EFFECTS OF NUTRITION AND ROOT MODIFICATION IN CONTAINERS ON PROPAGATION AND SUBSEQUENT GROWTH OF TREE SEEDLINGS

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CHAPTER I

INTRODUCTION

Container nursery production has increased rapidly since the early 1950's due to escalating land values, increasing labor costs, reduced production time and higher quality plants which can be marketed and planted anytime of year. However, many nurseries specializing in container grown plants still use seedling production methods developed by field nurseries. This practice is due to the tendency of seedlings to rapidly produce a twisted, malformed root system when germinated and grown in a conventional container. The production time of seedlings in raised beds or nursery rows is often lengthy, depending on species. Three to four years may be required to produce seedlings large enough to transplant into a container or "line out" in the field. Conventional seedling propagation is generally characterized by crowded conditions and keen competition for light, water and nutrients. Some species are transplanted from germination seed beds to a secondary or tertiary transplant bed in order to allow more room for development and to cull the many stunted or inferior seedlings.

Throughout the nursery bed production phase, seedling roots may be undercut or laterally pruned. When practiced correctly these techniques yield enhanced seedling survival by promoting secondary and tertiary root formation. Vigor of many seedlings is sufficient to overcome the stress imparted by roots cut and torn during root pruning and in lifting from the seed beds during transplanting. However, each time the root system is disturbed or reduced, there is a concurrent loss of sustained growth. Shoot and root growth represent time and money which is lost during each pruning operation, which provides a potential entrance for many disease organisms prior to healing.

The forest industry has devoted vast resources to develop a containerized seedling concept to aid in rapid reforestation. "Test tube" seedling nurseries now produce millions of conifer seedlings annually. Some ornamental nurserymen are using this system but seem to be reluctant to further modify the foresters production methods to coincide with their goals. For the reforestation container seedling to be economically feasible it must compete with the bed grown seedling which can be produced for as little as $.02 to $.04 cents per seedling. In order to achieve this goal, very small containers are used. This also produces a small seedling which can be mechanically transplanted at the reforestation site. Fertility is often maneuvered out of balance in order to achieve root:shoot ratios and dormancy requirements thought to be desirable on adverse planting sites. Few of these goals are consistant with the ornamental nursery industry since the projected monetary return on a young landscape tree is many times that of the same tree in an immature forest. The nurseryman cannot afford to engage in false economy by attempting to copy forestry methods, for differences in time and money and ultimate objectives are not the same.

Many advantages of growing in containers are recognized; accelerated and uniform growth due to high fertility, a uniform well aerated growing media and no loss of roots resulting in transplant shock. A container system which allows seedling propagation without malformed roots, significantly reduces production time and yields a higher quality plant would be economically advantageous. The objectives of this research were to investigate such a container system and to develop a controlled release nutritional system for the production of high quality seedlings.

CHAPTER II

LITERATURE REVIEW

Seed Propagation

Seed is the most common means of propagation for self pollinated plants and is extensively used for many cross pollinated plants (3). Many plants do not propagate readily from cuttings or form such deficient root systems that asexual propagation is not practiced. For many species, seed is the least expensive method of propagation (56). In addition, seeds offer a convenient method of storing a potential plant until needed in the production cycle (3). Asexual propagation is often limited by precise timing during which the cutting must be removed from the parent (4). Also the use of seedlings as rootstock for many grafted species is widespread in the nursery industry (13). Procedures for growing seedlings in ground beds is well documented (27) (100) (117) (118) (122) (124) but many problems have been encountered.

Seed Dormancy

Seed from many tree species which is sound and uninjured may be dormant and fail to germinate when placed in an optimum environment. As many as two-thirds of the trees display some form of seed dormancy (67). Dormancy may vary considerably between species and between individual trees at a given site. McLemore and Barnett (83) found that with Loblolly pine (Pinus taeda) dormancy varied between individual trees at a given site but was constant for four years in individual trees. Similar findings have been reported for Douglas fir (Pseudotruga menziesii) (1) (2). Dormancy due to genetics and environmental conditions is more common. Seed of Eastern White pine (Pinus strobus) from northern trees have a shorter dormancy than from southern trees (29) (89). The reverse is true for some deciduous species; for example, Sugar maple (Acer saccharum), European ash (Fraxinus excelsior), Sweetgum (Liquidambor spp.), and Sycamore (Platanus spp.) show a greater degree of dormancy in seed from northern seed sources (65) (125) (131) (137) (142). Dormancy may also result from low temperatures when the seed is maturing, delaying embryo development. Moisture relations were reported to influence dormancy of Black locust (Robinia pseudoacacia). Gassner (35) found that seed developing under moist conditions were only moderately dormant while arid conditions produced seed which was completely dormant. McLemore and Barnett (83), and Krugman (68) suggested that treatment methods during harvest, extraction, drying and storage may also induce dormancy. Too rapid a drying or drying at excessive temperatures and prolonged storage were major causes of dormancy.

Nondormant seeds in the proper environment proceed through three germination stages: (1) imbibition of water,(2) activation of metabolic processes, and (3) embryo growth. Morphological or physical dormancy results primarily from a hard, impermeable seed coat. Internal or physiological dormancy may exist due to the presence of an inhibitor, an embryo unable to mobilize and utilize food material or other conditions of anatomically immature seed (67).

Nurserymen speed the removal of dormancy barriers by the use of moisture, temperature and light treatments alone and in combination.

Chemical or mechanical treatments are also imposed in order to penetrate tough seed coats and promote germination (4) (109). Seed requiring only stratification in order to germinate is often fall sown in mulched beds to stratify and emerge in the spring (128).

Germination

Environmental requirements for nondormant seed to germinate include: 1) favorable temperature, 2) adequate moisture, 3) adequate gas exchange, and for some species, 4) light. Attempts by nurserymen to control or hasten nature's propagation methods can thus become limiting factors and often produce failures.

Removal of the plants from the seed bed must be accomplished during the dormant season and results in a substantial loss of roots. Murphy (93) felt this loss of roots and attendent exposure of roots to desiccation should be avoided by the use of individual containers. The survival and growth of bed grown seedlings after transplanting is also a significant problem. This factor has convenced some nurserymen to switch to an individual container propagation system (129).

Overcrowding of seedlings leads to greater difficulty with damping-off, mildew and other diseases and reduces vigor and size of the seedling (51), and fertility and seedling density in the germination beds is often a limiting factor in achieving optimum growth (80) (92) (101) (114). Thin spindly seedlings without a healthy, fibrous root system do not transplant well (66). Insect problems also tend to present a problem in the crowded seed bed (141).

Container Production

Container grown plants provide many advantages to the grower, retailer and consumer (59). Some advantages include:

1. Reduced production time,
2. Precise control of water, fertility, medium and other environmental growth factors,
3. Ease of harvest and harvest season less specific,
4. Fewer problems with soil pests encountered since most growing media are soilless,
5. Container plants may be marketed throughout the growing season and planted with ease by the consumer,
6. Maintenance in retail areas is easier with container plants than field grown plants,
7. Poor land or other wise non-productive land may be used for a container nursery,
8. Transportation costs are less since the relative weight of a container grown plant is much less than a balled and burlaped plant due to the less dense soilless media,
9. Expensive structures providing controlled atmosphere storage of the dormant bare root plant and attendent packaging may be eliminated,
10. It is much easier to produce a uniform crop when using containers.

Root Modification

While containers allow the seedling to be transplanted without the shock of root removal or disturbance, research has shown that confinement to a container for too long a period may create a malformed, contorted root system (23) (43) (44) (52) (71) (105). Seedlings with a deformed root system may result in a 20 percent reduction in height, depending on species (104). Tree seedlings with spiraling and kinked roots may later become stunted or break off at the crown (8).

Death of Maritime pine seedlings in northern Tunisia has been attributed to strangulation by spiraling lateral roots (18).

All containers modify root structure and because of the many attributes of container grown seedling production, problems found with some containers must be corrected or new concepts devised that will produce a sound root system (52).

The behavior of roots in a round container is part of the root girdling problem. When a growing root confronts a barrier it cannot penetrate it turns or buckles and follows the contour of the barrier. In a cylindrical container, no direction other than cyclic is provided and the root starts a spiral growth pattern. Davis and Whitcomb (21) found that by using square, bottomless containers on wire bench, roots grew out until contacting the container sides, then proceed to the 90 degree angle corner and grow downward. Roots reaching the container bottom are "air pruned" by desiccation. This pruning of primary roots induces development of lateral roots which in turn are air pruned as they reach the bottom. A fibrous root mass with no spiral growth is the result.

Root pruning of seedlings which have a dominant taproot should be done early (42) (43). Wire-bottomed flats or benches (30) stimulate formation of lateral roots but individual seedlings may still compete for nutrients and growing room. McDonald (81) suggested that ponderosa pine seed trees had an inhibitory effect on developing seedlings which increased with density and persisted four years after removal of the seed trees. Such plant competition or supression may be a factor in seed bed and flat seedling propagation.

The desirability of root pruning to increase survival is supported by Barnett and McGibray (6) who used a copper screen to restrict root growth out of containers to decrease root loss and damage prior to outplanting. Although copper screens prevented root emergence from the container bottom, it had no effect on the dry root weight of two species of southern pines. They suggest inhibition of primary roots by the copper stimulated lateral root development without decreasing total root production.

Research by Hathaway and Whitcomb (45) using three sizes of bottomless containers and five levels of osmocote 18-6-12 also showed no difference in fresh root weight of Shumard oaks regardless of container height or fertility level.

Root and shoot growth are interdependent and interregulated (70). Roots mechanically support the plant, absorb and translocate water and mineral solutes, synthesize organic compounds, especially amino acids, and store manufactured foods. Thus, root malfunction, injury, or death are reflected in reduced top growth (62).

In order to balance the root:shoot ratio and facilitate planting, many nurserymen severely prune the shoot to compensate for root loss when bed grown seedlings are lifted (149). There are considerable differences in species tolerance to this type pruning (143). However, severe pruning of the shoot is likely to lower survival (144) and root regeneration potential (74). The severe root and shoot pruning prior to transplanting undoubtedly plays a significant role in the transplant shock, reduced growth and high mortality of bed grown seedlings. Kramer (64, p. 134) suggests the cause of these problems: "Roots and shoots are dependent on each other in various ways, and if the growth of one is much modified, the other is likely to be also." He further calls for research in this area.

> More must be learned about factors controlling production of new roots following transplanting. To what extent is this related to time of year, and is it affected by mineral nutrition or other cultural practices to which the seedlings were subjected prior to transplanting (p. 149).

The removal of shoots to balance the loss of roots is common (85) (96), but may inhibit both root and shoot growth. Richardson (103) concluded that root growth of Acer saccharinum seedlings is dependent on chemical stimuli from the leaves or buds in addition to carbohydrates. Other research (20) (116) (119) also indicates the necessity of the shoot supplying harmones and carbohydrates.

Removal of roots and shoots may also severely deplete carbohydrate or starch reserves needed for spring growth. Normally, carbohydrate reserves close to the site of utilization, i.e., shoot expansion and growth, are used first. Clausen and Kozlowski (20) found that one year old shoots of red pine and Douglas fir supply reserves for initiation of new shoots in the spring. In young Taxus species plants, 20-50% of the carbohydrates utilized in spring growth are stored in old needles (116).

Root-Shoot Ratio

Much is written about the need for maintaining a "proper" root-shoot ratio (104) (109) (120) (128). It is suggested that a seedling with a very large root system and small shoot has a better survival rate. The ratio for success is said to be about unity, or an evenly balanced top and root by weight. This may be necessary if the seedling is grown under conditions of low fertility. High fertility container systems can produce seedlings with a very low root:shoot ratio (45). Research by Trapp (123) suggests that the importance of root:shoot ratio to seedling survival needs study. He further states, "a root system best suited to rapid extension might conceivably have a low 'unfavorable' ratio."

Many trees at maturity do not have a balanced root:top ratio. Will (140) reported that the root system of 18 year old monterey pines amounts to only about ten percent of the total weight of the trees. Bray (11) found that in four species of trees only about 18% of dry matter occurred in the roots.

Container Modification

Milk cartons with the bottom intact were used by Shreve (115) in 1970. Container grown seedlings of _Juglands nigra_ were planted along with bare root seedlings. Mortality was high among seedlings planted bare root, but survival of container grown seedlings was about 80 percent. Considerable research has been completed on the effects of container size (18) (31) (45) (72) (133) (134) (135).

Nine different sizes of paper tubes were tested by the Forestry Department of the Luis de Querey School of Agriculture in Brazil (10).

Tubes of 6 cm diameter and 10 cm high gave the best results. In a study at Peshawar, Pakistan, in 1971, seedlings of *Acacia arabian*, *Eucalyptus spp.*, *Pinus spp.*, and *Cedrus deodara* were grown in black polyethylene tubes for two years. It was concluded that tubes 5 x 6.3 cm and 15 x 5 cm were most suitable for broadleaved and coniferous species, respectively (41). Scarratt (108) using three diameters of split plastic tubes found increasing the tube diameter from 1.5 to 3.2 cm resulted in significantly better quality planting stock of white spruce and jack pine in a shorter period of time. Growth in the intermediate size (2 cm) was not significantly better than in the 1.5 cm tube.

Reforestation Container Seedlings

Millions of containerized seedlings for reforestation are being produced and outplanted on forest land in the Pacific Northwest and Canada. Over 23 million were grown in Oregon and Washington greenhouses and nurseries in 1973 and over 35 million in 1974 (107). Containers can be placed in three general categories: tubes, blocks and plugs. Tubes have an exterior wall and require filling with a growing medium. The seedlings remain in the tube for outplanting. Blocks have no outer wall and serve as both container and growing medium. The entire seedlings-block unit is planted. Plugs refer to seedlings grown in containers which are filled with a medium but the seedling and "plug" of roots and medium are removed for outplanting (5).

Extensive research in this new area of reforestation precepitated the North American Containerized Forest Tree Seedling Symposium in Denver, Colorado in August, 1974. Application of much of the research work presented at that symposium is difficult to apply to ornamental nursery seedling production. The goals of each industry are widely separated. Among the most pronounced differences include: (1) The forestry industry approaches container seedling production with a seedling factory approach, designed to mass produce millions of small seedlings of limited species; (2) The economic investment must be much smaller in order for reforestation seedling to be a viable economic alternative to the seed bed system. The ornamental nurseryman can invest more time and money in producing a larger, faster growing seedling since the economic and production goals are quite different.

Container Media

The rate of root growth as well as form and depth are greatly influenced by the rooting medium (62). The characteristics of the ideal container medium would probably vary with the species being grown and the cultural practices of the nurseryman. In most ornamental nurseries a single medium is used for many plants, realizing that watering regimes must be adjusted to suit the particular species. When selecting a growing medium, nurserymen must consider:

1. Availability and cost (72)
2. Uniformity
3. Practicality, i.e., will it consistently provide:
    a. support for the plant
    b. resist compaction and provide adequate air spaces
    c. hold sufficient water (53) while providing adequate drainage
    d. be free of pests
    e. be low in soluable salts or other toxic substances

f. be relatively inert so that interferance with nutrition is minimal (48).

The addition of field soil to the container medium is used by some growers to provide a source of micronutrients (48). However, field soil in containers is not aerated sufficiently, drainage is poor, undesirable pathogens and weeds may be introduced, and control of fertility is difficult if not impossible (32). Soilless media are used by many nurserymen and almost exclusively by reforestation seedling producers. The components vary considerably in different regions as each grower attempts to match availability of the medium with species, container system, watering practices and fertility system (146). Availability and economy also play important roles in selection of media components (72). A standard mix developed by the University of California is a 1:1 ratio of peat and coarse sand and is used by many growers (126). Pine bark is often substituted for peat (26) (102) (111) (146) and shale is sometimes substituted for sand (48) (77). Research at Oklahoma State University has usually been conducted using pine bark, peat and sand in a 2:1:1 ratio by volume (45) (134) (135). Rice hulls which are readily available in some areas are substituted for perlite or vermiculite and as a source of micronutrients (24) (25). Montano, et al. (91), used old sawdust and peatlite, old sawdust, new sawdust, old sawdust and soil, and 1:1 peat:vermiculite as a medium for container grown white fir seedlings. They found the old sawdust and peatlite would produce seedlings of equal quality to the peat:vermiculite medium. While most bark used in container media is from softwood conifers, hardwood bark is also successfully used (34) (60) (88).

Mycorrhizae

Virtually all tree species form mycorrhizal associations in the field (86). While mycorrhizae are not absolutely necessary for all species, growth is stimulated by the presence of mycorrhizal fungi on the root systems (40). There is evidence that soil fumigation of some species fail to achieve normal growth due to the eradication of indigenous mycorrhizae fungi (87) (145). This evidence supports nurserymen who do not sterilize soil mix used in containers. Some species show a strong growth response to the presence of a specific mycorrhizae. Bryan et al. (16), found that sweet gum seedlings grown in plots of soil innoculated with Glomus mosseae were 82 percent taller than control seedlings which were denied the mycorrhizal association. It was concluded that Liquidambar styraciflua is highly dependent on mycorrhizal association for optimum growth. The fungal symboiant Pisolithus tinctorius consistantly improved growth of Pinus taeda in several regions of North America (86) (87). Pisolithus tinctorius has been isolated from every area where Pinus taeda are grown from Mexico to Canada according to Marx et al. (86)

> The presence of ectomycorrhizae appears to increase tolerance of trees to drought, high soil temperature, soil toxins (organic and inorganic) and extremes of soil pH caused by high levels of sulfur and aluminum. They also deter infection of feeder roots by root pathogens (86, p. 253).

While little is known about mycorrhizal associations with many landscape trees, the numerous potential benefits suggest further study to find a method of innoculating container media.

Nutrition

If optimum growth is to be achieved, a continuous and adequate supply of all required nutrients must be available to the seedling. The media, container, soil volume, type of fertilizers used, all influence plant response to fertility (14) (22). Response also varies with species. Nutrition may be the limiting factor in achieving optimum seedling growth (75). Brix (14) suggested that amending container media with fertilizers was not desirable since concentrations of some elements would be undesirably high. He was contrasting seed bed fertilizer incorporation prior to seeding with small reforestation seedling containers and must have disregarded controlled release fertility systems altogether.

As previously discussed, soil is undesirable as a rooting medium in containers because other media have more desirable physical and chemical characteristics. A mixture of peat moss and vermiculite is most widely used in the Pacific Northwest (14) but ground bark is also a component for many growers (26) (73) (90) (94) (102) (111) (146). Soilless media require the addition of all required plant nutrients. Recommendations of various materials to supply these nutrients are diverse (132).

Single-superphosphate, dolomite, and perk (a micronutrient fertilizer manufactured by Kerr-McGee Chemical Company, Jacksonville, Florida) provide suitable slow release fertility sources for phosphorous, calcium, sulfur, magnesium and micronutrients (134) (135). Soluble liquid fertilizers are widely used (59) (121). Reforestation seedlings are often stressed by withholding nutrients especially nitrogen to achieve dormancy, bud set, and cold hardiness (120) (121). The use of controlled release fertilizers could eliminate many disadvantages of a liquid system: (1) eliminate expensive injection machinery, (2) provide a more uniform supply of nutrients to the plant throughout the growing season, (3) reduce the amount of fertilizer required (7), and (4) to reduce labor costs (120). Research by Ward (130) concluded that slow release nutrient sources produce larger plants of higher quality than liquid fertilization at the same rate. Furuta (33) found that when containers were watered with liquid fertilizer at 174 parts per million (ppm) nitrate, the runoff water contained 203 ppm nitrates. This value exceeds Environmental Protection Agency standards in some areas (7). Osmocote (a slow release nitrogen, phosphorus, and potassium source manufactured by Sierra Chemical Company, Newark, California) has been used extensively in container growing (17) (18) (37) (45) (72) (99) (106) (133) (134) (136).

Osmocote is produced by application of multiple, plastic polymer coatings to prills of various water-soluable dry fertilizer materials. The rate of nutrient release can be controlled by the use of various types and thicknesses of coatings. A moderate selection of fertilizer sources can be coated and this presents flexability to produce numerous controlled release formulations with varied nutrient release patterns, nutrient sources, and ratios. Nutrient release is by diffusion of water into the particle, dissolving the mineral within and allowing nutrients in solution to diffuse outward through the membrane where they become available for uptake by plants.

Factors which influence the release rate of osmocote: (1) increased soil temperature increases the rate of release, (2) intermittent, moderate drying of the particle as might occur with surface applications decrease the release rate, and (3) soil microbial activity, soil pH, and external salt concentrations have little or no effect (7).

McGuire and Bunce (82) suggested slow release fertilizers in the propagation medium when rooting cuttings, thereby reducing troublesome algae. Schulte and Whitcomb (110) incorporated osmocote 18-6-12 into a peat and perlite rooting medium and found that root quality and rooting percentage of Ilex spp. was increased at 200 and 400 grams per 35.2 liters of medium. Gouin (38) reported that osmocote 18-6-12 at 14 grams per 0.093 square meters produced azaleas of much higher quality than control plants without osmocote in the propagation medium.

Glenn, Hogan, and Whitcomb (36) reported increased root quality of Ilex cornuta 'Burford' using osmocote 18-6-12 in the rooting medium.

Increased rooting speed of several species by using osmocote 18-9-13 at 3.6 grams per liter was reported by Self and Pounders (112).

Johnson and Hamilton (57) used two osmocote formulations (14-14-14 and 18-6-12) at two rates each and measured rooting and leaf nutrient composition of Ligustrum japonicum and Juniperus conferta. The osmocote was top dressed and had little effect on rooting percentage of either species. The 14-14-14 formulation which has a faster release rate decreased rooting at the higher levels tested.

Hathaway (47) incorporated osmocote 18-6-12 into the medium and germinated Quercus acutissima, Pinus thunbergi, Betula nigra and Quercus shumardi without seedling damage up to 12 kg/m^3 of osmocote. Hathaway and Whitcomb (46) used three sizes of bottomless containers and five levels of osmocote 18-6-12 top dressed on the germinating medium after seedling emergence and found the growth of Quercus shumardi to be significantly increased by the three highest rates of osmocote (4.5 kg/m^3, 6.5 kg/m^3, and 9 kg/m^3). The 4.5 kg/m^3 rate produced seedlings essentially the same size as the unfertilized control seedlings at the end of 90 days, but were significantly larger one year later. This suggests that the benefits of fertility in the germinating medium influence plant growth long after the propagation phase. Maggs (84) found that neither the root or shoot continuously limits growth. Both usually operate considerably below their maximum efficiency. He suggested nutrition as a means of increasing growth.

Research Species Growth Habit

Shumard oak seedlings are characterized by hypogenous germination (50), monopodial (determinant) shoot growth and a dominant primary root with few lateral roots formed during early growth under uncultivated conditions (45) (78).

Japanese black pine germinates epigeously and unlike the oak, both cotyledons and primary needles are lost early in the seedling life. This requires most nutrients to come from the immediate root environment. Shoot formation normally involves bud formation during the first year and extention of the bud into a shoot the second year. Such shoot development is termed "preformed shoots" (63).

Container-grown pines are normally cultured one to five years before outplanting (69). Speeding up this process often involves extensive greenhouse controlled environmental equipment (121) (130).

Considerable difficulty in the production of pine seedlings with optimal root structure has also been documented (69) (75) (128).

The pecan, like oaks, has hypogenous germination and produces a very dominant primary root with few lateral roots and no root hairs

(148). Research in the past has indicated that a tap root 60 to 120 cm long is necessary for successful transplanting and seedling development (54).

Birch shoots do not expand from terminal buds, but are made up of secondary axes. This sympodial (indeterminant) type of growth results when the shoot tip aborts. Some of the shoots are fully predetermined in the bud and others are not (63). The shoots which are not fully preformed in the winter bud are called heterophyllus shoots (63) and produce two sets of leaves: (1) early leaves which are contained in the bud and (2) late leaves expand from primordia which continue to form as the shoot is elongating. Thus, by the end of the growing season such heterophyllus shoots have more leaves than were found in the winter bud. This characteristic eliminates a growth limitation imposed by the type of bud set and growth flushes inherent with oaks, pines and pecans.

CHAPTER III

METHODS AND MATERIALS

To evaluate the effects of nutrition and root modification during propagation, four species were selected with different shoot growth patterns, root structure, seed size and type of germination.

Shumard oak (Quercus shumardi), Buckl. (95), acorns were collected from a single parent tree on October 27, 1975, graded to size (79) and treated with hot water (49°C) for thirty minutes to kill any weevils present and stratified at 3°C until planted April 13, 1976. Polyethylene bags were used to hold acorns during stratification (49). Radicals were just emerging at planting time which insured uniform emergence of the seedlings.

Japanese black pine (Pinus thunbergi), Parl., seed was purchased from a commercial source and was tested to determine viability.

The pine seed was sown April 13, 1976, four to five seeds per container and thinned by hand after emerging to insure a complete stand.

Pecan (Carya illinoensis) (Wangh.), Koch. (9), var. "Western" nuts were stratified 120 days (3°C), soaked 72 hours in water and planted April 20, 1976.

River birch (Betula nigra) L. (12) seed was collected June 2, 1976 from a single tree by stripping the strobiles when they were still slightly green. Due to exceptionally late seed maturation, the birch seed was sown on June 9, 1976. A thin layer of sand was applied over the small seed to aid in moisture retention. It is thought to be necessary to shade birch seedlings for two to three months during the first summer (11). However, no shading was provided and germination was excellent (epigeous) requiring several thinnings to limit each container to one seedling. The four test species were grown outside in full sun without protection from the elements.

Containers were 7 x 7 cm square paper milk carton stock which were cut to 14 cm tall and held 683 cm^3 of growing medium (excluding a 1.5 cm space at the top to allow surface application of osmocote). A 2:1:1 mixture of ground pine bark, peat, and sand with 1.3 kg/m^3 of single superphosphate (0-20-0) constituted the basic growing medium. Combinations of various levels of osmocote 18-6-12, perk and dolomite were added (Table I). The 4 x 3 x 3 factorial experiment was replicated four times and arranged in a randomized complete block design. Treatments were prepared by adding the required amounts of the nutrient materials to 42,475 cm^3 of the basic medium and thoroughly mixing in a small cement mixer. Each experimental unit which consisted of four individual containers (sub-samples) was then filled by hand with the prescribed mixture. A conversion table is provided to simplify specific treatment additives (Appendix A). This experimental design was used on each of the four species. Each species was located on a separate table constructed with a (122 x 245 cm) sheet of expanded metal as the bench top (Appendix B). A border row was provided to buffer the experimental treatments. These benches in combination with the bottomless, square containers allowed the root system to grow downward out of the medium and dessicate or "air-prune."

TABLE I

AMOUNTS OF OSMOCOTE 18-6-12, PERK, AND DOLOMITE ADDED TO PROPAGATION MEDIUM CONSTITUTING TREATMENTS

	Kg/m^3			
Rates Kg/m^3	Level 1	Level 2	Level 3	Level 4
Osmocote	0	3.40	6,80	10.2
Perk	0	1.39	2.77	
Dolomite	0	1.39	2.77	

Species were watered by hand as required to prevent water stress. Treatments receiving osmocote had 4.45 kg per meter incorporated when mixing the treatments. The two highest levels of osmocote were then top dressed by adding three or six grams of osmocote after seedling emergence. The highest rates of osmocote were equal to 8.9 and 13.36 kg of osmocote per cubic meter, respectively.

One application of diazinon was necessary in early June to control insect larvae feeding on the Japanese black pines.

Evaluation

At the termination of the propagation phase, sub-samples of each treatment were evaluated in the following manner:

1. The seedling which was most unlike the other three in a treatment sub-sample, i.e., excessively tall or short, was discarded in order to decrease error due to seedling genetic variability (Figure 1). Of the three seedlings remaining height, bud breaks (flushes), and caliper was measured on August 12, 1976.

2. One seedling was sacrificed to determine top weight, root weight and foliar nutrient analysis of nutrient elements.

3. One seedling was planted in a container.

4. One seedling was planted in the field.

After fresh top weight was recorded for Shumard oaks and Japanese black pines, leaves were dried and ground to determine foliar nutrient levels. Foliar analysis for total nitrogen was done by the Soil Testing Facility of the Department of Agronomy, Oklahoma State University, using a Technicon nitrogen analyzer. The remaining tissue was dry ashed and

1 Cull (least representative)	2 Measure, then to field
3 Measure, then assay for top wt., root wt., and foliar analysis 8-14-76	4 Measure, then to container

Figure 1. Disposition of Subsamples Within Each Experimental Unit

diluted in hydrochloric acid before being read on the atomic absorption spectrophotometer for potassium, magnesium, calcium, manganese, iron, and zinc.

Seedlings planted in containers (11,309 cm^3) had a growing medium of 2:1:1 ground pine bark, peat, and sand with the following amendments per 0.7646 cubic meter (cubic yard): 1.8 kg (4 pounds) each of perk and single superphosphate (0-20-0), 3.6 kg (8 pounds) of dolomite and 6.35 kg (14 pounds) of osmocote 18-5-11 (12 to 14 month formulation). Ronstar (oxydiazon) was applied as a 2 percent granular formulation at 9.7 kg/ha as a preemergent herbicide.

The randomized complete block design with four replications was maintained in containers and the field. A flow diagram (Figure 2) best illustrates the chronology of different species as the research progressed.

It is important to emphasize that all seedlings in the field and in containers were treated alike after the propagation phase. Planting in containers and field was accomplished by placing the seedling while still in the propagation container in a hole approximately two times the container diameter. The hole was then partially filled and by grasping the top edges of the milk carton and swiftly pulling the carton upward, the container was removed without disturbance or exposure of the root system of the seedling. Soil or medium was then added to place the surface of the propagation medium just under the surface of the soil (field) or medium (container).

Seed	Propagation	Transplanted
Oak	planted 4-13-76 emergence 4-26-76	field 8-14-76 container 8-13-76
Pine	sown 4-13-76 emergence 4-29-76	field 9-20-76 container 9-20-76
Birch	sown 6-9-76 emergence 6-29-76	field 8-15-76 container 8-15-76
Pecan	sown 4-20-76 emergence 5-29-76	field 8-14-76 container 8-14-76

Figure 2. Chronological Flow Diagram of Experiment.

CHAPTER IV

RESULTS AND DISCUSSION

Air pruning of the roots by using bottomless containers produced a very fibrous root system in all species. Shumard oak and Pecan, which normally have a corrot-like seedling primary root, had a multitude of small lateral roots. The lateral roots emerged uniformly on the air pruned primary root. No spiral or kinking of roots was found on any seedling of the species tested during the air pruned seedling stage. Reaction of the primary root apex to desiccation is in agreement with studies by Zimmerman and Hitchcock (150). Who observed a rapid growth of lateral roots following hormone treatment to the primary root. They postulated the existance of apical dominance in roots to account for their observations. Horsley and Wilson (55) also suggest that there is some form of apical control over lateral root initiation and subsequent growth activity. Air pruning of the primary root apparently removed the apical dominance.

Lateral roots were initiated in the pericycle, opposite the protoxylem ridges (27) (139). According to Wilcox (138), this is the same location where lateral roots arise when young roots are pruned. This continuous air pruning of the young primary root does not produce roots in the same morphogenic manner characterized by roots pruned after secondary tissues have been formed. Pruning a bed of field grown seedling at harvest results in removal of secondary root tissues which stimulates replacement root production. Replacement roots arise in various positions around the circumference of the vascular cylinder and are initiated in the vascular cambium that has developed in the callus at the cut surface (28). None of the test species in this research showed a reduction in shoot growth due to root modification. This is in agreement with the root to shoot imbalance theory suggested by Leopold (76) which suggests that abrupt removal of roots sets up a root to shoot imbalance causing a reduction in shoot growth until roots have grown to again balance the plant. The gradual modification of roots in lieu of abrupt removal probably accounts for the sustained shoot growth during air pruning.

Foliar analysis showed that some tissue nutrient levels were consistant with findings of other research, however, there is no published data on tissue levels of container grown tree seedlings using a controlled release fertility system during propagation. It is doubtful whether the seedlings produced by fertility regimes used in this research can be compared or related to seedlings grown with liquid systems in containers or beds or measurements from mature trees.

Shumard Oak

Osmocote in the germinating medium dramatically increased the growth of shumard oak seedlings. Plant height, bud breaks, stem caliper, top weight and root weight significantly increased when the rate of osmocote was increased from 0 to 4.45 kg/m^3 (Table II and Figure 3). Further increasing the osmocote levels did not significantly increase top growth parameters, however, root weight decreased (Table II and Figure 4).

TABLE II

EFFECTS OF OSMOCOTE LEVEL ON HEIGHT, BREAKS, CALIPER, TOP WEIGHT, ROOT WEIGHT, AND TOTAL WEIGHT OF SHUMARD OAKS

Osmocote[1] Level	Height[2] cm	Breaks[2]	Caliper[2] cm	Top Wt.[3] g	Root Wt.[3] g	Tot. Wt.[3] g
0.00	14.7[4]a	1.94 a	0.31 a	3.3 a	6.4 a	9.7 a
4.45	51.4 b	3.87 b	0.44 b	12.1 b	8.3 b	20.4 b
8.90	51.8 b	3.85 b	0.45 b	13.2 b	7.5 a	20.7 b
13.36	55.6 b	3.95 b	0.45 b	13.4 b	7.3 a	20.7 b
Probability >F	0.0001	0.0001	0.0001	0.0001	0.05	0.0001

[1]Kilograms of osmocote per cubic meter.

[2]Values are means of 144 observations.

[3]Values are means of 36 observations.

[4]Means in columns followed by the same letter are not significantly different at 0.05 using a protected LSD test.

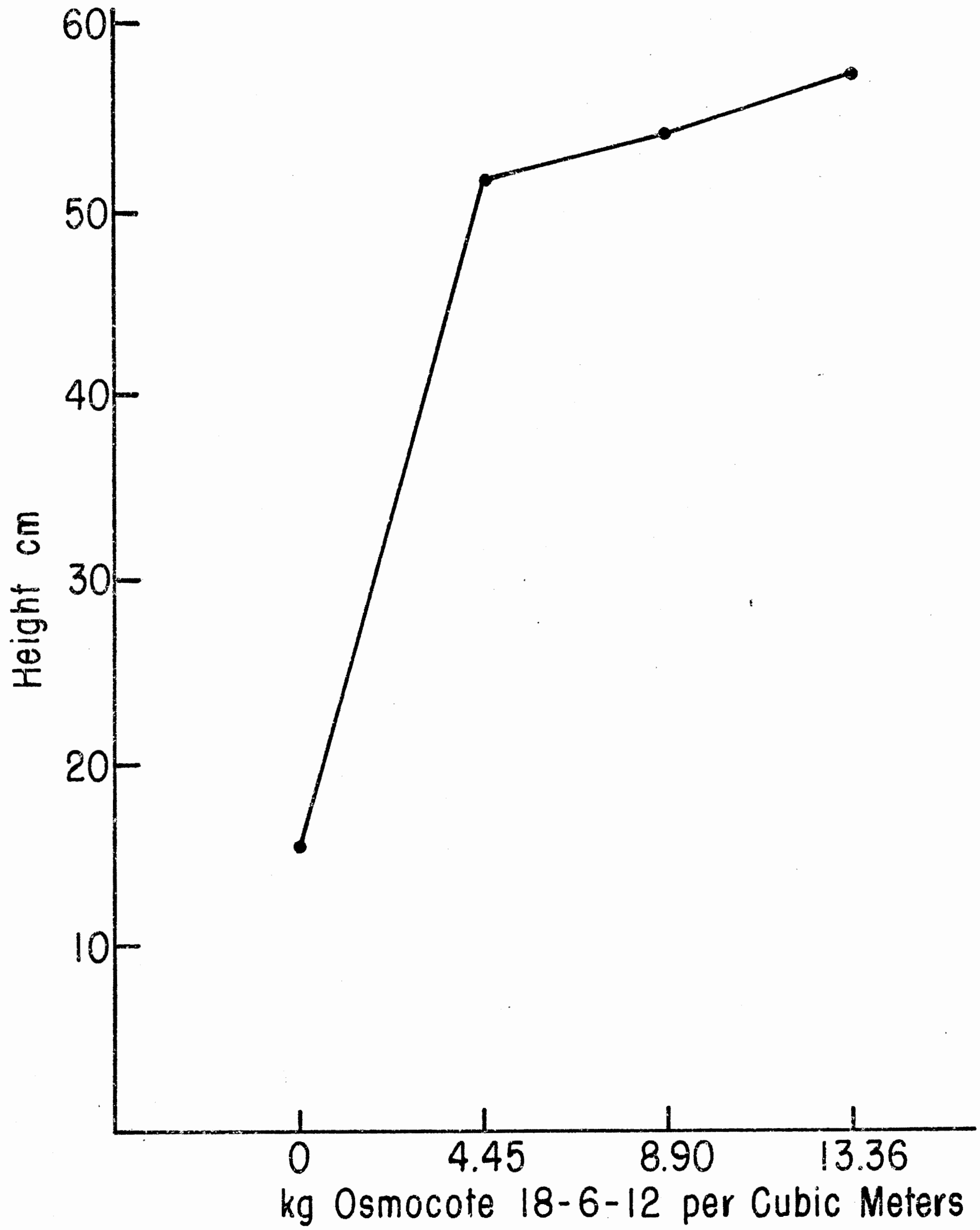

Figure 3. Effects of Osmocote on Height of Shumard Oak 120 Days After Seeding.

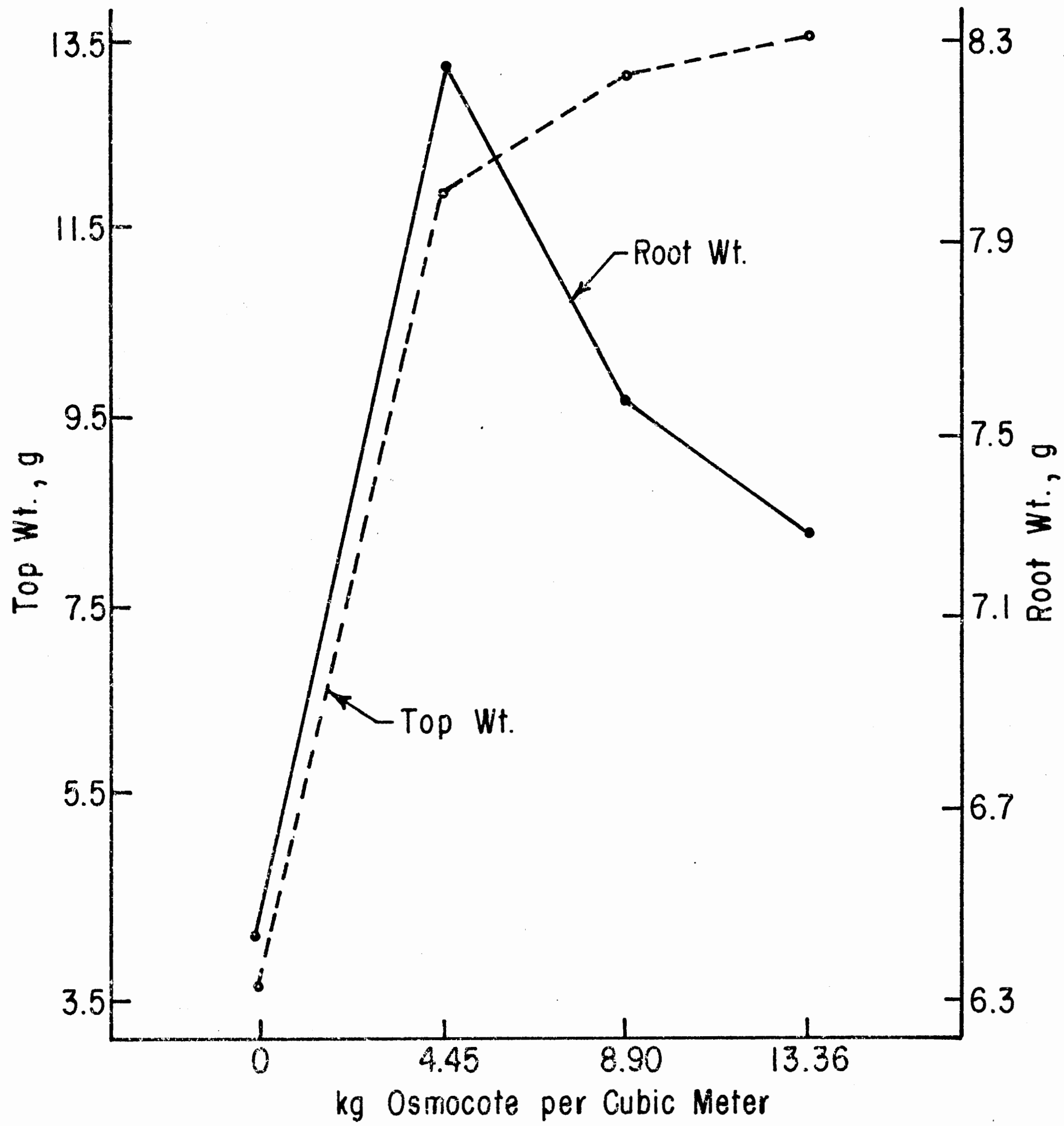

Figure 4. Effects of Osmocote on Top Weight and Root Weight of Shumard Oaks During Propagation.

Percent nitrogen in the leaves increased with the addition of osmocote as did potassium, manganese, magnesium, and total grams of nitrogen per plant while calcium decreased (Table III). Parts per million (PPM) of iron was the only foliage nutrient level which was not changed by the addition of osmocote. Zinc was highest when no osmocote was present and decreased as osmocote level increased. Applied nitrogen has been reported as a possible cause of zinc deficiency in citrus trees when the supply of zinc is marginal (39). Ozanne (98) suggested that an increase in the nitrogen supplied caused more zinc to be retained in the roots as a zinc-protein complex. This retention of zinc in roots caused a deficiency in foliar zinc levels. He burther noted that this nitrogen zinc interaction occurred in experiments when the pH was unchanged.

Perk increased plant height (Figure 5), bud breaks and stem caliper while top weight, root weight and total weight were not affected (Table IV). Perk did not influence potassium tissue levels or total grams of nitrogen in the plant (Table V). Percent nitrogen significantly decreased when perk level changed from 0 to 2.375 kg then increased again at the 4.75 kg level was not different from those plants not receiving perk. Iron, manganese and zinc levels all increased when perk was added to the medium. Magnesium increased as perk increased from 0 to 2.375 kg, however, plants not receiving perk contained the same as the 4.75 kg level. Calcium was not significantly different at the 0 and 2.375 kg perk levels but decreased when 4.75 kg of perk was added to the medium.

Dolomite had no effect on plant height, bud breaks, stem caliper, root weight and total weight while top weight decreased as dolomite

TABLE III

EFFECTS OF OSMOCOTE LEVEL ON FOLIAR CONCENTRATIONS OF ELEMENTS IN SHUMARD OAKS

Osmocote[1] Level	% N	% K	PPM Fe	PPM Mn	% Mg	PPM Zn	% Ca	N (g)[3]
0.00	1.95[4] a	0.342 a	110 a	190 b	0.43 b	86 c	0.62 b	1.86 a
4.45	2.57 bc	0.398 b	117 a	110 a	0.38 a	82 bc	0.58 a	5.16 b
8.90	2.45 b	0.390 b	118 a	102 a	0.37 a	73 ab	0.55 a	5.02 b
13.36	2.67 c	0.397 b	114 a	106 a	0.39 a	70 a	0.56 a	5.44 b
Probability >F	0.0001	0.0004	0.6	0.0001	0.002	0.0015	0.07	0.0001

[1]Kilograms of osmocote per cubic meter.

[2]Values are means of 36 observations.

[3]Grams of nitrogen (dry weight of top and root multiplied by % N).

[4]Means in the same column followed by the same letter are not significantly different at 0.05 using a protected LSD test.

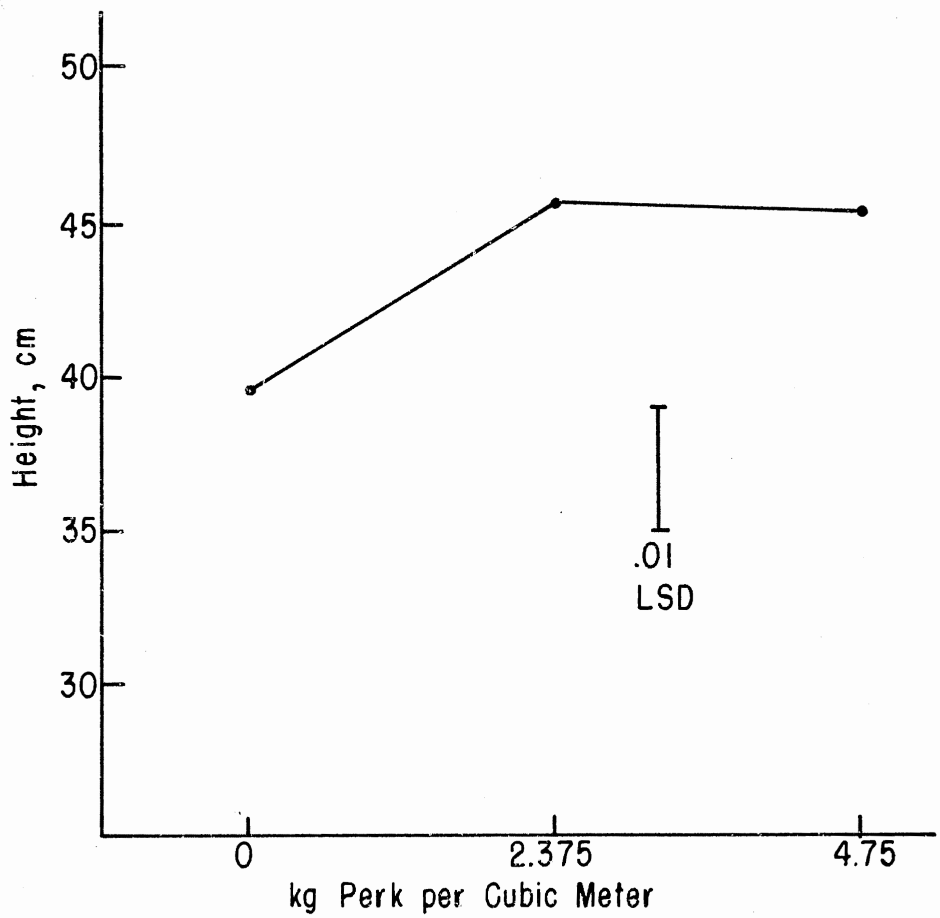

Figure 5. Effects of Perk on Height of Shumard Oaks.

TABLE IV

EFFECTS OF PERK LEVEL ON HEIGHT, BREAKS, CALIPER, TOP WEIGHT, ROOT WEIGHT, AND TOTAL WEIGHT OF SHUMARD OAKS

Perk[1] Level	Height[2] cm	Breaks[2]	Caliper[2] cm	Top Wt.[3] g	Root Wt.[3] g	Tot. Wt.[3] g
0.000	39.35[4]a	3.10 a	0.41 a	10.33 a	7.85 a	18.13 a
2.375	45.54 b	3.31 ab	0.43 b	10.35 a	7.31 a	17.66 a
4.750	45.22 b	3.35 b	0.40 a	10.81 a	6.91 a	17.72 a
Probability >F	0.0006	0.01	0.05	0.05	0.19	0.86

[1]Kilograms of perk per cubic meter.

[2]Values are means of 192 observations.

[3]Values are means of 48 observations.

[4]Means in columns followed by the same letter are not significantly different at 0.05 using a protected LSD test.

TABLE V

EFFECTS OF PERK LEVEL ON FOLIAR CONCENTRATIONS OF ELEMENTS IN SHUMARD OAKS

Perk[1] Level	% N[2]	% K[2]	PPM Fe[2]	PPM Mn[2]	% Mg[2]	PPM Zn[2]	% Ca[2]	N (g)[3]
0.000	2.46[4] b	0.387 a	108 a	67 a	0.385 a	66 a	0.62 b	4.58 a
2.375	2.29 a	0.388 a	118 b	152 b	0.413 b	81 b	0.61 b	4.11 a
4.750	2.49 b	0.371 a	118 b	162 b	0.384 a	85 b	0.51 a	4.42 a
Probability >F	0.005	0.29	0.05	0.0001	0.05	0.0001	0.0002	0.22

[1]Kilograms of perk per cubic meter.

[2]Values are means of 48 observations.

[3]Grams of nitrogen (dry weight of top and root multiplied by % N).

[4]Means in the same column followed by the same letter are not significantly different at 0.05 using a protected LSD test.

increased (Table VI). However, highly significant decreases in tissue levels of zinc, manganese and potassium accompanied increased amounts of dolomite (Table VII). Calcium and magnesium level increased with increasing levels of dolomite as might be expected.

Perk and dolomite interacted significantly on height, percent N and top weight, indicating perk may offset the apparent detrimental effects of dolomite on the seedlings. Seedling height decreased dramatically as dolomite level was increased when no perk was present (Figure 6). However, at higher rates of perk, increasing dolomite had no significant effect on height. A similar interaction shows that percent nitrogen increased with an increase in dolomite with no perk. However, when perk was present, increased dolomite greatly decreased percent nitrogen (Figure 7).

Seedling top weight increased with increasing perk at the 4.75 kg level of dolomite (Figure 8). However, the highest level of perk and dolomite did not increase top weight over the level of both nutrient sources. These data suggest that the lowest rate (2.375 kg) of dolomite is too high for growing shumard oak seedlings.

Japanese Black Pine

Increasing osmocote in the growing medium from 0 to 4.45 kg/m^3 produced a striking increase in plant height, bud breaks, stem caliper, top weight and root weight (Table VIII). Additional osmocote did not significantly increase seedling growth, and the highest rate decreased root weight. However, foliar nitrogen concentrations increased in direct proportion to increased rates of osmocote (Table IX). Potassium, iron, and magnesium increased as osmocote level increased from 0 to

TABLE VI

EFFECTS OF DOLOMITE LEVEL ON HEIGHT, BREAKS, CALIPER, TOP WEIGHT, ROOT WEIGHT, AND TOTAL WEIGHT OF SHUMARD OAKS

Dolomite[1] Level	Height[2] cm	Breaks[2]	Caliper[2] cm	Top Wt.[3] g	Root Wt.[3] g	Tot. Wt.[3] g
0.000	45.18[4]a	3.29 a	0.41 a	11.46 b	7.20 a	18.66 a
2.375	43.19 a	3.25 a	0.41 a	9.88 a	7.20 a	17.08 a
4.750	41.75 a	3.22 a	0.42 a	10.17 a	7.66 a	17.83 a
Probability >F	0.12	0.77	0.57	0.05	0.59	0.32

[1]Kilograms of dolomite per cubic meter.

[2]Values are means of 192 observations.

[3]Values are means of 48 observations.

[4]Means in columns followed by the same letter are not significantly different at 0.05 using a protected LSD test.

TABLE VII

EFFECTS OF DOLOMITE LEVEL ON FOLIAR CONCENTRATIONS OF ELEMENTS IN SHUMARD OAKS

Dolomite Level[1]	% N[2]	% K[2]	PPM Fe[2]	PPM Mn[2]	% Mg[2]	PPM Zn[2]	% Ca[2]	N (g)[3]
0.000	2.49[4] a	0.414 b	118 a	140 b	0.315 a	85 b	0.53 a	4.69 a
2.375	2.38 a	0.371 a	114 a	131 ab	0.421 b	75 a	0.59 ab	4.14 a
4.750	2.36 a	0.360 a	111 a	109 a	0.446 b	72 a	0.62 b	4.28 a
Probability >F	0.13	0.0002	0.31	0.009	0.0001	0.003	0.006	0.11

[1]Kilograms of dolomite per cubic meter.

[2]Values are means of 48 observations.

[3]Grams of nitrogen (dry weight of top and root multiplied by % N).

[4]Means in the same column followed by the same letter are not significantly different at 0.05 using a protected LSD test.

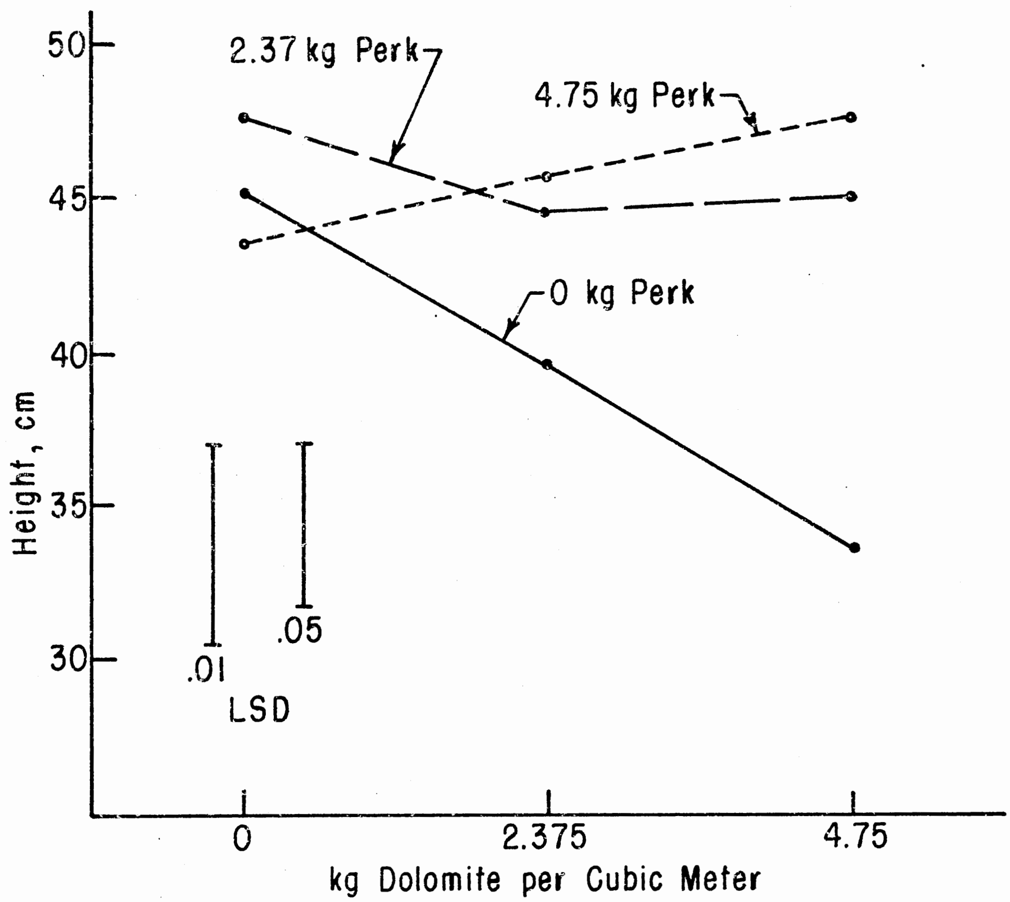

Figure 6. Effects of Perk and Dolomite on Height of Shumard Oak Seedlings.

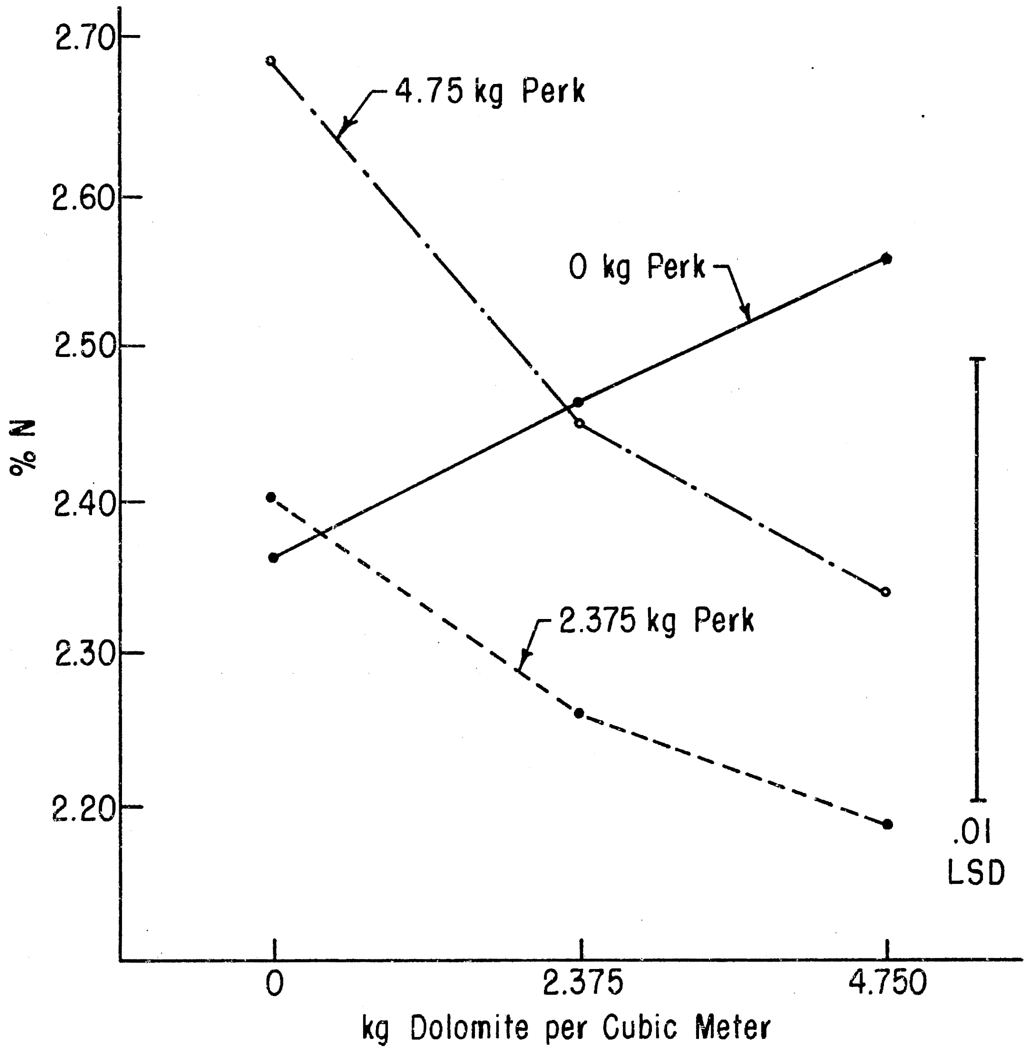

Figure 7. Effects of Perk and Dolomite on Percent Nitrogen in Foliage of Shumard Oak.

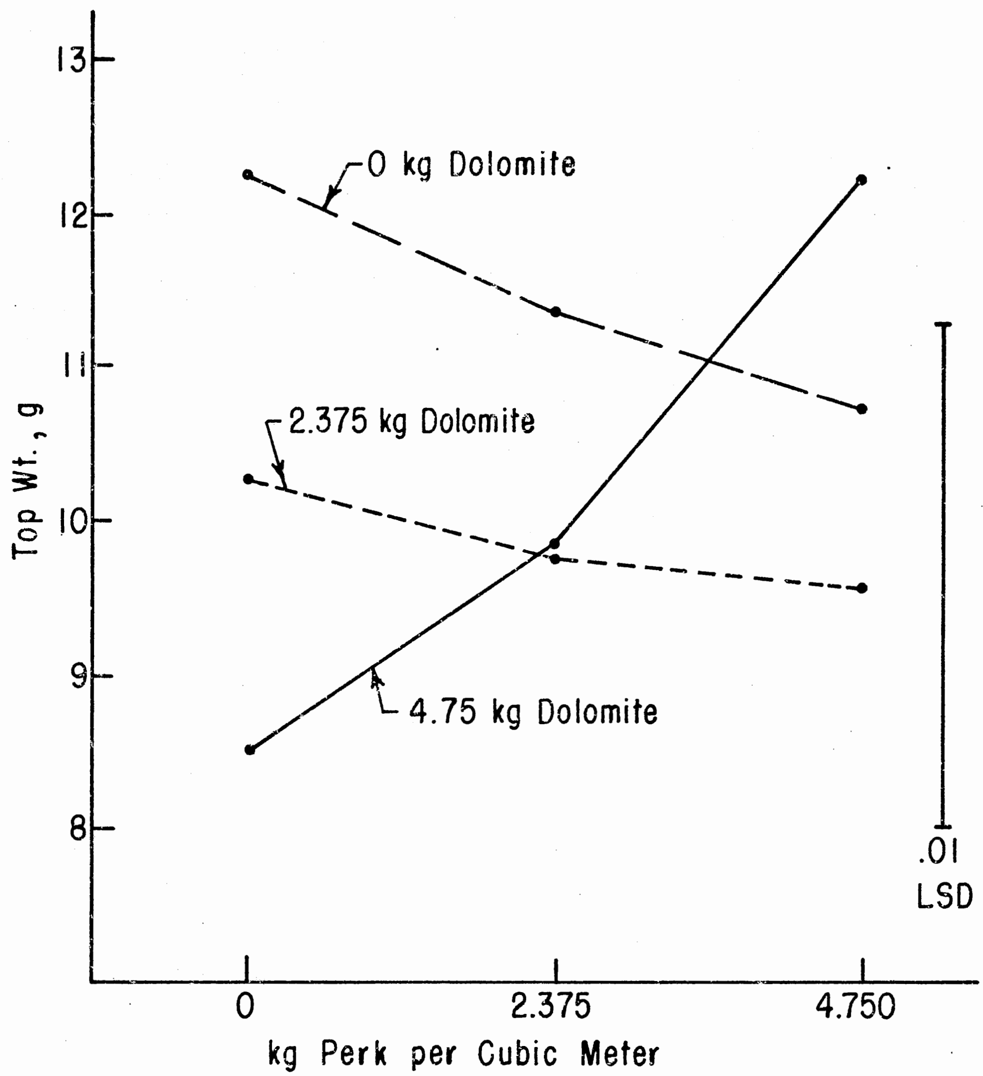

Figure 8. Effects of Perk and Dolomite on Top Weight of Shumard Oaks.

TABLE VIII

EFFECTS OF OSMOCOTE LEVEL ON HEIGHT, BREAKS, CALIPER, TOP WEIGHT, ROOT WEIGHT, AND TOTAL WEIGHT OF JAPANESE BLACK PINES

Osmocote[1] Level	Height[2] cm	Breaks[2]	Caliper[2] cm	Top Wt.[3] g	Root Wt.[3] g
0.00	4.6[4]a	0.97 a	1.52 a	1.7 a	1.5 a
4.45	15.9 b	4.02 b	5.05 b	13.6 b	4.8 c
8.90	15.4 b	4.19 b	5.22 b	14.9 b	4.3 bc
13.36	15.7 b	3.91 b	5.19 b	14.3 b	3.9 b
Probability >F	0.0001	0.0001	0.0001	0.0001	0.0001

[1]Kilograms of osmocote per cubic meter.

[2]Values are means of 144 observations.

[3]Values are means of 36 observations.

[4]Means in columns followed by the same letter are not significantly different at 0.05 using a protected LSD test.

TABLE IX

EFFECTS OF OSMOCOTE LEVEL ON FOLIAR CONCENTRATIONS OF ELEMENTS IN JAPANESE BLACK PINES

Osmocote[1] Level	% N[2]	% K[2]	PPM Fe[2]	PPM Mn[2]	% Mg[2]	PPM Zn[2]	% Ca[2]	N (g)[3]
0.00	0.72[4] a	0.33 a	48 a	188 a	0.098 a	71 a	0.08 a	0.22 a
4.45	1.92 b	0.63 b	61 b	183 a	0.153 b	80 a	0.10 a	3.50 b
8.90	2.40 c	0.66 b	56 b	184 a	0.163 b	80 a	0.13 ab	4.66 c
13.36	2.70 d	0.68 b	59 b	226 b	0.165 b	82 a	0.16 b	4.95 c
Probability >F	0.0001	0.0001	0.0001	0.0001	0.0001	0.58	0.007	0.0001

[1]Kilograms of osmocote per cubic meter.

[2]Values are means of 36 observations.

[3]Grams of nitrogen (dry weight of top and root multiplied by % N).

[4]Means in the same column followed by the same letter are not significantly different at 0.05 using a protected LSD test.

4.45 kg with no response to higher levels. In contrast, manganese levels did not increase above the control except for the highest level of osmocote which resulted in a highly significant increase. Calcium also increased with increasing osmocote. Total nitrogen increased up to the 8.9 kg rate with no further change with additional osmocote. Zinc tissue level was not affected by the level of osmocote.

Perk increased plant height, top weight and root weight but did not increase bud breaks or stem caliper (Table X).

As perk level increased, iron, manganese and zinc increased dramatically (Table XI). This was probably due to the increased concentration in the growing medium. Perk rate had no effect on percent nitrogen, magnesium or calcium. However, potassium decreased when perk was added to the growing medium, thus suggesting a competitive ion effect.

Dolomite decreased plant height and top weight slightly but had no effect on bud breaks, stem caliper or root weight (Table XII). These data show that the levels of dolomite used were detrimental to Japanese black pine seedlings during propagation.

Adding dolomite to the growing medium decreased foliar nitrogen and manganese levels and increased calcium and magnesium (Table XIII). Since the dolomite used in this study contained fourteen percent magnesium and twenty-one percent calcium, such an increase was expected. Zinc increased as dolomite increased from 0 to 2.375 kg/m^3 or higher (Table XIII). This may be due to a more favorable balance of nutrients at this level of dolomite. Iron concentration remained essentially the same, independent of dolomite levels. This may be due to a calcium, phosphorus and iron interaction. Brown, et al. (15) showed that calcium and phosphorus supplied to one part of a root system prevented

TABLE X

EFFECTS OF PERK LEVEL ON HEIGHT, BREAKS, CALIPER, TOP WEIGHT, ROOT WEIGHT, AND TOTAL WEIGHT OF JAPANESE BLACK PINES

Perk[1] Level	Height[2] cm	Breaks[2]	Caliper[2] cm	Top Wt.[3] g	Root Wt.[3] g
0.000	12.1 a	3.25 a	4.04 a	10.0 a	3.18 a
2.375	13.1 b	3.23 a	4.33 a	11.6 b	3.85 b
4.750	13.6 b	3.35 a	4.37 a	11.8 b	3.83 b
Probability >F	0.0005	0.76	0.17	0.02	0.006

[1]Kilograms of perk per cubic meter.

[2]Values are means of 192 observations.

[3]Values are means of 48 observations.

[4]Means in columns followed by the same letter are not significantly different at 0.05 using a protected LSD test.

TABLE XI

EFFECTS OF PERK LEVEL ON FOLIAR CONCENTRATIONS OF ELEMENTS IN JAPANESE BLACK PINES

Perk[1] Level	% N[2]	% K[2]	PPM Fe[2]	PPM Mn[2]	% Mg[2]	PPM Zn[2]	% Ca[2]
0.000	1.91[3] a	0.75 b	52 a	146 a	0.15 a	68 a	0.14 a
2.375	1.93 a	0.64 a	59 ab	219 b	0.17 a	84 b	0.15 a
4.750	1.98 a	0.65 a	62 b	250 c	0.17 a	92 c	0.14 a
Probability >F	0.68	0.0002	0.01	0.05	0.27	0.05	0.70

[1]Kilograms of perk per cubic meter.

[2]Values are means of 48 observations.

[3]Means in the same column followed by the same letter are not significantly different at 0.05 using a protected LSD test.

TABLE XII

EFFECTS OF DOLOMITE LEVEL ON HEIGHT, BREAKS, CALIPER, TOP WEIGHT, ROOT WEIGHT, AND TOTAL WEIGHT OF JAPANESE BLACK PINES

Dolomite[1] Level	Height[2] cm	Breaks[2]	Caliper[2] cm	Top Wt.[3] g	Root Wt.[3] g
0.000	13.6[4]b	3.25 a	4.35 a	12.52 b	3.75 a
2.375	12.9 a	3.37 a	4.25 a	10.97 ab	3.60 a
4.750	12.2 a	3.21 a	4.14 a	9.93 a	3.52 a
Probability >F	0.0005	0.64	0.51	0.002	0.61

[1]Kilograms of dolomite per cubic meter.

[2]Values are means of 192 observations.

[3]Values are means of 48 observations.

[4]Means in columns followed by the same letter are not significantly different at 0.05 using a protected LSD test.

TABLE XIII

EFFECTS OF DOLOMITE LEVEL ON FOLIAR CONCENTRATIONS ELEMENTS IN JAPANESE BLACK PINES

Dolomite Level[1]	% N[2]	% K[2]	PPM Fe[2]	PPM Mn[2]	% Mg[2]	PPM Zn[2]	% Ca[2]
0.000	2.05[3] b	0.56 a	57 a	289 c	0.13 a	66 a	0.11 a
2.375	1.90 a	0.68 b	56 a	192 b	0.17 b	93 b	0.15 ab
4.750	1.86 a	0.77 c	61 a	134 a	0.19 c	87 b	0.17 b
Probability >F	0.04	0.0001	0.10	0.0001	0.0001	0.0001	0.008

[1]Kilograms of dolomite per cubic meter.

[2]Values are means of 48 observations.

[3]Means in the same column followed by the same letter are not significantly different at 0.05 using a protected LSD test.

another part contacting the sole source of iron in soil from translocating iron to the leaves. The calcium and phosphorus, translocated into the roots that were exposed to iron, blocked either iron absorption or translocation. The decrease in manganese may have masked the effects of dolomite on iron, i.e. the increasing dolomite changed the iron-manganese levels, influencing iron concentrations in the leaves. Knezek and Greinert (61) applied FeEDTA and decreased the manganese uptake in navy beans as the iron:manganese ratio was increased.

As the dolomite was increased, potassium concentration in the foliage increased (Figure 9). Other research has produced similar results (19) (97). Kahn and Hanson (58) found an accumulation of potassium promoted by increased calcium and to a lesser extent, magnesium. This effect of calcium on potassium occurred with corn and was reversed with soybeans, i.e., calcium inhibited potassium uptake. Viets (127) suggested that by increasing the Ca:K ratio the potassium concentration increased. He further concluded that a variety of polyvalent cations accelerate potassium and bromine absorption, calcium being the most effective for barley roots. Shear, et al. (113) found a definite relationship between the accumulation of calcium, magnesium and potassium, in the leaves and the accumulation of manganese, zinc, copper, and iron in tung trees. The increasing levels of calcium, magnesium and potassium produced a manganese deficiency in the tung trees. Although manganese was also decreased in the Japanese black pines by increasing dolomite, tissue concentrations remained well above what is thought to be a deficiency level.

There was also a strong interaction between perk and dolomite on the foliar concentration of iron (Figure 10). The increase in iron at

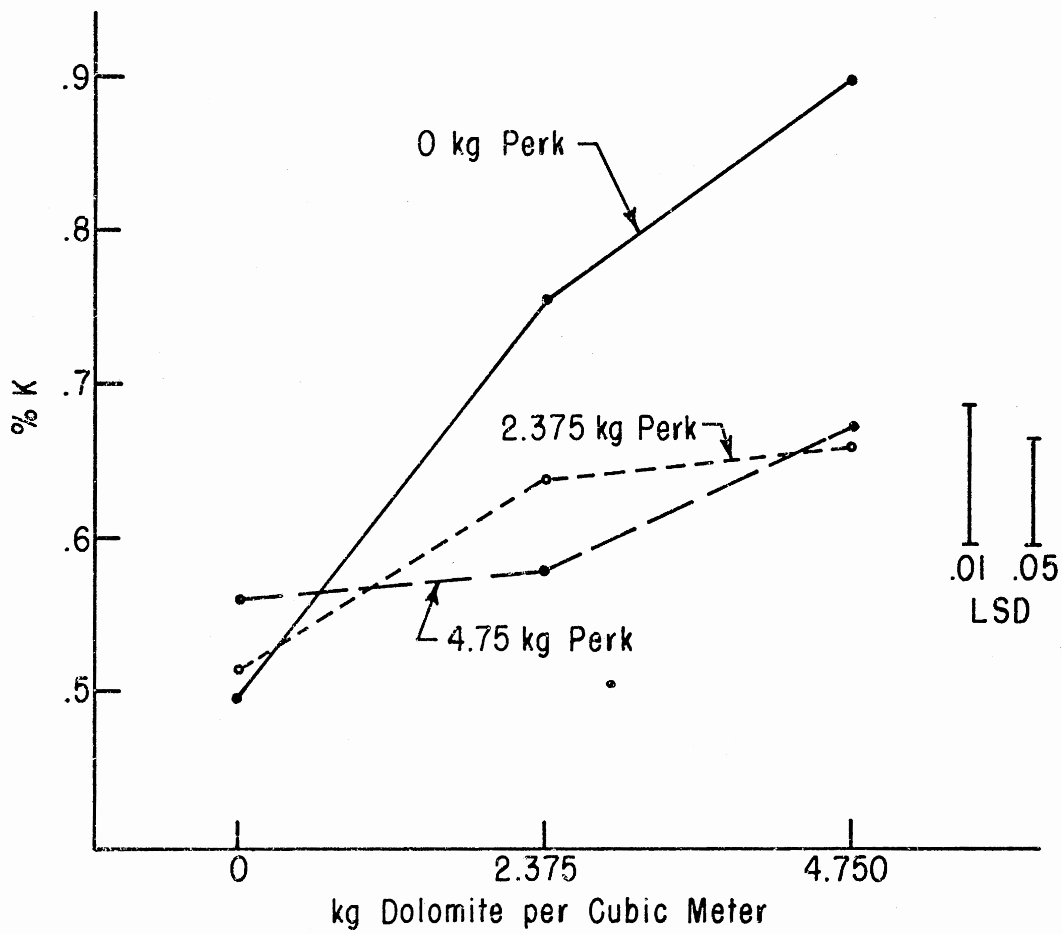

Figure 9. Effects of Perk and Dolomite on Foliar Concentration of Potassium in Japanese Black Pine.

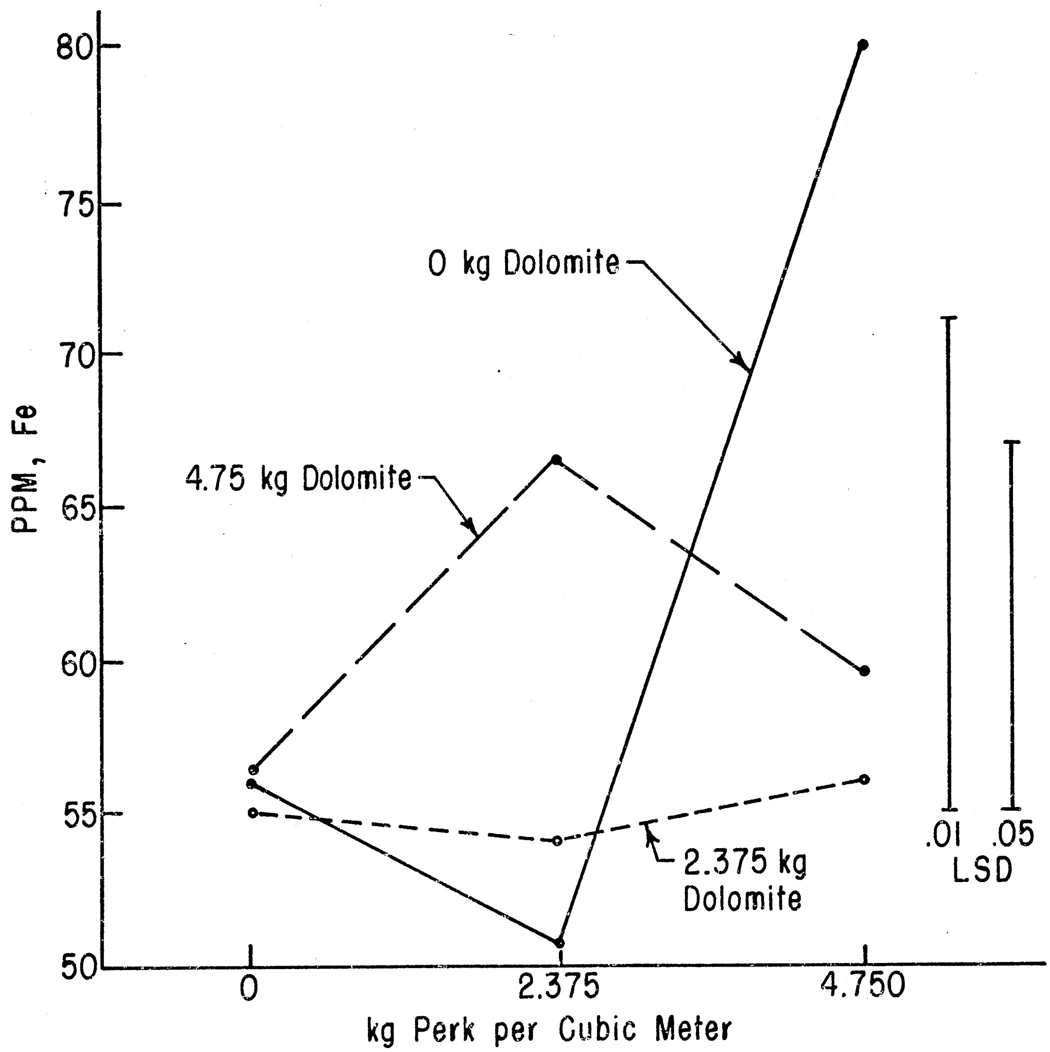

Figure 10. Effects of Perk and Dolomite on Foliar Concentration of Iron in Japanese Black Pines.

the 4.75 kg level of perk when dolomite was absent suggests that inadequate iron was provided at the 2.375 kg level of perk unless dolomite is present.

Pecan

Increasing osmocote from 0 to 4.45 kg/m^3 significantly increased plant height, bud breaks, stem caliper, top weight, and root weight of pe ans (Table XIV). Further increase in osmocote level was not beneficial at the time data was recorded and the seedlings were transplanted. While osmocote at 4.45 kg/m^3 did not further increase top weight, height or bud breaks (Figure 11) there was a strong interaction between osmocote and dolomite on root weight (Figure 12). The 2.375 kg level of dolomite was superior at the 8.90 kg of osmocote rate, but was decidedly inferior at 13.36 kg of osmocote. The highest level of dolomite (4.75 kg/m^3) was inferior at 0, 4.45 and 8.90 kg of osmocote but increased root weight dramatically when osmocote was increased to 13.36 kg. This indicates that for each level of osmocote a different level of dolomite is critical for maximum root growth.

The interaction between perk and osmocote was significant with regard to stem caliper (Figure 13). Perk at 2.375 kg/m^3 was superior to 4.75 kg/m^3 when 4.45 kg/m^3 of osmocote was used. However, the 2.375 kg/m^3 perk rate was not significantly better than no perk when osmocote was at the 8.90 and 13.36 kg/m^3 levels. Since the increase in caliper to just over 0.5 cm would allow early budding this may be a good example of a mean exceeding the arbitrary 0.05 probability level and still deserving consideration.

TABLE XIV

EFFECTS OF OSMOCOTE LEVEL ON HEIGHT, BREAKS, CALIPER, TOP WEIGHT, ROOT WEIGHT, AND TOTAL WEIGHT OF PECANS

Osmocote[1] Level	Height[2] cm	Breaks[2]	Caliper[2] cm	Top Wt.[3] g	Root Wt.[3] g
0.00	24.8[4]a	1.89 a	3.79 a	4.80 a	7.86 a
4.45	33.0 b	2.67 b	4.60 b	8.55 b	9.16 b
8.90	31.7 b	2.53 b	4.52 b	9.13 b	9.58 b
13.36	34.0 b	2.69 b	4.54 b	9.33 b	9.30 b
Probability >F	0.0001	0.0001	0.0001	0.0001	0.003

[1]Kilograms of osmocote per cubic meter.

[2]Values are means of 144 observations.

[3]Values are means of 36 observations.

[4]Means in columns followed by the same letter are not significantly different at 0.05 using a protected LSD test.

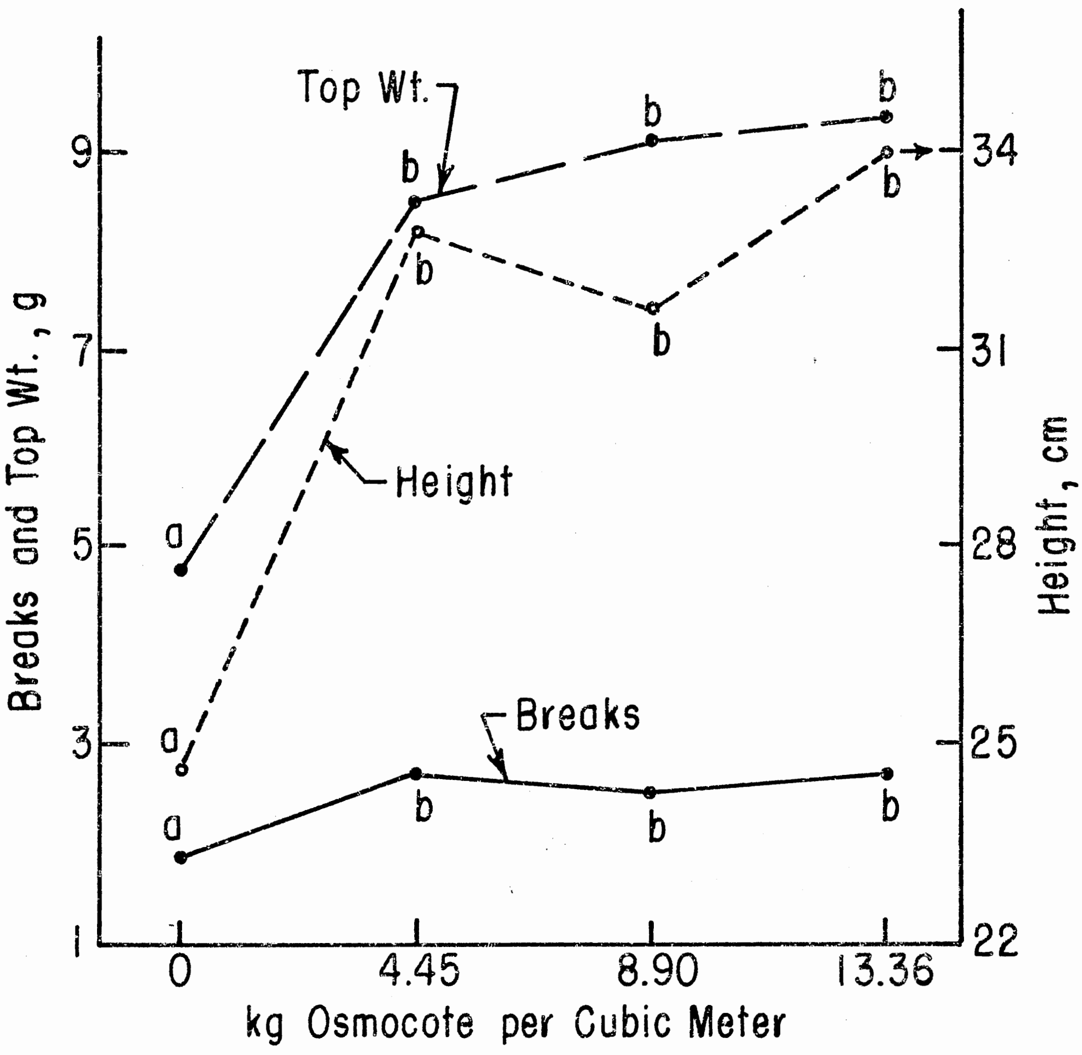

Figure 11. Effects of Osmocote on Top Weight, Height, and Breaks of Pecans.

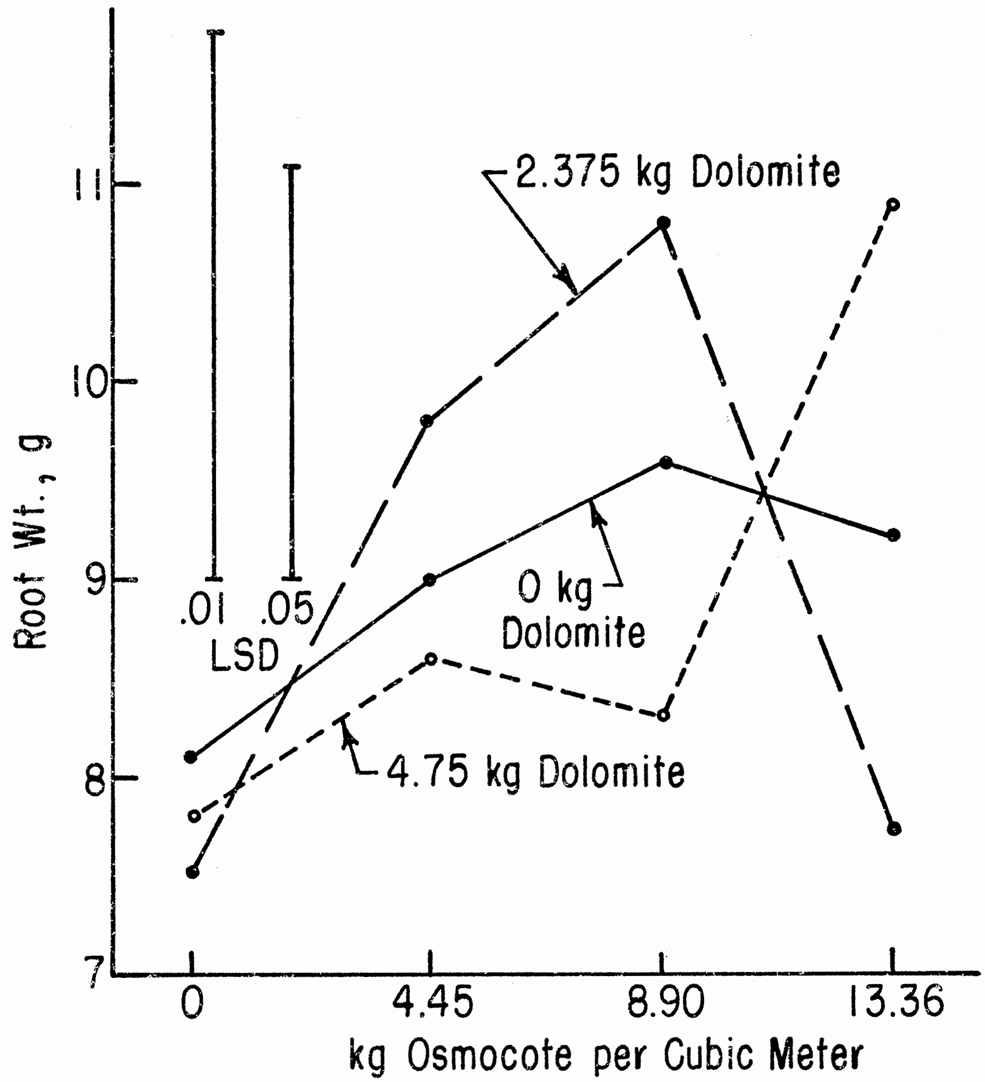

Figure 12. Effects of Dolomite and Osmocote on Root Weight of Pecans.

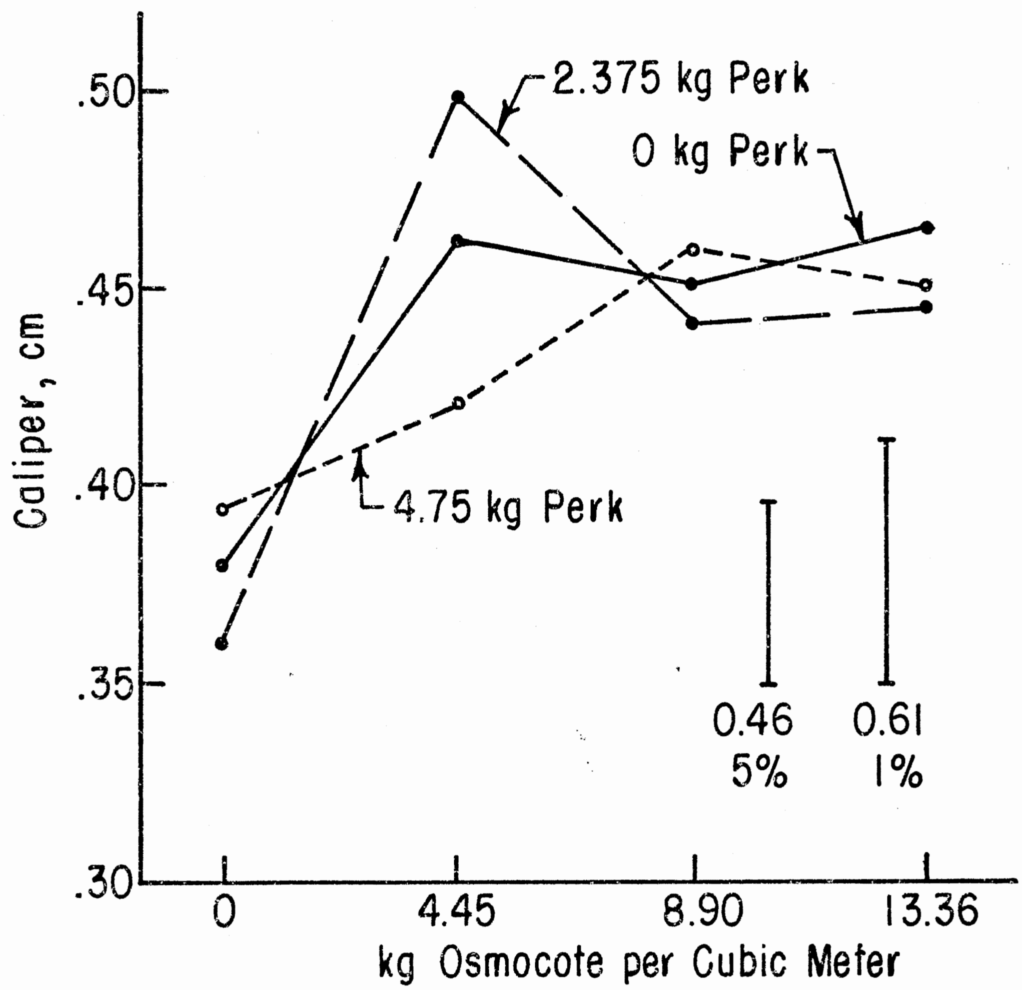

Figure 13. Effects of Perk and Osmocote on Stem Caliper of Pecans.

River Birch

The addition of osmocote to the growing medium of the germinating River birch proved to be vital to seedling survival. Treatments which had no osmocote grew very slowly after germination and mortality was near 100% three weeks after seedling emergence. A striking contrast was provided by those treatments which had 4.45 kg of osmocote in the medium (Table XV). Plant height, bud breaks, stem caliper, top weight, and root weight increased dramatically due to osmocote. These seedlings grew at such an accelerated rate that transplanting was necessary prior to the planned addition of the top dressed osmocote which would have constituted osmocote rates 8.9 and 13.36 kg/m^3. Therefore, the birch experimental design became a 2 x 3 x 3 factorial arrangement of treatments instead of a 4 x 3 x 3. Since the design was already implemented no additional degrees of freedom could be utilized, however, the subsample precision for this species doubled and since the osmocote levels were then none and 4.45 kg/m^3, the river birch seedlings became primarily a perk and dolomite nutritional study.

Perk did not increase seedling height or root weight, but as perk increased from 0 to 2.375 kg/m^3 bud breaks and stem caliper increased then decreased with further increase in perk (Table XVI). Top weight was not affected by perk at the 2.375 kg/m^3 level but was decreased at the 4.45 kg/m^3 rate.

As dolomite increased, plant height, bud breaks, stem caliper, top weight, and root weight were less than when no dolomite was added (Table XVII). This suggests that if dolomite is necessary in the germinating medium for this species, the optimum level is less than 2.375 kg/m^3.

TABLE XV

EFFECTS OF OSMOCOTE LEVEL ON HEIGHT, BREAKS, CALIPER, TOP WEIGHT, ROOT WEIGHT, AND TOTAL WEIGHT OF RIVER BIRCH

Osmocote[1] Level	Height cm	Breaks	Caliper cm	Top Wt. g	Root Wt. g
0.00[2]	5.8[4]a	1.09 a	1.57 a	0.13 a	0.13 a
4.45[3]	34.1 b	6.41 b	2.53 b	4.50 b	2.46 b
Probability >F	0.0001	0.0001	0.0001	0.0001	0.0001

[1]Kilograms of osmocote per cubic meter.

[2]Values are means of 144 observations.

[3]Values are means of 432 observations.

[4]Means in columns followed by the same letter are not significantly different at 0.05 using a protected LSD test.

TABLE XVI

EFFECTS OF PERK LEVEL ON HEIGHT, BREAKS, CALIPER, TOP WEIGHT, ROOT WEIGHT, AND TOTAL WEIGHT OF RIVER BIRCH

Perk[1] Level	Height[2] cm	Breaks[2]	Caliper[2] cm	Top Wt.[3] g	Root Wt.[3] g
0.000	26.4[4]a	4.75 a	1.99 a	3.45 b	2.06 a
2.375	27.9 a	5.85 b	2.19 b	3.79 b	1.89 a
4.750	26.6 a	4.64 a	1.94 a	2.89 a	1.68 a
Probability >F	0.50	0.01	0.04	0.006	0.08

[1]Kilograms of perk per cubic meter.

[2]Values are means of 192 observations.

[3]Values are means of 48 observations.

[4]Means in columns followed by the same letter are not significantly different at 0.05 using a protected LSD test.

TABLE XVII

EFFECTS OF DOLOMITE LEVEL ON HEIGHT, BREAKS, CALIPER, TOP WEIGHT, ROOT WEIGHT, AND TOTAL WEIGHT OF RIVER BIRCH

Dolomite[1] Level	Height[2] cm	Breaks[2]	Caliper[2] cm	Top Wt.[3] g	Root Wt.[3] g
0.000	30.17[4]b	6.48 b	2.37 b	4.10 b	2.10 b
2.375	26.25 a	4.54 a	1.94 a	3.14 a	1.79 a
4.750	24.57 a	4.22 a	1.82 a	2.97 a	1.75 a
Probability >F	0.001	0.0001	0.0001	0.0005	0.05

[1]Kilograms of dolomite per cubic meter.

[2]Values are means of 192 observations.

[3]Values are means of 48 observations.

[4]Means in columns followed by the same letter are not significantly different at 0.05 using a protected LSD test.

A perk and dolomite interaction on bud breaks show the detrimental effect of dolomite (Figure 14). When perk was not added, the decrease in bud breaks was linear with increasing dolomite. The addition of perk lessened the detrimental effects of dolomite but did not increase bud breaks above those seedlings which were grown without either perk or dolomite.

An interaction of osmocote and dolomite shows the tremendous effect of osmocote on bud breaks and the reduced response as dolomite levels increased (Figure 15). The interaction of perk and osmocote on caliper indicates that at the 4.45 kg level of osmocote 2.375 kg of perk was the preferred rate (Figure 16).

Top weight was also significantly influenced by a perk, dolomite interaction (Figure 17). The greatest top weight occurred when no dolomite was added regardless of the level of perk. However, when dolomite was present at the 4.75 kg/m^3 rate there appeared to be a favorable balance with the 2.375 kg/m^3 rate of perk. This coincides with studies using asexually propagated nursery crops.

Post Propagation Performance

Container

Seedlings transplanted into large containers remained on the container production bed and were subjected to an unusually adverse winter. Prolonged freezing temperatures resulted in desiccation and injury of some plants. Pines, oaks and pecans showed a higher mortality than river birch which suffered moderate shoot dieback. Dieback of shoots in all species was related to a north-south gradient, therefore no further data was taken. However, some observations appear relevant to

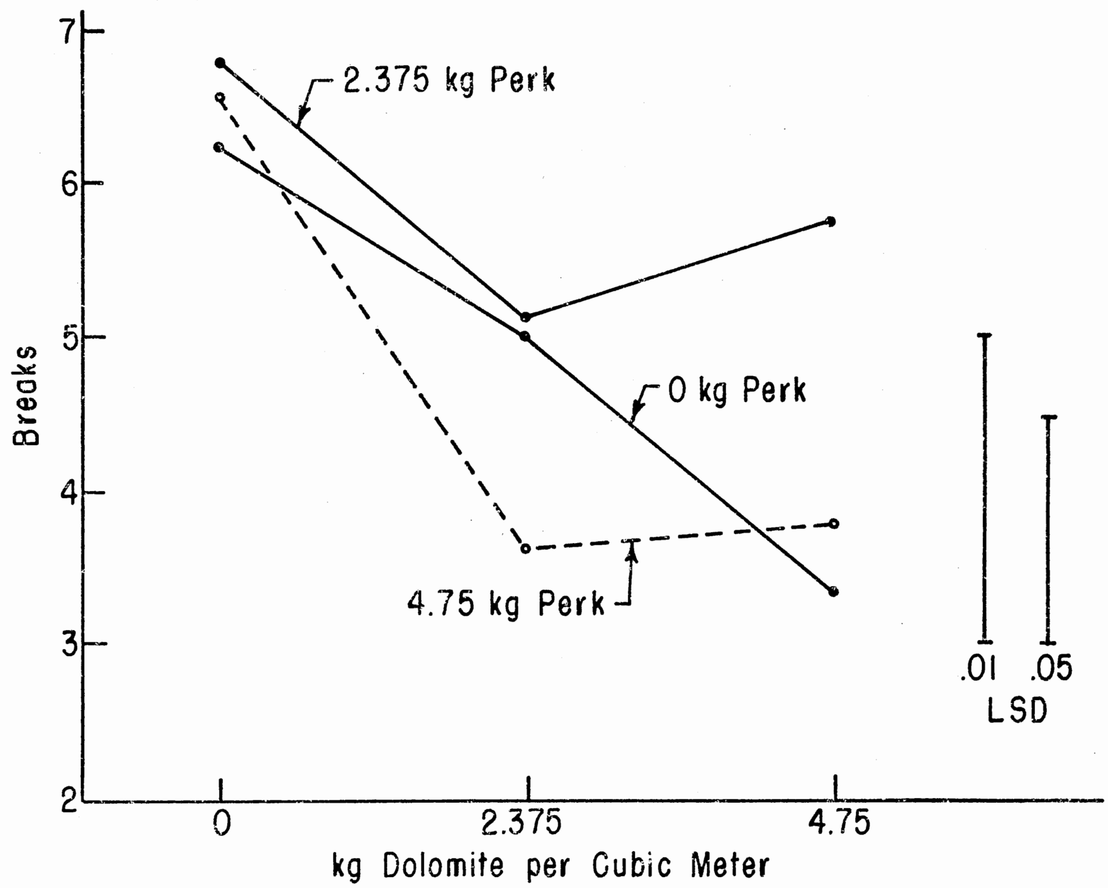

Figure 14. Effects of Perk as Dolomite Levels Increase on Bud Breaks of River Birch.

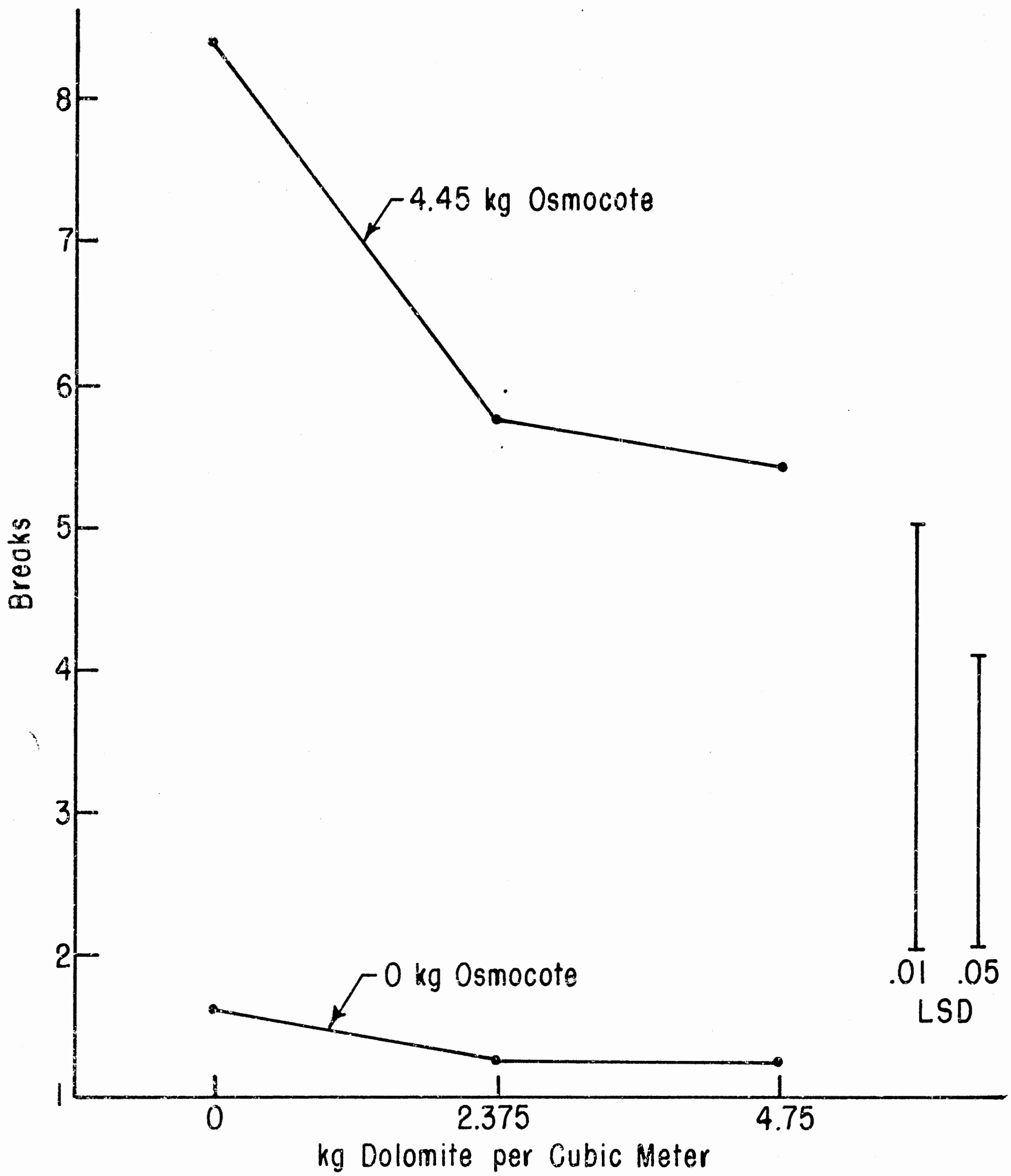

Figure 15. Effects of Osmocote and Dolomite Levels on Bud Breaks of River Birch.

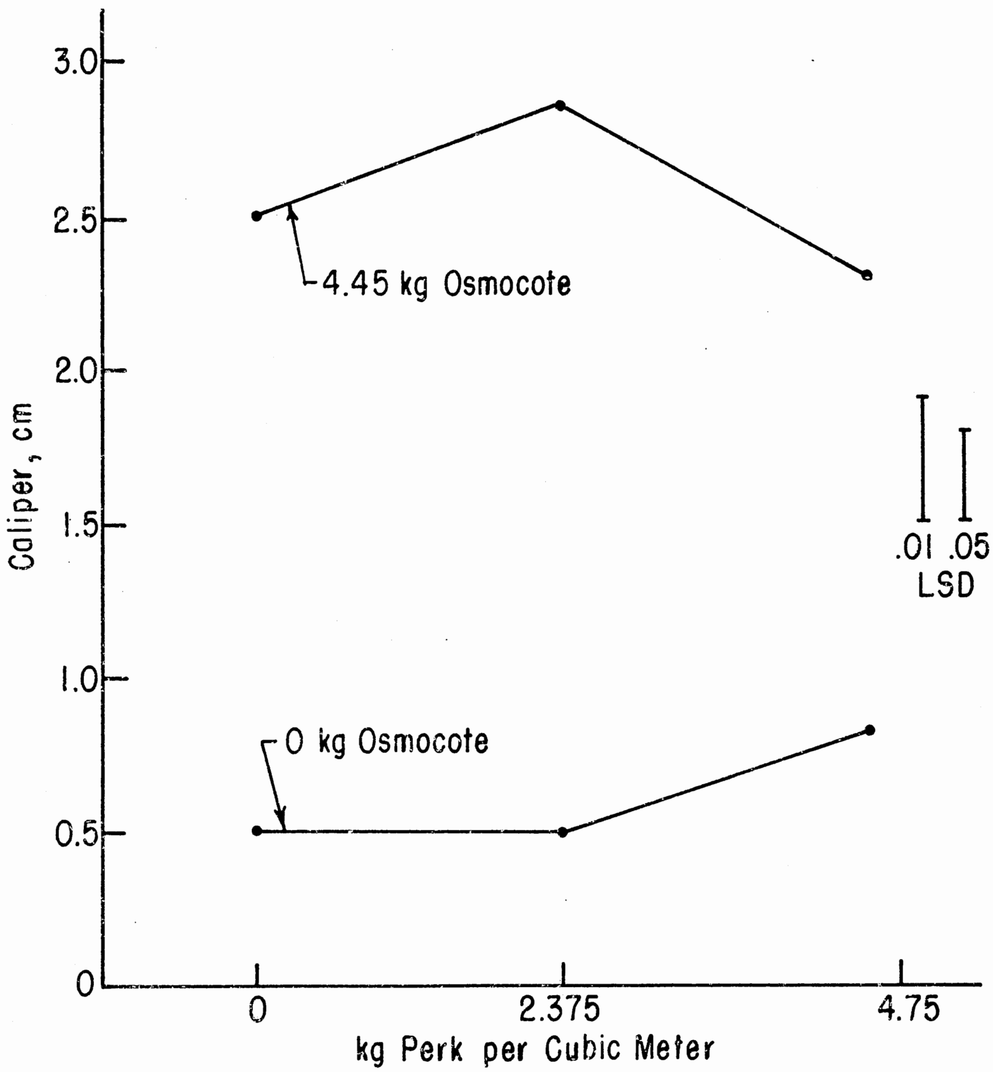

Figure 16. Effects of Osmocote and Perk on Caliper of River Birch.

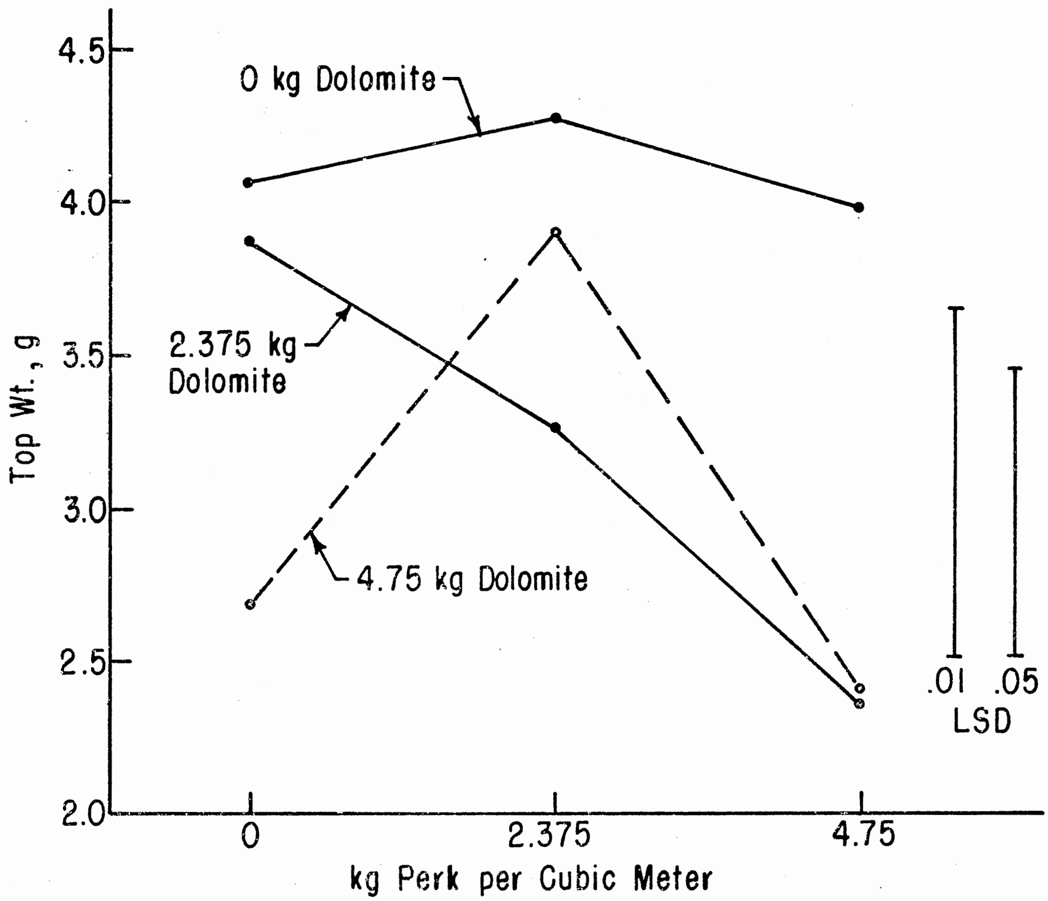

Figure 17. Effects of Perk and Dolomite on Top Weight of River Birch.

the study. Survival of seedlings suggested a strong relationship to fertility levels during propagation. Plants with higher fertility levels generally survived the winter while most seedlings which had not received osmocote during propagation did not. River birch had a much higher survival rate than the other species, but all river birch transplanted had 4.45 kg/m^3 of osmocote during propagation. One treatment, consisting of 2.375 kg/m^3 of Perk, 4.75 kg/m^3 of dolomite and 4.45 kg/m^3 of osmocote, gave 100% survival of Japanese black pines. Inspection of roots revealed that surviving seedlings had all rapidly regenerated extensive root system. Dead seedlings could be removed from the container easily, revealing the root system created during propagation had not proliferated. The low RRP (Root Regeneration Potential) appears to be correlated to low fertility during propagation.

Field

Seedlings transplanted into the field showed excellent survival, regardless of propagation treatment. However, subsequent growth was significantly influenced by nutrition treatments during propagation. Levels of osmocote above 4.45 kg/m^3 did not produce a significant difference in plant height during propagation of Shumard oak. However, one year later, the 13.36 kg/m^3 rate of osmocote yielded a significantly taller tree than the 8.9 or 4.45 kg/m^3 rate (Table XVIII). Seedlings receiving no osmocote during propagation increased in height dramatically during the year following transplanting but were still significantly smaller than those seedlings grown with osmocote present during the first 90 days. Caliper at the end of the propagation phase and caliper measured one year later followed a similar pattern. These data show

TABLE XVIII

EFFECTS OF OSMOCOTE DURING PROPAGATION ON HEIGHT AND CALIPER INCREASE OF SHUMARD OAKS ONE YEAR AFTER TRANSPLANTING

Osmocote Level During Propagation[1]	HT[2]	YRHT[3]	% HTINC[4]	Caliper[5]	YRCALP[6]	Root:Shoot Ratio[7]
0.00	15 a[8]	55 a	304 a	0.13 a	1.2 a	1.89 a
4.45	51 b	67 b	35 b	0.44 b	1.7 b	0.71 b
8.90	52 b	72 b	43 b	0.46 b	1.8 bc	0.61 ab
13.36	55 b	85 c	57 b	0.46 b	2.0 c	0.56 a
Probability >F	0.0001	0.05	0.0001	0.0001	0.0001	0.0001

[1]Kg of Osmocote per cubic meter.

[2]Height in centimeters when transplanted.

[3]Height in centimeters one year after transplanting.

[4]Percent increase in height one year after transplanting.

[5]Caliper in centimeters when transplanted.

[6]Caliper one year after transplanting.

[7]Root Weight/top weight when transplanted.

[8]Means in the same column followed by the same letter are not significantly different at 0.05 using a protected LSD test.

that the absence of osmocote created an internal deficiency which could not be overcome by nutrients available in the field and justifies amending the propagation medium with 13.36 kg/m^3 of osmocote.

The root to shoot ratio decreased dramatically with increasing osmocote during propagation (Table XVIII). Numerous theories suggest that a high root to shoot ratio is essential for survival and further growth (104) (109) (121) (128). However, these data suggest a re-evaluation of this theory.

Height and caliper of Shumard oaks during propagation increased as perk levels increased from 0 to 2.375 kg/m^3 (Table IXX). Height and caliper one year later continue to show 2.375 kg/m^3 to be the most desirable. However, percent height increase one year after transplanting showed no differences due to perk levels (Table IXX). In addition, there was no change in the root to shoot ratio between 0 and 2.375 kg/m^3 of perk but 4.75 kg/m^3 decreased the ratio significantly. Stem caliper of Shumard oaks one year after transplanting was significantly smaller when the seedlings were grown with dolomite in the propagation medium (Figure 18).

Japanese black pines showed a dramatic increase in height due to osmocote in the propagation medium and continued to respond to the favorable treatments one year after field planting (Table XX). Although after one year there was a 200 percent increase in height of seedlings propagated without osmocote, all osmocote treatments which were much larger when planted were also over 130 percent taller one year after transplanting and over twice as tall. The root to shoot ratio, contrary to popular opinion was not related to survival and growth. The influence of perk one year after transplanting in the field was still

TABLE XIX

EFFECTS OF PERK ON HEIGHT AND CALIPER INCREASE OF SHUMARD OAKS ONE YEAR AFTER TRANSPLANTING

Perk Level During Propagation[1]	HT[2]	YRHT[3]	% HTINC[4]	Caliper[5]	YRCALP[6]	Root:Shoot Ratio[7]
0.000	39 a[8]	60 a	117 a	0.42 a	1.4 a	0.98 b
2.735	45 b	78 b	122 a	0.43 b	1.9 b	0.98 b
4.750	45 b	71 b	90 a	0.40 a	1.8 b	0.86 a
Probability >F	0.0006	0.005	0.12	0.05	0.0001	0.03

[1]Kg of Perk per cubic meter.

[2]Height in centimeters when transplanted.

[3]Height in centimeters one year after transplanting.

[4]Percent increase in height one year after transplanting.

[5]Caliper in centimeters when transplanting.

[6]Caliper one year after transplanting.

[7]Root weight/top weight when transplanted.

[8]Means in the same column followed by the same letter are not significantly different at 0.05 using a protected LSD test.

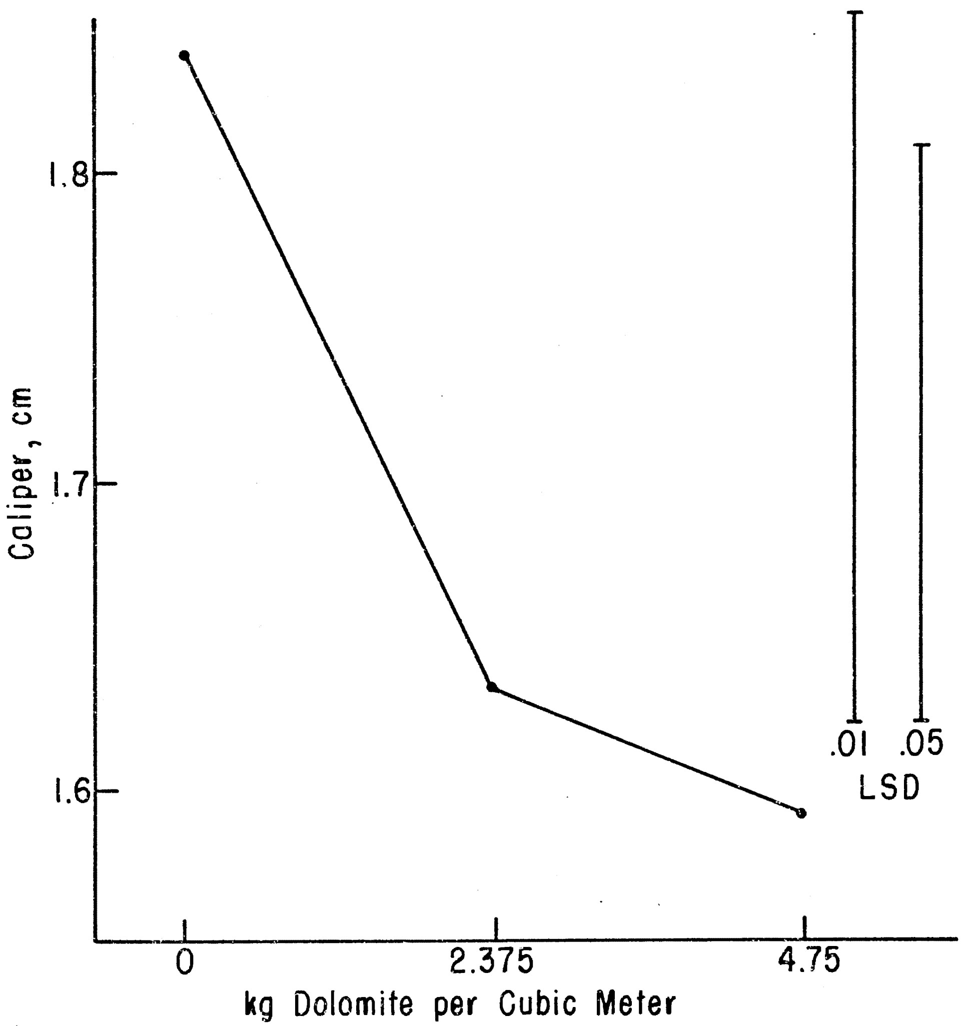

Figure 18. Effects of Dolomite Levels During Propagation on Stem Caliper One Year After Transplanting.

TABLE XX

EFFECTS OF OSMOCOTE DURING PROPAGATION ON HEIGHT OF JAPANESE BLACK PINE ONE YEAR AFTER TRANSPLANTING

Osmocote Level During Propagation[1]	HT[2]	YRHT[3]	% HTINC[4]	Root:Shoot Ratio[5]
0.00	4.6 a[6]	13.4 a	201 b	0.98 b
4.45	15.9 b	38.5 b	145 a	0.37 a
8.90	15.4 b	37.5 b	144 a	
13.36	15.6 b	36.7 b	131 a	0.29 a
Probability >F	0.0001	0.0001	0.0003	0.0001

[1]Kg of osmocote per cubic meter.

[2]Height in centimeters when transplanted.

[3]Height in centimeters one year after transplanting.

[4]Percent increase in height one year after transplanting.

[5]Root weight/top weight when transplanted.

[6]Means in the same column followed by the same letter are not significantly different at 0.05 using a protected LSD test.

apparent on height and percent increase in height (Table XXI). Dolomite continued to be detrimental to Japanese black pine height one year after transplanting (Table XXII). The inability of a seedling to overcome the incluence of poor nutrition during the early stages of growth can not be over emphasized. Many nurserymen feel they can "save" stunted seedlings by providing a more desirable, nutritional environment following transplanting. This idea is challenged by these data.

As a comparative demonstration, 50 two-year-old bed grown Japanese black pine seedlings were obtained from a large commercial grower. The average three month old container grown pine was slightly larger than the two-year-old bed grown seedlings. However, one year after transplanting into identical fertility regimes the differences in growth was dramatic (Figure 19). Similar differences were observed in the field. Loss of roots during harvest and poor fertility practices probably contributed to the stunted growth.

During propagation, all pecans were significantly taller when osmocote was present with no difference between osmocote levels. One year later, however, a pronounced increase in height at the 8.9 and 13.36 kg/m^3 levels of osmocote compared to the 4.45 kg/m^3 shows a benefit not detectable at time of transplanting (Figure 20).

These data show that a pecan seedling with only a 12 cm "air pruned" tap root grown under desirable nutritional conditions can be successfully transplanted and will continue to grow. No literature was found to indicate that a pecan seedling with such a short root system could be transplanted. In this study, when 144 seedlings were transplanted to containers, survival was 100 percent. A more dramatic example was when 144 seedlings were transplanted into a field during August

TABLE XXI

EFFECTS OF PERK DURING PROPAGATION ON HEIGHT OF JAPANESE BLACK PINE ONE YEAR AFTER TRANSPLANTING

Perk Level During Propagation[1]	HT[2]	YRHT[3]	% HTINC[4]	Root:Shoot Ratio[5]
0.000	12.1 a[6]	25.5 a	114 a	0.48 a
2.375	13.0 b	34.4 b	180 b	0.47 a
4.750	13.6 b	34.8 b	172 b	0.50 a
Probability >F	0.0001	0.0001	0.0001	0.77

[1]Kg of perk per cubic meter.

[2]Height in centimeters when transplanted.

[3]Height in centimeters one year after transplanting.

[4]Percent increase in height one year after transplanting.

[5]Root weight/top weight when transplanted.

[6]Means in the same column followed by the same letter are not significantly different at 0.05 using a protected LSD test.

TABLE XXII

EFFECTS OF DOLOMITE DURING PROPAGATION ON HEIGHT OF JAPANESE BLACK PINE ONE YEAR AFTER TRANSPLANTING

Dolomite Level During Propagation[1]	HT[2]	YRHT[3]	% HTINC[4]	Root:Shoot Ratio[5]
0.000	13.6 b	33.8 b	162 a	0.46 a
2.375	12.9 a	31.8 b	155 a	0.47 a
4.750	12.2 a	29.0 a	151 a	0.53 a
Probability >F	0.0005	0.001	0.70	0.35

[1]Kg of dolomite per cubic meter.

[2]Height in centimeters when transplanted.

[3]Height in centimeters one year after transplanted.

[4]Percent increase in height one year after transplanting.

[5]Root weight/top weight when transplanted.

[6]Means in the same column followed by the same letter are not significantly different at 0.05 using a protected LSD test.

Figure 19. A Liner Which Was Bed Grown Two Years, Then Planted in the Container One Year; Three Years Old From Seed (Left) and a Pine Propagated and Grown With the Air Pruning and a Good Nutritional System for Three Months, Then Planted in Container One Year (Right).

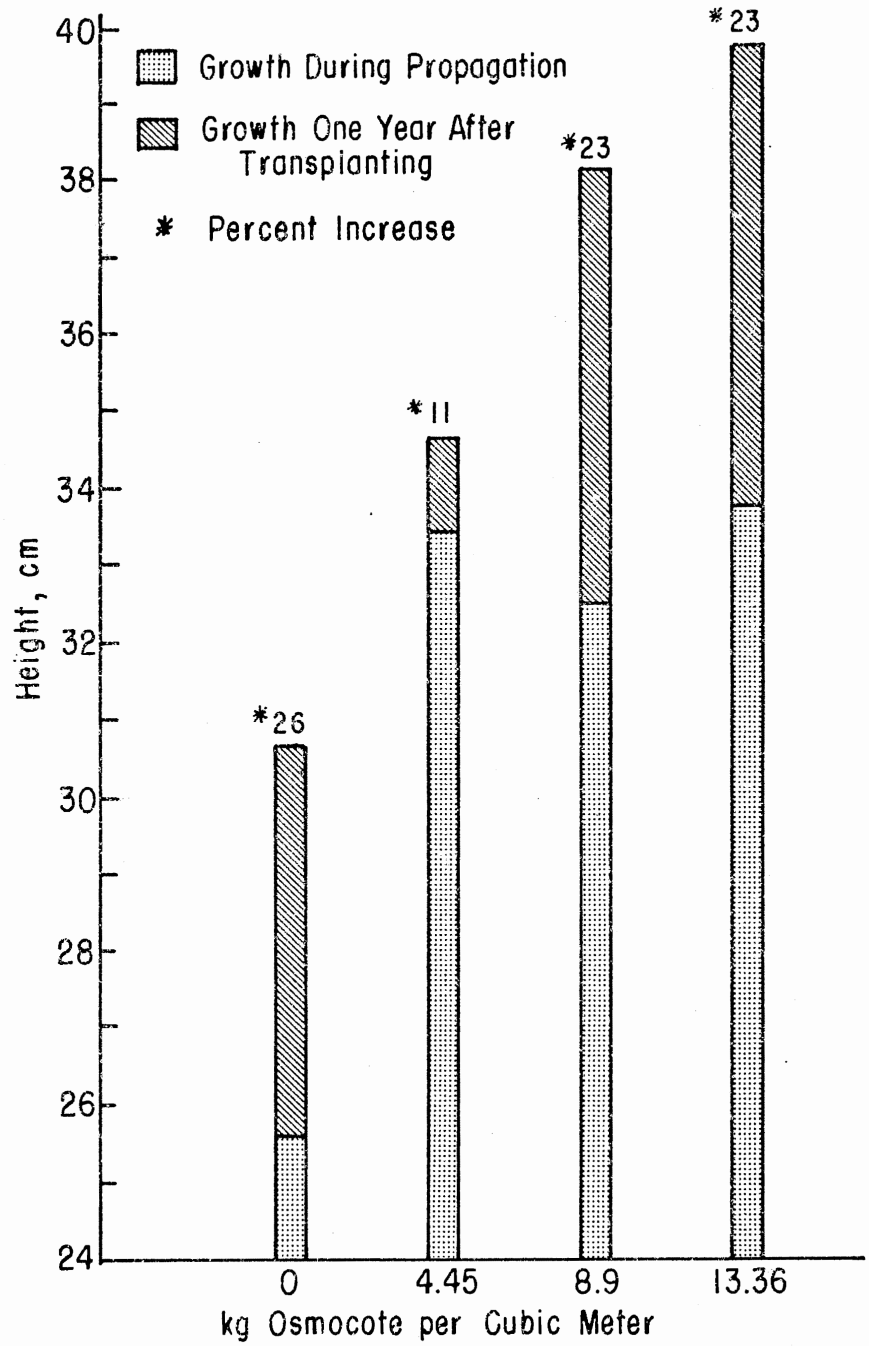

Figure 20. Effects of Osmocote Levels on Height of Pecans During Propagation and One Year After Transplanting into the Field.

(39°C/102°F, full sun). Two months later all seedlings were alive and those treatments receiving adequate nutrition during propagation continued to flush and grow. This may be one of the most significant findings of this research. Other researchers state that a 75 to 102 cm tap root is essential for pecan seedling transplant survival and further growth (76) (54) (147). The lack of a container system which would create a fiberous mass of roots without malformed growth and low levels of nutrition used in the past have no doubt contributed to this misconception. However, what makes the short "air pruned" tap root successful is the excellent root regeneration potential which the seedling carries to the transplant site.

When excavated one year later, numerous large replacement roots were present near the air pruned root apex which apparently established the seedling very rapidly.

The higher nutrient levels utilized in this research may have produced a higher concentration of carbohydrates in the root or available to the roots thus eliminating the requirement for a much longer tap root.

Since no roots are lost during harvest using this system, no pruning of the top was required and root growth was not impaired. This too must have influenced the rapid regeneration of roots and continued growth in the field.

River birch seedlings which were transplanted into the field did not show a significant response to perk levels. Dolomite continued to be detrimental to height growth one year after transplanting (Figure 21).

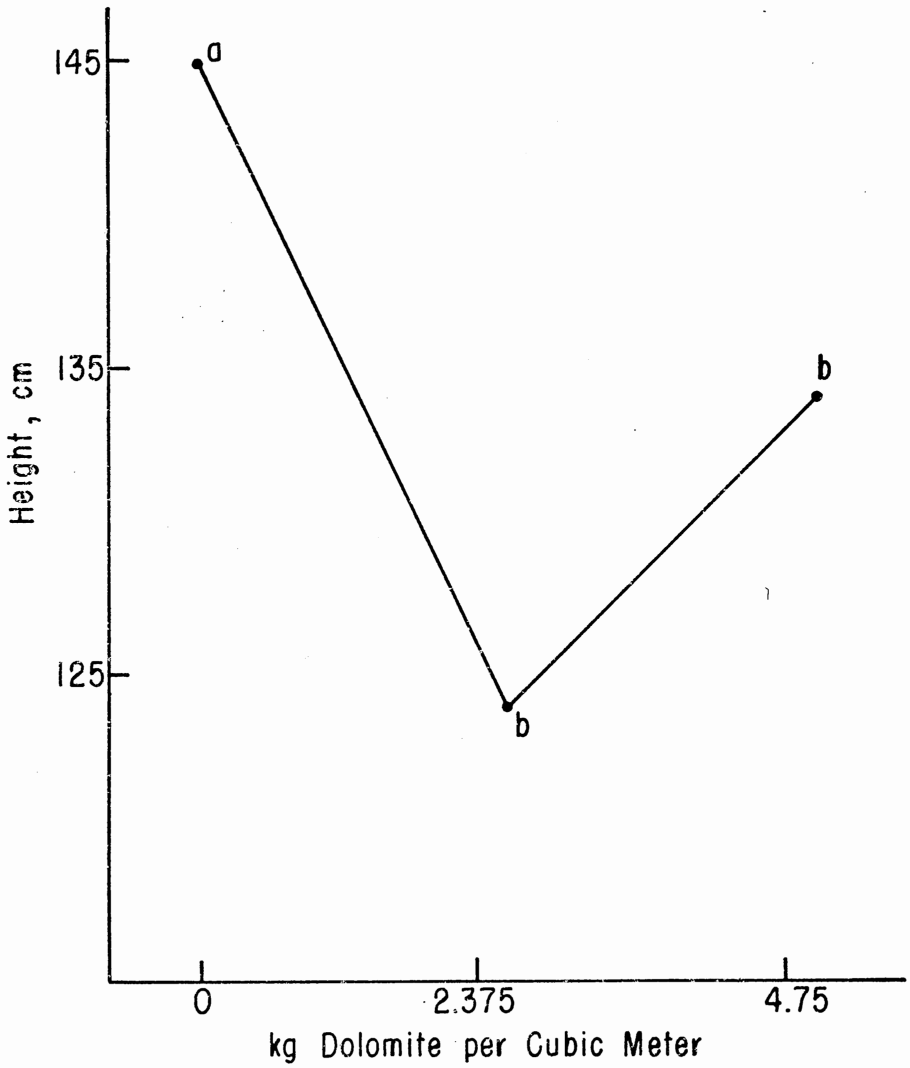

Figure 21. Effects of Dolomite Level During Propagation on Height of River Birch One Year After Transplanting into the Field.

Root to shoot ratios for all test species were not correlated to height when transplanted or height one year after transplanting (Table XXIII).

There was also no correlation between root to shoot ratio and caliper when transplanted or caliper one year after transplanting with Shumard oaks. This again suggests that a high root to shoot ratio may not only be a poor criterium to determine survivability and future growth, but may actually be detrimental under some nutritional regimes.

TABLE XXIII

CORRELATION OF ROOT:SHOOT RATIO AT TIME OF TRANSPLANTING AND HEIGHT, HEIT ONE YEAR LATER, CALIPER, AND CALIPER YEAR LATER OF SHUMAR OAK, JAPANESE BLACK PINE PECAN AND RIVER BIRCH

	Oak Root:Shoot Ratio	Pine Root:Shoot Ratio	Pecan Root:Shoot Ratio	Birch Root:Shoot Ratio
Height when transplanted	-0.8391	-0.7892	-0.3525	-0.4552
Prob. <|R| under H_0:RHO = 0	0.0001	0.0001	0.0001	0.0001
Height one year after transplanted	-0.3624	-0.6601	-0.2388	-0.1214
Prob. <|R| under H_0:RHO = 0	0.0001	0.0001	0.042	0.2000
Caliper when transplanted	-0.5756	---	---	---
Prob. <|R| under H_0:RHO = 0	0.0001	---	---	---
Caliper one year after transplanted	-0.4722	---	---	---
Prob. <|R| under H_0:RHO = 0	0.0001	---	---	---

CHAPTER V

SUMMARY AND CONCLUSIONS

The objective of this research was to evaluate the effects of nutrition and root modification on tree seedlings. Four species: Shumard oak, Japanese black pine, Pecan and River birch were evaluated after the propagation phase and one year after transplanting. Over 2,000 seedlings were grown and over 6,000 measurements recorded.

Nutrition during propagation significantly influenced growth of all species. Seedlings grown under less desirable nutritional regimes continued to be inferior to better treatments one year later. A balanced slow release fertility system combined with the fibrous root system produced by "air pruning" the primary seedling root produced seedlings which were larger in three months than two-year-old seedlings grown in conventional ground beds. Root regeneration after transplanting was very high, resulting in continued growth without transplant shock.

Dominant tap rooted species such as pecan and oak transplanted with ease and grew well when transplanted with only a 12 cm tap root.

Root to shoot ratios were not correlated to plant height survival, or further growth in the field.

No malformed roots which are often encountered using conventional containers were observed on any species tested.

This system for producing tree seedlings was found to be infinitely superior to the production methods currently in use.

LITERATURE CITED

1. Allen, G. S. 1962. Factors affecting the viability and germination behavior of coniferous seed. VI. Stratification and subsequent treatment, Pseudotsuga mengiesii. For. Chron., 38:485-496.

2. __________. 1961. Testing Douglas fir seed for provenance. Proc. Int. Seed Test. Assoc., 26:388-403.

3. Bailey, L. H. 1939. The Standard Encyclopedia of Horticulture. New York, NY. The Macmillan Co.

4. __________. 1935. The Nursery Mannual. 22nd ed., New York, NY. The Macmillan Co.

5. Barnett, J. P. 1974. Containerized planting--a new generation technique. Proc., Symp. on Mgmt. of Young Pines, pp. 129-133.

6. __________ and J. M. McGilvray. 1974. Copper screen controls root growth and increases survival of containerized southern pine seedlings. Tree Pl. Notes, 25(2):11-12.

7. Barron, H. M. 1974. The use of slow release fertilizers for ornamental crops. Proc. Int. Pl. Prop. Soc., 24:221-229.

8. Bergman, F. and B. Haggstrom. 1976. Some important facts concerning planting with rooted forest plants. (Eng. Trans. by R. A. Hellonius.) For. Chron., 52:266-273.

9. Bonner, F. T. and L. C. Marsenhelder. 1974. Carya Nutt. Hickory. IN: Seeds of the Woody Plants in the United States. For. Serv., U.S. Dept. Agric. Handb. 450.

10. Brasil, V. M., J. W. Simones, and R. M. Speltz. 1972. The suitable size of paper tubes for raising Eucalyptus seedlings. For. Abs., 34, no. 5744.

11. Bray, J. R. 1963. Root production and the estimation of net productivity. Can. J. Bot., 41:65-72.

12. Brinkman, K. A. 1974. Betula L. Birch. Seeds of Woody Plants in the United States. For. Serv., U.S. Dept. Agric. Handb. 450.

13. Brison, F. 1974. Pecan Culture. Austin, TX. Capitol Printing.

14. Brix, H. and R. Van den Driessche. 1974. Mineral nutrition of container grown tree seedlings. Proc. North Amer. Containerized For. Tree Seedling Symp. Great Plains Agric. Counc. Publ. 68.

15. Brown, J. C., L. O. Tiffin, R. S. Holmes, A. W. Specht, and J. W. Resnicky. 1959. Internal activation of iron in soybeans as affected by root growth medium. Soil Sci., 87:89-94.

16. Bryan, W. C. and J. L. Ruehle. 1976. Growth stimulation of sweetgum seedlings induced by the endomycorrhizal fungus Glomus mosseae. Tree Pl. Notes., 27(2):

17. Carlson, D. E., C. E. Whitcomb, and R. D. Hathaway. 1974. Effects of container size and fertilizer level on growth and quality of nursery stock. Hortscience., 9:277.

18. Carlson, L. W. and L. D. Nairn. 1977. Root deformities in some container grown Jack pines in southwestern Manitoba. For. Chron., 53:176.

19. Carolus, R. L. 1938. Effect of certain ions, used signly and in combination on the growth and potassium, calcium, and magnesium absorption of the bean plant. Pl. Physiol., 13:349-363.

20. Clausen, J. J. and T. T. Kozlowski. 1967. Food sources for growth of Pinus resinosa shoots. Adv. Frontiers Pl. Sci., 18:23-32.

21. Davis, R. E. and C. E. Whitcomb. 1975. Effects of propagation container size on development of high quality tree seedlings. Proc. Int. Pl. Prop. Soc., 25:251-257.

22. Dirr, M. 1975. Plant nutrition and woody ornamental growth and quality. Hortscience, 10(1):15-7.

23. Donald, D. G. M. 1968. Fundamental studies to improve nursery production of Pinus radiata and other pines. Annale Unw. Van Stellenkosch 43, Ser A(1), 180 pp.

24. Einert, A. E. 1974. Rice hulls as a component of growing media for container stock. Proc. Sou. Nur. Assoc. Res. Conf., 9:10.

25. __________. 1973. Media nutrient levels as influenced by rice hull content and steaming time. Proc. Sou. Nur. Assoc. Res. Conf., 18:28.

26. Elstrodt, C. J. and D. C. Milbocker. 1975. Root development as affected by particle sizes in container media. Proc. Sou. Nur. Assoc. Res. Conf., 20:36.

27. Engstrom, H. E. and J. H. Stoeckeler. 1941. Nursery practice for trees and shrubs suitable for planting on the prairie-plains. U.S. Dept. Agric. Misc. Publ. 434, 159 pp.

28. Esau, K. 1977. Anatomy of seed plants. 2nd ed. New York. John Wiley and Sons.

29. Fowler, D. P. and T. W. Dwight. 1964. Provenance difference in the stratification requirements of white pine. Can. J. Bot., 42:669-675.

30. Frolich, E. F. 1971. The use of screen bottom flats for seedling production. Proc. Int. Pl. Prop. Soc., 21:79-80.

31. Funk, D. T. 1971. Pot size, pot shape, and soil mix all influence black walnut seedling growth. Pl. Prop., 77(1):10-14.

32. Furuta, T. 1976. Nitrogen fertilization of container grown ornamentals. Amer. Nurseryman., 142(12):14, 106-109.

33. ________. 1974. Environmental plant production and marketing. Arcadia, CA. Cox Publ. Co.

34. Gartner, J. B., M. M. Meyer, Jr., and D. C. Soupe. 1971. Hardwood bark as a growing media for container grown ornamentals. For. Prod. J., 21:25-29.

35. Gassner, G. 1938. Uber die. Hartschagligkeit von robiniensamen und eine methode zu ihrer beseitigung. (Eng. Trans. Abstr.) Angew. Bot., 20:293-303.

36. Glenn, R., C. Hogan, and C. E. Whitcomb. 1975. Effect of osmocote in the rooting medium and auxin levels on rooting and subsequent growth of cuttings. Okla. Agri. Exp. Sta. Res. Rep., P-724, pp. 43-44.

37. Gouin, F. B. 1974. Osmocote in the propagation house. Proc. Int. Pl. Prop. Soc., 24:337-341.

38. ________ and C. B. Link. 1973. Growth response of container grown ornamentals to slow-release fertilizers. Hortscience, 8(3):208-209.

39. Haas, A. R. 1936. Zinc relation in mottle-leaf of citrus. Bot. Gaz., 98:65-86.

40. Hacskaylo, E. 1971. Mycorrhizae. Proc. First North Amer. Conf. on Mycorrhizae., Apr., 1969. Urbana, IL. U.S. Dept. Agric., Misc. Publ. 1189.

41. Hafeez, M. 1973. Polyethylene tube suze in relation to seedling growth in the nursery. Pakistan J. For., 23(1):18-26.

42. Harris, R. W., W. B. Davis, N. W. Stice, and D. Long. 1971. Root pruning improves nursery tree quality. J. Amer. Soc. Hort. Sci., 96:105-109.

43. Hartmann, H. T. and D. E. Kester. 1975. *Plant propagation: principles and practices*. 3rd ed., Englewood Cliffs, NJ. Prentice Hall.

44. Hathaway, R. D. 1977. The effects of root malformation during propagation on growth and survival of Bur oak. *Okla. Agri. Exp. Sta. Res. Rep.* P-760, p. 35.

45. __________ and C. E. Whitcomb. 1977. Effects of 3 sizes of bottomless containers and 5 levels of osmocote during propagation on root modification and growth of *Quercus shumardi* seedlings. *J. Arboric.*, 3(11):208-212.

46. __________ and __________. 1977. Growth of tree seedlings in containers. *Okla. Agri. Exp. Sta. Res. Rep.* P-741, p. 33-38.

47. __________. 1976. Effects of slow release fertilizer on the germination of tree seedlings. *Okla. Agri. Exp. Sta. Res. Rep.* P-741, p. 39-40.

48. Havis, J. R. and W. W. Hamilton. 1976. Physical properties of container media. *J. Arboric.*, 2(7):139-140.

49. Heit, C. E. 1967. Propagation from seed. Part 5: Control of seedling density. *Amer. Nurs.*, 125(8):14-15, 56-59.

50. __________. 1967. Propagation from seed. Part 7: Germinating six hardseeded groups. *Amer. Nurs.*, 5(12):10-12, 37-41, 44-45.

51. __________. 1967. Propagation from seed. Part 11: Storage of deciduous tree and shrub seeds. *Amer. Nurs.*, 126(10):12-13, 86-94.

52. Heth, D. 1961. Nursery techniques for Eucaluptus--production of balled stock in recepticles. Israli Dept. For. Lft. 16., p. 6.

53. Hewitt, E. J. and T. A. Smith. 1975. *Plant mineral nutrition*. New York, NY. John Wiley and Sons.

54. Hinrichs, H. A. and M. W. Smith. 1975. Greenhouse production of pecans in plastic tubes. *Proc. Okla. Pecan Growers Assoc.*, 45:22-26.

55. Horsley, S. B. and B. F. Wilson. 1971. Development of the woody portion of the root system of *Betual papyrifera*. *Amer. J. Bot.*, 58:141-147.

56. Janic, J. 1972. *Horticultural Science*. 2nd ed., San Francisco, CA. W. H. Freeman and Co., p. 325.

57. Johnson, C. R. and D. F. Hamilton. 1977. Effects of media and controlled release fertilizers on rooting and leaf nutrient composition of Juniperus conferta and Ligustrum japonicum cuttings. J. Amer. Soc. Hort. Sci., 102(3):320-322.

58. Kahn, J. S. and J. B. Hanson. 1957. The effects of calcium on potassium accumulation in corn and soybean roots. Pl. Physiol., 32:312-316.

59. Kelley, J. D. 1959. Fertilization studies with container grown nursery stock. Amer. Nurs., 109(10):12-14, 79-84.

60. Klett, J. E., J. B. Gartner, and T. D. Hughes. 1972. Utilization of hardwood bark in media for growing woody ornamental plants in containers. J. Amer. Soc. Hort. Sci., 97:449-450.

61. Knezek, B. D. and H. Greinert. 1971. Influence of soil Fe and MnEDTA interactions upon the Fe and Mn nutrition of bean plants. Agron. J., 63:617-619.

62. Kozlowski, T. T. 1973. Tree physiology colloquim. Mar. 29-30. Madison, WI. Univ. of Wisc.

63. __________. 1971. Growth and development of trees. New York, NY. Academic Press.

64. Kramer, P. J. 1969. Plant and soil water relationships: a modern synthesis. New York, NY. McGraw-Hill.

65. Kriebel, H. B. 1958. Geograpic differentiation in seed dormancy and juvenile growth rate of Ontario sugar maple. Proc. 6th Meeting Comm. For. Tree Breeding, 2:R-7 to R-11. Montreal, Canada.

66. Krizek, D. T., N. A. Bailey, and H. H. Klueter. 1970. A 'head start' program for bedding plants through controlled environments. Proc. 3rd Natl. Bedding Plant Conf. East Lansing, MI. Mich. State Univ. October, 1970.

67. Krugman, S. L. and J. L. Brinkman. 1974. Pinus L. pine. Seeds of Woody Plants in the United States. For. Serv. U.S. Dept. Agric. Handb. 450.

68. __________, W. I. Stein, and D. M. Schmitt. 1974. Seed biology. Seeds of Woody Plants in the United States. For. Serv. U.S. Dept. Agri. Handb. 450, p. 27.

69. __________. 1966. Artificial ripening of sugar pine seeds. USDA For. Serv. Res. Paper PSW-32, p. 7.

70. Kuntz, J. D. 1973. Root growth. Tree Physiology colloquim. Mar. 29-30. Madison, WI. Univ. of Wisc., p. 83.

71. Laiche, A. J. 1976. Growth evaluation studies of one year old pecan seedlings of selected varieties, seed treatments and growing methods. Proc. SE Pecan Growers Assoc. 69th Ann. Conv., pp. 169-177.

72. __________. 1974. Effects of growing medium, fertility, and container size on the rooting and subsequent growth of Rhododendron indicum and Photinia glabra cuttings. The Pl. Prop., 20(4):4-13.

73. __________. 1973. Old bark vs. fresh bark growing media studies. Proc. So. Nur. Assoc. Res. Conf., 18:6.

74. Larson, M. M. 1975. Pruning northern red oak nursery seedlings: effects on root regeneration and early growth. Can. J. For. Res., 5(3):381-386.

75. Larson, P. R. 1974. The upper limit of seedling growth. Proc. North Amer. Containerized For. Tree Seedling Symp. Great Plains Agri. Counc. Publ. 68.

76. Leopold, A. C. 1964. Plant growth and development. New York, NY. McGraw-Hill.

77. Lindstrom, R. 1975. A comparison of growth rates between container grown azaleas using selected media with and without a slow-release fertilizer. Proc. Sou. Nurs. Assoc. Res. Conf., 20:38.

78. Lotti, T. 1965. Shumard oak (Quercus shumardii Buckl). Silvics of Forest Trees of the United States. U.S. Dept. Agric. Handb. 271, pp. 615-617.

79. __________. 1959. Selecting sound acorns for planting bottomland hardwood sites. J. For., 57:923.

80. McClain, K. M. and K. A. Armson. 1976. Effect of water supply, nitrogen, and seedbed density on White Spruce seedling growth. Soil Sci. Soc. Amer. J., 40(3):443-446.

81. McDonald, P. M. 1976. Inhibiting effect of Ponderosa pine seed trees on seedling growth. J. For., 24(4):220-224.

82. McGuire, J. J. and V. J. Bunce. 1970. The use of slow-release fertilizers in a propagation medium. The Pl. Prop., 16(2):10-14.

83. McLemore, B. F. and J. P. Barnett. 1966. Loblolly seed dormancy influenced by cone and seed handling procedures and parent tree. U.S. Dept. Agri. For. Serv. Res. Note SO-41., 4 pp.

84. Maggs, D. H. 1964. Growth rates in relation to assimilate supply and demand. J. Exp. Bot., 15:574-583.

85. Malstrom, H. L. and G. A. Madden. 1976. Establishing and training young pecan trees. Proc. SE Pecan Growers Assoc., 69:161-168.

86. Marx, D. H. and W. C. Bryon. 1975. Growth and ectomycorrhizal development of loblolly pine seedlings in fumigated soil infested with the fungal symbioant Pisolithus tinctorius. For. Sci., 21(3):245-254.

87. _________ and J. P. Barnett. 1974. Mycorrhizae and containerized forest tree seedlings. Proc. North Amer. Containerized For. Tree Seedling Symp. Great Plains Agri. Counc. Publ. 68.

88. Mazur, A. R., T. D. Hughes, and J. B. Gartner. 1975. Physical properties of hardwood bark growth media. Hortscience, 10(1):30-33.

89. Mergen, F. 1963. Ecotypic variation in Pinus strobus. L. Ecolo., 44:716-727.

90. Milbocker, D. C. 1973. Hardwood bark as a medium for container grown Japanese holly. Proc. So. Nurs. Assoc. Res. Conf., 18:11.

91. Montano, J. M., J. T. Fisher, and D. J. Cotter. 1977. Sawdust for growing containerized forest tree seedlings. Tree Pl. Notes. U.S. Dept. Agric. For. Serv., 28(2):6-9.

92. Mullin, R. E. and L. Bowdery. 1977. Effects of seedbed density and nursery fertilization on survival and growth of 3-0 White Pine. Tree Pl. Notes., 28(1):11-13.

93. Murphy, J. D., Jr., J. B. Gartner, and M. M. Myer. 1969. Comparisons of various individual media for direct rooting of cuttings. Proc. Int. Plant Prop. Soc., 19:279-283.

94. New, E. H. 1974. Fine shredded hardwood bark container media for forsythia. Proc. So. Nurs. Assoc. Res. Conf., 19:24.

95. Olson, D. F. 1974. Quercus L. oak. Seeds of Woody Plants in the United States. For. Serv. U.S. Dept. Agric. Handb. 450.

96. Overcash, J. P. and W. W. Kilby. 1976. Transplanting pecan trees. Proc. SE Pecan Growers Assoc., 69:149-159.

97. Overstreet, R., J. Jacobson, and R. Handley. 1952. The effect of calcium on the absorption of potassium by barley roots. Pl. Physiol., 27:583-590.

98. Ozanne, P. G. 1955. The effect of nitrogen on zinc deficiency in subterranean clover. Aust. J. Biol. Sci., 8:47-55.

99. Patel, A. J. and G. C. Sharma. 1977. Nitrogen release characteristics of controlled release fertilizers during a four month soil incubation. J. Amer. Soc. Hort. Sci., 102(3):364-367.

100. Patterson, J. M. 1969. Container growing. Chicago, IL. Amer. Nurs. Publ. Co., pp. 51-60.

101. Phipps, H. M. 1977. White spruce seedlings respond to density and fertilizer treatments in a plastic greenhouse. Tree Pl. Notes., 28(1):8-10.

102. Pokorny, F. A. 1975. A physical characterization of pine bark used in six commercial nurseries. Proc. So. Nurs. Assoc. Res. Conf., 20:25-27.

103. Richardson, S. D. 1953. A note on some differences in root hair formation between seedlings of sycamore and American oak. New Phytol., 52:80-82.

104. Rudolf, P. O. 1939. Why forest plantations fail. J. For., 37:377-383.

105. Salem, B. 1971. Root strangulation: a neglected factor in container grown nursery stock. (M.S. Thesis, Univ. of Cal. at Berkely), 50 pp.

106. Sanderson, K. C. and W. C. Martin, Jr. 1974. Performance of woody ornamentals in municipal compost medium under nine fertilizer regimes. Hortscience, 9:242-243.

107. Scarratt, J. B. 1973. Japanese paperpots for containerized planting of tree seedlings. Great Lakes For. Res. Cent. Rep. 0-X-188.

108. __________. 1972. Container size affects dimensions of White spruce, Jack pine planting stock. Tree Pl. Notes., 23(4):21-25.

109. Schubert, G. H. and R. S. Adams. 1971. Reforestation practices for conifers in California. Calif. For. Div.

110. Schulte, J. and C. E. Whitcomb. 1973. Effects of fertilizer in the rooting medium on rooting and subsequent growth response. Okla. Agric. Exp. Sta. Res. Rep. P-691, pp. 28-31.

111. Self, R. L. 1975. Azalea potting mix study using two grades of pine bark as an ingredient. Proc. So. Nurs. Assoc. Res. Conf., 20:4.

112. __________ and C. T. Pounders, Jr. 1974. Addition of fertilizer to rooting media. Proc. So. Nurs. Assoc. Res. Conf., 19:98.

113. Shen, C. B., H. L. Crane, and A. T. Myers. 1946. Nutrient-element balance: a fundamental concept in plant nutrition. *Proc. Amer. Soc. Hort. Sci.*, 47:239-248.

114. Shipman, R. D. 1962. Nursery seeded hardwoods--influenced by depth and density of sowing. *Tree Pl. Notes*, 54:27-31.

115. Shreve, L. W. 1974. The use of preformed paper milk cartons for containerized black walnut seedlings, grafts, and rooted cuttings. *Proc. No. Amer. Containerized For. Tree Seedling Symp.* Great Plains Agric. Counc. Publ. 68, pp. 137-138.

116. Splittstoesser, W. E. and M. M. Myer. 1971. Evergreen foliage contributions to the spring growth of *Taxus*. *Physiol. Plant.*, 24:528-533.

117. Stoeckeler, J. H. and R. E. Slabaugh. 1965. *Conifer nursery practice in the prairie plains*. U.S. Dept. Agric. Handb. 279, 93 pp.

118. __________ and G. W. Jones. 1957. Forest nursery practice in the lake states. U.S. Dept. Agric. Handb. 110, 124 pp.

119. Street, H. E. 1966. The physiology of root growth. *Ann. Rev. Pl. Physiol.*, 17:315-344.

120. Timmis, R. 1974. Effect of nutrient stress on growth, bud set and hardiness in Douglas fir seedlings. *Proc. No. Amer. Containerized For. Tree Seedling Symp.* Great Plains Agric. Counc. Publ. 68.

121. Tinus, R. W. 1974. Large trees for the Rockies and Plains. *Proc. No. Amer. Containerized For. Tree Seedling Symp.* Great Plains Agric. Counc. Publ. 68.

122. Toumey, J. W. and C. F. Korstian. 1942. *Seeding and planting in the practice of forestry*. 3rd ed. New York, NY. John Wiley and Sons.

123. Trappe, J. M. 1971. Root pruning conifers in nursery beds: does it increase survival potential? *Tree Pl. Notes*, 27:3.

124. VandeLinde, F. 1964. Nursery practices for southern oaks and gums. *Tree Pl. Notes*, 65:24-26.

125. Varasova, N. N. 1956. Peculiarities of the seeds of the common ash in relation to different geographic region. *Acta Inst. Bot. Acad. Sci.* USSR, Ser. IV, Bot. Exp. 11:370-387.

126. Vermeulen, J. P. 1965. Rooting-growing media. *Proc. Int. Plant Prop. Soc.*, 15:97-104.

127. Viets, F. G. 1944. Calcium and other polyvalent cations as accelerators of ion accumulation by excised barley roots. Pl. Physiol., 19:466-480.

128. Wakeley, P. C. 1954. Planting the southern pines. U.S. Dept. Agric. Monogr. 18.

129. Wallis, M. 1968. The future of mist and capillaries. Int. Pl. Prop. Soc. Proc., 20:140.

130. Ward, J. D. 1977. Nutrition of Ilex crenata 'Hetzi' during propagation and production. (Unpubl. Ph.D. dissertation, Library, Oklahoma State University.)

131. Webb, D. C. and R. E. Former, Jr. 1968. Sycamore seed germination: the effects of provenance, stratification, temperature and parent tree. USDA For. Serv. Res. Note SE-100, 6 pp.

132. Whalley, D. N. 1974. Nutrition of hardy ornamental nursery stock. ADAS Q. Rev., 13:27-41.

133. Whitcomb, C. E. 1976. A comparison of IBDU and osmocote formulations on the growth and quality of container grown nursery stock. Okla. Agric. Exp. Sta. Res. Rep. P-741.

134. __________. 1975. Response of Juniperus chinensis 'Hetzi' and Ilez cornuta 'Burford nana' to three levels of osmocote 18-6-12 and four levels of single-guperphosphate in two container sizes. Okla. Agric. Exp. Sta. Res. Rep. P-741, pp. 37-38.

135. __________. 1975. Response of Juniperus chinensis 'Hetzi' and Ilex cornuta 'Burford nana' to three levels of dolomite and three levels of micronutrient fertilizer in two container sizes. Okla. Agric. Exp. Sta. Res. Rep. P-741, pp. 39-40.

136. __________ and J. G. Rackley. 1972. Effects of container size, number of plants, and fertilizer levels on growth and quality of Ligustrum japonicum. Hortscience, 7:321.

137. Wilcox, J. R. 1968. Sweetgum seed stratification requirements related to winter climate at seed source. For. Sci., 14:16-19.

138. Wilcox, H. 1962. Growth studies of the root of incense cedar. Libocedrus decurrers morphological features of the root system and growth behavior. Amer. J. Bot., 49:237-245.

139. __________. 1955. Regeneration of injured root system in Noble fir. Bot. Gaz., 116:221-234.

140. Will, G. M. 1966. Root growth and dry-matter production in a high producing stand of Pinus radiata. N.Z. For. Ser. Res. Note 44.

141. William, R. D. and S. H. Hanks. 1976. Hardwood nurseryman's guide. U.S. Dept. Agric. Handb. 473.

142. Winstead, J. B. and D. Belk. 1968. Populational differences in seed germination, stratification requirements and amylase activity in Liquidambar spp. Bull. Ecol. Soc. Amer., 49:108. (Abstr.)

143. Woessner, R. A. and V. Hicks, Jr. 1973. Three year height of green ash not affected by root and top pruning. Tree Pl. Notes, 24(4):13-14.

144. Woessner, R. A. 1972. Four hardwood species differ in tolerance to pruning. Tree Pl. Notes, 23(1):28-29.

145. Wojahn, K. E. and J. G. Iyer. 1976. Eradicants and mycorrhizae. Tree Pl. Notes, 27(2):12-13.

146. Wood, E. A. 1974. Producing containerized tree seedlings at the wood nursery. Proc. No. Amer. Containerized For. Tree Seedling Symp. Great Plains Agric. Counc. Publ. 68.

147. Woodroof, J. G. 1967. Tree nuts: production, processing, products. Vol. 2. Westport, Conn. Avi Publ. Co.

148. __________ and N. C. Woodroof. 1934. Pecan root growth and development. J. Agr. Res., 49:511-530.

149. Wycoff, H. B. 1959. Lateral root pruner. Tree Pl. Notes, 38:23.

150. Zimmerman, P. W. and A. E. Hitchcock. 1935. The response of roots to "root forming" substances. Contrib. Boyce Thompson Inst., 7:439-445.

APPENDIX A

TREATMENT CONVERSIONS

TABLE XXIV

CONVERSION CHART FOR LEVELS OF NUTRIENTS

Osmocote 18-6-12 Rates	g/container (683 cm^3) (41.5 in^3)	lb/yd	kg/m	g/ft	lg/N/A/yr	kg/N/ha/yr
1	0	0.0	0.0	0	0	0
2	3	7.5	3.4	126.0	1000	1121
3	6	15.0	6.8	252.0	2000	2242
4	9	22.5	10.2	378.0	3000	3363
Perk Rates						
1	0	0	0.0	0.0		
2	1.6	4	1.39	67.2		
3	3.2	8	2.77	134.4		
Dolomite Rates						
1	0	0	0.0	0.0		
2	1.6	4	1.39	67.2		
3	3.2	8	2.77	134.4		

APPENDIX B

ARRANGEMENT OF SPECIES AND REPLICATIONS

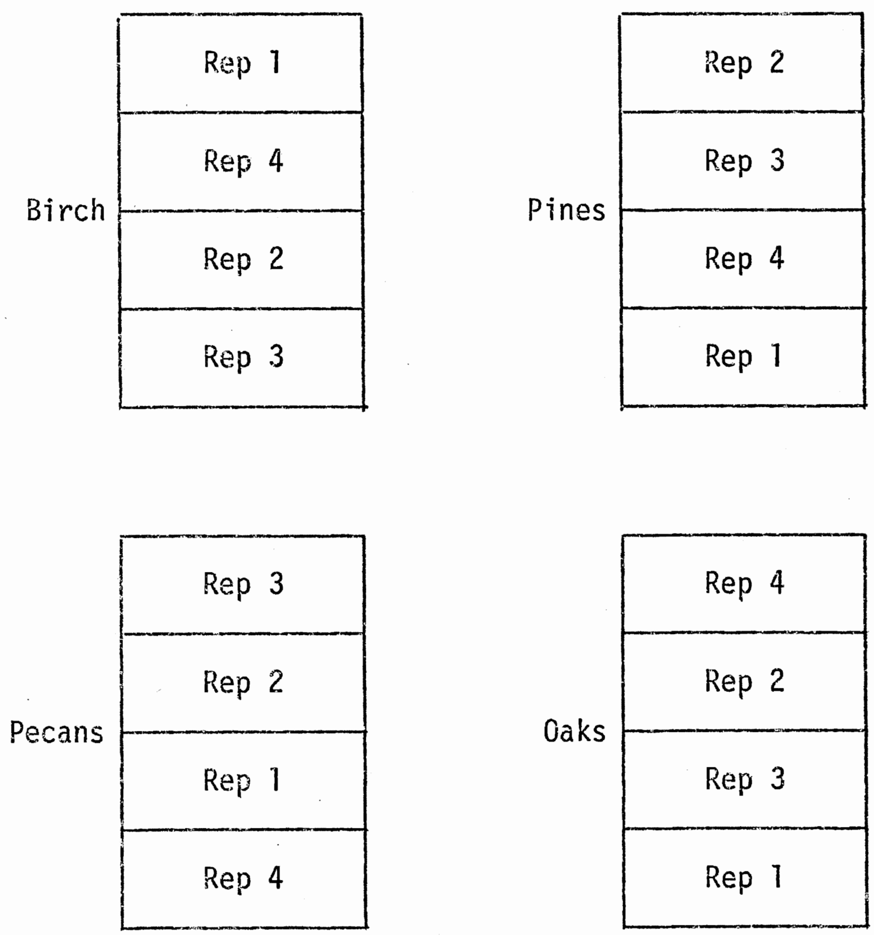

Figure 22. Arrangement of Species and Replications on Expanded Metal Benches.

VITA

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Doctor of Philosophy

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