plants.
4. Reduction of shoot growth and the development of spindly twigs.

Even though oxygen is required for a healthy root system, a deficiency for a relatively short period will not result in serious damage. Apple tree roots will grow slowly with as little as 3% oxygen, but 10% is essential to attain good growth (60). The slight growth which can occur at low oxygen concentrations is probably due to stored materials (23). The concentration of carbon dioxide must be very high (over 20%) to cause direct injury to roots, consequently, any decrease in root growth or injury to roots is most likely caused by an oxygen deficiency (23, 39, 60).

When oxygen decreases to a partial pressure less than about 2 X 10^{-3} atm., microbial activities produce sulphide and butyric acid which will inhibit root elongation. However, if the low oxygen concentration is not continued these substances can be quickly detoxified by oxidation (32, 60).

Poor aeration can prevent the roots from absorbing water and minerals. A low oxygen level, along with an excessive level of carbon dioxide, decreases the permeability of the roots to water and indirectly inhibits the absorption of minerals (16, 48, 51, 60, 68, 71). In addition there will be a loss of nitrate from soil due to denitrification (32, 43, 68). The growth reduction which occurs under flooded conditions is probably a result of both a reduction in mineral absorption and photosynthesis. Stomatal closure occurs 1-2 days after flooding and is considered an early response to flooding (70). Stomatal closure results from a reduction in hydraulic conductivity of longitudinal roots which maintains leaf turgor pressure and reduces photosynthesis.

Improper aeration can make roots more susceptible to attack by plant pathogenic fungi such as *Phytophthora cactorum*. *Phytophthora* species attack plants at or immediately below the soil line. The mobile zoospores of *Phytophthora* spp. move through water to the infection site. In one study, root rots were initiated by subjecting the plants to 48-hour flooding every two weeks (3, 33, 60). Trees can be killed by *Phytophthora* spp. if the collar of the tree trunk stays wet for prolonged periods of time. The fungus may first attack a main root causing drought-like symptoms, but more commonly attacks the plant at or near the soil line causing a dark, depressed canker. Later, the area will appear shrunken and cracked. Initially the tree will respond with reduced growth, small fruit, show sparse foliage and die-back of twigs. Eventually plant parts above and below the infected area may die (3, 28, 79, 80, 92).

C. *Moisture*. Young apple trees that were grown in large containers had a root:shoot ratio of 1:1, however, with fluctuating changes in moisture conditions the ratio increased in favor of the roots. Tree growth was greatest when irrigation was utilized to maintain the soil moisture level at field capacity (25). Plants which have an adequate supply of water throughout their rooting zone will produce a root density higher than is needed for their support (76). This is useful in production of container stock because some roots are lost during transplanting.

Although growth patterns of tree root are controlled genetically, moisture supply can modify them (76, 87). In one experiment, watered and non-watered trees had approximately the same total weight, however, watered trees had more than two times the weight of roots in the top 0-15 cm of soil than the non-watered trees. Yet below 15 cm this proportion was reversed. Roots will respond only to the water potential in their immediate surroundings and are not influenced by the water potential in other parts of the soil (76, 87).

The major influence of water on root configuration is the extent to which it affects rooting depth. Root systems of non-watered trees extend to greater depths than those of watered trees (25, 76). In water-logged soils, root growth is exclusively near the soil surface. Roots below the water table are usually dead or black in appearance (25, 39, 64). Because the volume of roots is restricted under this environment, these trees will be the first to suffer in a drought (64, 67, 76).

When moisture stress occurs there is a marked decrease in the proliferation of roots. Apple root growth may be impeded long before the permanent wilting point is reached (25). Drought conditions can cause a complete cessation of root growth even though the soil temperature may be suitable for rapid growth (7, 25, 64, 66).

D. Soil Texture. In coarse to medium textured soils, tree root distribution is more extensive than in fine textured soils (87). In sand, roots are long, relatively straight, and thin as opposed to roots growing in clay, which tend to be more tapered and contorted in appearance (66). In addition, the depth of rooting is usually shallower than that found in heavier textured soils (84). Bark, like most coarse textured soils, tends to be highly porous and loose, which should result in a very extensive root system.

E. Fertility. Root proliferation is greatest when nutrients are available in adequate amounts (76). In an experiment conducted at East Malling Research Station, loamy soil was found to have a stem:root ratio of 2:1 as compared to the 1:1 ratio obtained on nutrient-poor sandy soil. Because of low fertility, the sandy soil required twice as large a root system to support the same amount of shoot growth. In soils with low nutrient status more extension roots and fewer laterals develop. Fertilizers and organic matter stimulate root branching. High levels of nitrogen are associated with root auxin levels related to differences in root configuration (67).

F. Pruning. Apple trees left completely unpruned exhibit maximum root growth in June and July, whereas pruned trees produce maximum growth in May (67). Pruned trees show a marked decline in root growth during June and July as a result of stimulated shoot growth during that period (37, 44, 67). Removal of lateral shoots on young trees during the summer halted root growth completely (36). Severe root pruning of one and two-year-old apple seedlings at planting time, reduced both shoot and root growth (54, 64).

G. Defoliation. For trees that are intended for several years of container culture, special care should be taken to avoid premature defoliation. An early leaf fall may reduce the number of white, unsuberized roots, and can completely stop root growth (38, 40, 67). prematurely defoliated trees are slow to initiate growth the following spring (38).

III. PRELIMINARY STUDY

A preliminary study determined that apples, 'Newton Pipin', on either Malling Merton 106 or seedling rootstock, 'D'Anjou' pear on either old Home x Farmingdale 333 or Bartlett seedling rootstock, and 'Italian' prune on either Marianna 4001 or peach seedlings rootstock, could be grown in a 100% bark media. Also, it was determined that granular fertilizers could replace slow release fertilizers, and that frequent irrigation was imperative.

IV. EXPERIMENTAL STUDY

Materials and Methods

This experiment was conducted using apple, *Malus domestica* Borkh., c.v. Newtown Pipin on Malling Merton 106 (MM 106) rootstock. Seventy-two, one-year-old unbranched and barerooted trees (mean trunk diameter of 12.7 ∓ 1.2 mm) were planted on March 20, into a plastic-lined, raised wooden box, containing two different volumes of coarse (3.2 cm screened) Douglas-fir bark. Every 0.9 m, plastic was draped over guy wires, or 15 lb. roofing felt was nailed to the structure, to partition the long rectangular box into separate cubicles for each tree. This prevented the roots of each tree from becoming entangled with those of adjacent trees, and it gave complete control over the nutrition each tree was to receive. Each cubicle was 0.9 m in width by 0.9 m in length, with a height of .25 m or .50 m. This resulted in bark volumes of 0.2 m^3 and 0.4 m^3 per tree respectively. Holes were punched into the plastic liner for drainage.

On March 28, all trees were headed back to 76 cm above the graft union. The trees were later summer pruned for structure and young succulent limbs were spread and held in position with spring-type clothes pins. A simple trellis system was utilized to stabilize the trees against the wind. It consisted of wire supported by 5 cm by 10 cm posts. Twine was used to secure the trees to the wire.

Because of the high porosity (31.5-54.7%) it was necessary to irrigate on a daily basis. Each tree received approximately 11.5 liters of water per day. The irrigation system consisted of a time clock solenoid valve/pressure regulator, cloth filter (needed due to the small orifice of the emitter), polyethylene tubing, tubing stabilizer bar, and a Geor-Jet low pressure plastic sprinker (5.1 GPH at 15 PSI). Other management practices included periodic hand weeding and painting the tree trunks white to prevent sunscald. Since insect damage and the incidence of apple scab was low, no chemical sprays were applied.

All 12 treatments were replicated six times and arranged in a split-split-plot design. Bark volume was the main plot, fertility level the split-plot, and soil vs. no soil was the split-split-plot. Two bark volumes were used to determine the minimum amount of bark necessary to insure good growth. And since further definition of an optimum nutritional level was desired, the following three fertilizer rates were established:

Nutrient level #1 contained:

726 g concentrated super phosphate (0-36-0)
681 g potassium sulfate (0-0-60-18)
908 g dolomitic limestone
908 g gypsum
1,360 g urea (46-0-0)

Nutrient level #2 contained:

1,090 g concentrated super phosphate
1,044 g potassium sulfate
1,590 g dolomitic limestone
1,590 g gypsum
2,080 g urea

Nutrient level #3 contained:

2,041 g concentrated super phosphate
1,950 g potassium sulfate
3,175 g dolomitic limestone
3,175 g gypsum
2,722 g urea

Concentrated super phosphate, potassium sulfate, dolomitic limestone, and gypsum were placed in layers throughout the bark prior to planting the trees. Urea was banded 30 cm from the trunk in weekly applications beginning on June 7 and terminating on August 4. Half the trees had an addition of soil (7.6 liters) added to the bark, to determine what effect this would have on growth. The soil was added only in the immediate rooting zone during the process of backfilling the holes into which the trees were planted.

Trunk diameter and shoot growth were measured. Diameter measurements were taken monthly, 5 cm above the graft union, with a final diameter measurement taken in October. Total shoot growth was determined by measuring each shoot length after the trees had stopped growing in the fall. Two leaf samples from each treatment were collected, the first on August 7 and the last on September 7. Samples consisted of 30 disease-free leaves, randomly selected from the middle of the current season's growth. The tissue was washed in a solution of 10 g EDTA (disodium salt) in 20 liters of distilled water, and rinsed 3 times in distilled water. The clean tissue was placed in an oven for initial drying at 70° C for 48 hours. It was then ground in a Wiley Mill (20 mesh screen) and stored in resealable plastic bags. The samples were later redried to remove moisture and weighed. From each sample 1.0 g was taken for mineral analysis and 0.4 g used for nitrogen analysis.

For mineral analysis, the samples were ashed in a Muffle furnace (thermolyne) for 6 hours at 227° C, and then treated with 5 ml of 1.8% HCL containing an internal standard consisting of 0.1% Co and 0.5% Li. Analysis of 11 elements were made by a Jarrell-Ash spark emission spectograph. Nitrogen content was determined using the standard Kjedahl method. Results were reported on a percent dry weight basis for N, P, K, Ca, Mg, and as ppm for Mn, Fe, Cu, B, Zn, and Al.

All data were analyzed using analysis of variance and means were compared by LSD, at the .05% level whenever F values were significant (21).

Results

General observations. Bud break occurred during the fourth week of April and the trees grew well until mid-July. At that time three trees were observed with chlorotic leaves and irregular brown spots located on the leaf margins. This problem was first manifested on the lower limbs, but later moved progressively upward on the trees. During the first week of August several more trees were observed with the same symptoms, bringing the total to six trees. Most of these affected trees were planted at the lower bark volume 0.2 m^3 and all were planted with the soil addition. Later observations in mid-September showed the trees to have necrotic leaves and an overall dead appearance.

Inspection of the trunks immediately below the bark surface (collar area) revealed dark, spongy cankers.

All trees stopped growing in mid-November and leaf abscission followed 1-2 weeks later.

Effects on tree diameter. The trees planted without soil had final trunk diameters greater than those observed on trees with soil added, regardless of bark volume or fertilizer rate (Table 1). An interaction was observed between fertilizer regimes and presence of soil. Trunk diameter was greatest without the addition of soil and under the low or middle fertilizer rates (Table 2). Mean trunk diameters increased steadily throughout the growing season.

Effects on total shoot growth. Total shoot growth was affected by bark volume, fertilizer rate, and soil vs. no soil.

Trees under the high fertilizer rate grew less than in the two lower rates. No differences existed between the low and middle levels (Table 3). Trees planted in the 0.2 m^3 bark volume produced a mean total shoot growth of 251.5 cm as compared to 382.9 cm which was observed in trees grown in the 0.4 m^3 volume. The trees with the soil additions produced a mean total shoot growth of 257.5 cm as compared to 376.9 cm for

Table 1. Means of all measured growth parameters.[z]

Fertilizer Rate	Bark Volume	Soil	No. of Shoots	Total Shoot growth (cm)	Shoot length (cm)	Final Trunk Diameter (mm)
High	.4 $(m)^3$	no	8	345	43.7	18.2
"	"	yes	7	226	31.1	17.5
"	.2 $(m)^3$	no	7	207	32.2	17.4
"	"	yes	7	234	31.6	17.3
Middle	.4 $(m)^3$	no	8	511	66.3	21.6
"	"	yes	7	305	43.6	18.2
"	.2 $(m)^3$	no	7	306	44.1	19.0
"	"	yes	6	167	27.3	16.5
Low	.4 $(m)^3$	no	7	539	76.8	21.5
"	"	yes	8	373	47.1	18.0
"	.2 $(m)^3$	no	8	355	46.8	19.5
"	"	yes	7	240	35.1	17.1

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[z] Mean starting trunk diameter was 12.7 ∓ 1.2 mm.

Table 2. Effect of fertilizer rate and soil on final trunk diameter.[y]

Treatment		
Fertilizer rate	Soil	Final trunk diameter (cm)
Low	no	20.5 A[z]
Middle	"	20.9 A
High	"	17.7 B
Low	yes	17.5 B
Middle	"	17.3 B
High	"	17.4 B

[z] Mean separation in columns by LSD, 5% level.

[y] Mean starting trunk diameter was 12.7 ∓ 1.2 mm.

Table 3. Effect of fertilizer rate on level of Mg in leaf tissue and total shoot growth.

Treatment Fertilizer rate	Mg	Total shoot growth
Low	.37 B[z]	376.7 A
Middle	.41 A	322.0 A
High	.43 A	253.0 B

[z] Mean separation in columns by LSD, 5% level.

trees in 100% bark media.

The greatest total shoot growth occurred in the 0.4 m^3 bark volume without soil, under the low and middle fertilizer rates (Table 1).

Effects on leaf nutrient levels. Based on the Oregon State University Plant Analysis Laboratory's Tentative Leaf Element Level Guide (1981), all element levels in leaves were adequate for normal growth under each fertilizer rate. Mean N levels were excessive (greater than 3.0%) for all fertilizer rates. Mean Mn levels were higher than normal, but not excessive. Mean levels for both B and Zn were below normal to barely normal (Table 4).

Even though nutritional levels were for the most part adequate, there were some differences due to independent factors and/or interactions between factors.

The additions of soil increased the leaf level of Mg from .38% for 100% bark to .42%, and decreased the leaf level of K from .21% for 100% bark to .16%. Calcium leaf levels were increased to 1.03% in the 0.4 m^3 bark volume as opposed to 0.87% in the 0.2 m^3 volume. Mg leaf levels were decreased under the low fertilizer rate (Table 3).

Table 4. Mean nitrogen and mineral content of leaves (Aug. 7, 1982).

			Element										
			% Dry weight					ppm Dry weight					
Fertilizer rate	Bark volume	Soil	N	K	P	Ca	Mg	Mn	Fe	Cu	B	Zn	Al
High	.4 (cm)^3	no	3.60	1.95	.29	.95	.35	240	136	6	29	19	36
"	"	yes	3.43	1.53	.27	1.07	.49	249	151	7	27	18	45
"	.2 (m)^3	no	3.74	1.93	.34	.82	.41	165	138	6	24	16	34
"	"	yes	3.28	1.56	.21	.88	.46	124	130	6	25	14	42
Middle	.4 (m)^3	no	3.41	1.99	.26	1.10	.39	312	148	7	30	18	48
"	"	yes	3.40	1.76	.26	1.03	.45	260	144	7	30	18	44
"	.2 (m)^3	no	3.79	2.11	.35	.83	.41	209	151	6	26	19	54
"	"	yes	3.31	1.47	.22	.86	.42	136	148	6	23	11	45
Low	.4 (m)^3	no	3.29	2.14	.25	1.05	.36	328	149	7	34	18	36
"	"	yes	3.08	1.77	.22	1.01	.34	287	150	6	31	16	48
"	.2 (m)^3	no	4.06	2.19	.40	.81	.36	212	152	5	27	20	43
"	"	yes	3.60	1.44	.28	1.01	.41	186	147	6	27	15	44

Foliar N levels were lower where soil was added, regardless of bark volume, but in the lower bark volume with soil N levels were not greater than in the higher bark volume without soil. In both bark volumes, P levels were higher without soil, but with soil P levels were not affected by bark volume (Table 5). Within the larger bark volume, N leaf levels were higher under high fertilizer rates, but in the .2 m^3 volume, leaf levels were greatest under the low fertilizer rate. The results were the same for the leaf level of P, except that there were no differences between bark volumes under the high fertilizer rate (Table 6).

Discussion

Examination of the unhealthy trees by the Oregon State University Plant Clinic diagnosed the problem to be collar rot caused by (*Phytophora cactorum*). The addition of unsterilized soil to the bark media was probably the source of innoculum. Following irrigation, it was noted the soil in the media remained saturated, probably due to the interface between the bark and soil. This created ideal conditions for infection and stressed the trees reducing their natural resistance to disease (3, 33, 79).

Table 5. Effect of bark volume and soil on the level of nitrogen and phosphorus in leaf tissue.

Treatment			
Bark volume	Soil	N(%)	P(%)
0.4 m^3	yes	3.27 C[z]	.24 C
"	no	3.43 B	.27 B
0.2 m^3	yes	3.40 B	.24 C
"	no	3.88 A	.36 A

[z] Mean separation in columns by LSD, 5% level.

Table 6. Effect of bark volume and fertilizer rate on the level of nitrogen and phosphorus in leaf tissue.

Treatment			
Bark volume	Fertilizer rate	N(%)	P(%)
.4 $(m)^3$	Low	3.18 C[z]	.23 D
"	Middle	3.36 BC	.25 CD
"	High	3.51 B	.28 BC
.2 $(m)^3$	Low	3.83 A	.34 A
"	Middle	3.55 B	.29 B
"	High	3.54 B	.28 BC

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[z] Mean separation in columns by LSD, 5% level.

Trees planted with the soil additions grew poorly, even when not affected by collar rot. Waterlogged conditions within the soil greatly diminished or stopped root growth (22, 32, 60). Often the small amount of root growth that was produced was restricted to the soil mass. However, trees that developed roots beyond the soil had more shoot growth than those that didn't, yet total shoot growth was still below average. A strong correlation existed between root growth and shoot growth.

Total shoot growth was increased with the higher bark volume 0.4 m^3 (Table 1). Trees planted in the lower volume 0.2 m^3 had their downward root growth impeded. Many root initials were located near the bottom of the containers, so that growth was exclusively horizontal (Appendix I). In addition, the top 10-15 cm of bark remained dry the majority of the time, while the lower 10-15 cm contained a sufficient supply of available moisture. This was true in both volumes, but since the higher volume was deeper a greater absolute volume of the bark remained moist. In both bark volumes, lateral root growth reached the extremes of the container and some root circling was observed.

The analysis of the measured growth parameters indicate that the low rate of nutrition is apparently the closest to optimal. Trunk diameter and total shoot growth under the low and middle rates did not vary significantly, but there was a significant reduction in total shoot growth under the high rate, suggesting salt problems (Table 3).

Trees in the different bark volumes at low nutrient level varied in leaf levels of N and P, with levels decreasing in the higher bark volume (Table 6). This was most likely a result of diluting the fertilizer. Decreased leaf levels of N, P, and K were attributed to the addition of the soil. In addition to decreasing absorption of nutrients by limiting root growth, waterlogged conditions in soil can decrease the permeability of roots to water and indirectly inhibit the roots from absorbing nutrients (16, 48, 51, 60, 71). In the case of Mg, leaf levels were increased with the addition of soil. Apparently, soil was a source of Mg.

Since leaf mineral and nitrogen mean levels were adequate for normal growth and few differences were observed, no evidence was provided by the leaf analyses to explain the variances in trunk diameter and total shoot growth.

The mean N levels for all fertilizer rates were excessive, but for young nonbearing trees this is desirable, since vegetative growth is the only objective. In this study, B and Zn levels were low to barely normal, thus, for future experiments, applications of these micronutrients may be necessary (Table 4).

All trees (excluding those infected by collar rot) continued to grow until mid-November. Although late defoliation is characteristic of the MM 106 rootstock, this condition at least in part may have been induced by late season urea applications. It has been shown that, with ample supply of water and nitrogen, trees retain leaves later in the Fall. To reduce the possibility of winter injury, it would be desirable to discontinue N applications earlier (40, 79).

The two treatments which resulted in the greatest total shoot growth and largest trunk diameters were the 0.4 m^3 bark volume without soil, and under the low and middle fertilizer rates. The mean total shoot growth for these two treatments exceeded that of 'Newtown Pipin' on MM 106 in the preliminary study by 70-100 cm, and that of 3-year-old field grown 'Red Delicious' on EM II rootstock by 100-130 cm (27). Likewise, the mean shoot growth obtained in this study (66.3-76.8 cm) was higher than (35-42 cm) which was obtained with 6-year-old field grown 'Golden Delicious' (29).

Conclusion

The treatments which resulted in the most growth, based on greatest trunk diameter and total shoot growth, were the 0.4 m^3 bark volume with no addition of soil, under the low and middle fertilizer rates. Since growth was not significantly different between the low and middle rates, there is no reason to use the higher rate.

The leaf analysis indicated that B and Zn levels were on the low side of normal, so for future experiments, applications of these micronutrients may be necessary. Amendments should also be tried in order to reduce moisture loss. This would decrease the frequency of irrigation and reduce the amount of leached plant nutrients.

Studies must still be forthcoming to determine the economic feasibility of this technique versus present practices and other experimental production methods, and also to examine the success of transplant with trees produced by this technique.

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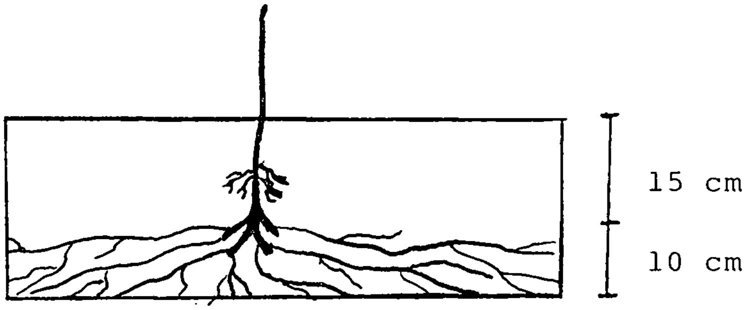
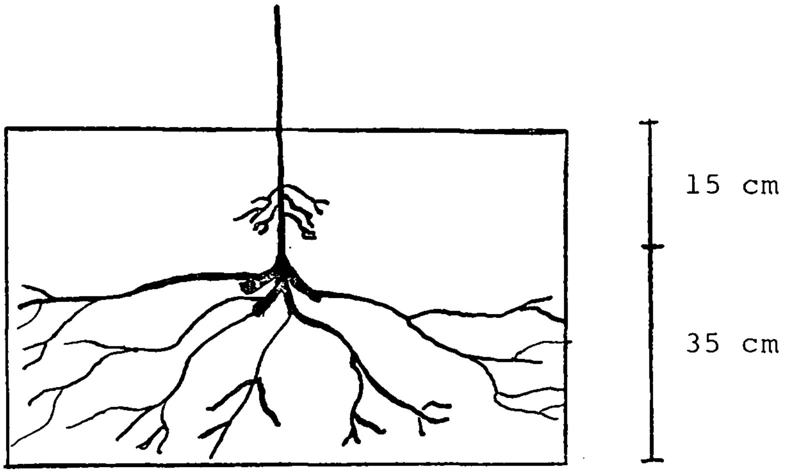
APPENDIX

Appendix 1. Comparison of root distribution between bark volumes.

1) 0.2 m^3 volume



2) 0.4 m^3 volume



* Roots grew through fertilizer layers with no apparent problems.