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CONTROL OF WATER BALANCE IN TRANSPLANTED TREES[1]

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Most of the water available to plants in the form of precipitation or irrigation is lost through transpiration, which is defined as the loss of water vapor from plants. Most transpiration occurs through pores (stomata) in the undersurface of the leaf. Some water, usually a small fraction of the whole, is lost through the cuticle of the leaf. Stomatal pores open and close in response to environmental changes. Stomata tend to open in the light and close at night. In most species, transpiration is effectively reduced by closure of stomata.

In established trees, because of resistance within plants to water uptake, there is a tendency for water absorption through roots to lag behind transpiration from shoots during the day. As a result, water stresses tend to develop even in plants growing in moist soil. Water stresses in plants increase as soil dries, causing reduction in growth, injury to shoots, and death of plants.

The most important cause of death of transplanted seedlings is desiccation. Transplants undergo massive physiological shock when removed from the soil and, even after resetting, roots often do not grow fast enough to absorb water in sufficient amounts to keep up with transpirational water losses. Even seedlings which survive transplanting may have their growth quite substantially reduced for some time. For these reasons, attention must be given to control of plant water loss.

The most important considerations in increasing growth and survival of transplanted trees are that transpiration should be reduced, absorption of water should be increased, or both should occur. Much can be done to achieve these objectives by careful selection of trees, root pruning, site preparation, transplanting broadleaved trees in a leafless condition if possible, transplanting under appropriate environmental conditions, maintaining favorable top-root ratios, using antitranspirants, lifting trees from the nursery when they are still dormant, selecting healthy trees with a high potential for root growth, proper handling of planting stock, and careful supervision of transplanting and post-planting practices.

Root Pruning

Trees that have been root-pruned every few years in the nursery transplant much better than those that have not been so treated. This is because the absorbing roots of the former are confined to a small area, resulting in little injury during lifting and because root pruning stimulates root branching and production of many small absorbing roots. Hence, root pruning eventually leads to efficient absorption of water by transplants. Large trees growing in fields or woods, with few long scraggly roots, do not transplant easily because many of their absorbing roots (which are at some distance from the trunk) are lost during lifting. Such trees should also be root pruned, preferably for 2 years before they are moved, by digging a

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trench around the tree. The distance of the trench from the stem will vary with tree size. Pirone (1972) recommends that the radial distance of the trench from the trunk should be about 5 inches for each inch of trunk diameter. The excavated soil should be mixed with manure, leaf mold, or fertilizer and replaced in the trench.

Undercutting (wrenching) of nursery stock in beds is useful in conditioning plants for transplanting. This can be done by drawing a blade under the plant so as to break off deeply penetrating roots or by heaving the soil with a fork and then refirming. This practice holds back top development and stimulates production of new absorbing roots above the cut. The end result is a plant with a compact fibrous root system (high absorbing capacity) and low transpiration capacity. Undercutting or root pruning is especially beneficial with tap-rooted species and with container-grown plants having roots growing out of the container and penetrating the soil.

Site Preparation

An extremely important factor in transplanting success is preparation of the planting hole. Trees planted in heavy or poorly drained soils will not grow well. Therefore, heavy soil should be replaced with topsoil and, if necessary, additional precautions should be taken to assure good drainage.

The problem of poor soil aeration is common. Two general situations are commonly encountered:

1) where the soil is flooded and little or no soil air is present
2) where gas exchange between the soil and atmosphere is insufficient to replace the oxygen depletion and carbon dioxide (CO_2) accumulates as a result of respiration of roots and soil organisms, compaction, trampling, presence of sidewalks or pavements, dense growth of grass, increasing grade around a tree, etc.

The composition of the atmosphere aboveground differs from that below ground. The above-ground atmosphere contains about 21% oxygen, 78% nitrogen and only 0.03% carbon dioxide or about 3 parts in ten thousand. Free oxygen from the air must get down into the soil for normal root respiration to take place. The amount of carbon dioxide normally increases with depth of soil, whereas oxygen content decreases with soil depth.

The composition of soil air varies seasonally. Soil air contains most CO_2 in summer, less in autumn, still less in spring, and least in winter. Carbon dioxide content in the soil is increased by root respiration as well as by organic matter, manure, soil fungi, molds, bacteria and algae, together with various soil animals.

The greater the water content of soil the smaller the air content and amount of available oxygen. Soil aeration is also greatly influenced by soil texture. For example, aeration is commonly a problem in clay soil because most of the pores are so small that water does not drain properly. Such a soil holds little air and movement of air between the soil and atmosphere is slow. By contrast, aeration problems are uncommon in sandy soils because they contain considerable air, drain rapidly, and permit free movement of gases. The entire oxygen supply of a heavy clay soil of poor structure might have to be replaced 15 times during the summer, or more than twice as often as in a loam soil of good structure. The air capacity of heavy soils can be increased by adding organic matter, cinders, or sand in adequate amounts.

Trees are adversely affected in various ways by a deficiency of oxygen and excess of carbon dioxide in the soil. Root respiration changes from an aerobic to an anaerobic type, at least in part, with a consequent accumulation of toxic compounds. There often is a decrease in permeability of roots to water, causing decreased water absorption by plants. Absorption of minerals requires energy released in respiration. Hence, mineral uptake is greatly reduced by lack of oxygen in poorly aerated soils. In addition, poor soil aeration affects mineral nutrition indirectly by inhibiting activities of soil organisms involved in nitrification.

The symptoms of poor soil aeration, whether caused by heavy soils, flooding, compaction, trampling, sidewalks, pavements, etc., include leaf yellowing and mottling as well as death and shedding of leaves; inhibition of shoot and root growth; death of twigs, branches, and roots; and, when flooding is severe and prolonged, death of trees. In view of these facts it is not surprising to find that many trees suffer from oxygen deficiency at least during part of the season.

Oxygen is usually suboptimal in concentration beneath the surface of the soil. Roots usually do not begin to show definite injury until the oxygen content of the soil atmosphere drops as low as 10%. Ordinarily, the oxygen content of the upper levels of drained soils lies somewhere between the lower critical value of 10% and the 21% characteristic of free air. A reduction of soil oxygen to about 3% practically stops root growth in most plants. Because the oxygen content of soil drops abruptly to about 1% just above the water table, the roots of most land plants are restricted to soil horizons above this level.

The extent of injury from poor aeration varies with species, drainage conditions, duration of flooding, etc. Roots of species such as cypress (*Taxodium*), gums (*Nyssa sp.*), and willows (*Salix*) are well known to have low oxygen requirements and to be very tolerant to flooding. In general, conifers are injured much more than broadleaved trees by poor aeration. Pirone (1972) classified susceptibility of species to poor aeration as follows:

Most Severely Injured
Sugar maple (*Acer saccharum*)
Beech (*Fagus*)
Dogwood (*Cornus*)
Oak (*Quercus*)
Tulip tree (*Liriodendron*)
Pines (*Pinus*)
Spruces (*Picea*)

Less Severely Injured
Birch (*Betula*)
Hickory (*Carya*)
Hemlock (*Tsuga*)

Least Injured
Elm (*Ulmus*)
Poplar (*Populus*)
Willow (*Salix*)
Plane (*Platanus*)
Pin oak (*Quercus palustris*)
Locust (*Robinia*)

Time of Transplanting

Trees are best moved when conditions are least conducive to high transpirational water loss. Deciduous trees are best planted in the autumn after the leaves fall and before the soil is frozen or in early spring after the soil thaws and before the buds open. Certain trees with fleshy roots (e.g., *Cornus, Magnolia, Liriodendron, Quercus phellos, Cladrastis* are best transplanted in spring. Other trees that are recommended for spring planting include *Carya, Fagus, Liquidambar,* and *Juglans nigra* (Pirone, 1972). Spring planting is best in areas where soil freezes deeply, where there are strong winds, or where there is little soil moisture. It cannot be emphasized too strongly that the danger of losing growth or of losing trees from desiccation increases very rapidly as transplanting is postponed into summer. This is so because 1) the increasing leaf area after shoots begin to expand will increase transpiration greatly, and 2) the increase in temperature will steepen the vapor pressure gradient between the leaves and air and thereby increase the transpiration rate. Despite the difficulties of summer transplanting some skilled arborists are able to transplant trees in mid-summer. However, this generally involves extensive preparation of trees long before they are moved.

In cold areas conifers (e.g., *Pinus, Picea, Juniperus, Thuja*) can be planted early in the autumn or spring after the soil has thawed. Container-grown or balled and burlapped conifers can be planted anytime that the ground is workable. Such plants should be mulched and irrigated after transplanting.

In warm areas conifers can be moved anytime but they should be irrigated regularly. Broadleaved evergreens (e.g., *Magnolia, Ilex*) are best planted in spring. They can also be planted in the autumn but ample time should be allowed for resumption of root growth before the ground freezes.

It should not be assumed that antitranspirants will always provide adequate protection for transplanting broadleaved trees in midsummer, especially if such trees had not been root-pruned. Our experiments showed that even though antitranspirants decreased water loss of trees that were transplanted on hot days in August, they did not prevent development of severe internal water deficits and injury to foliage.

Top-Root Ratios

As mentioned, the balance between transpiration and absorption determines whether or not critical internal water stresses develop. If the root surface is inadequate to supply the water lost by the shoots, internal water deficits in trees will inevitably follow. Hence, reduction of the extent of roots relative to the size of the shoot system by fertilizers, eradicants, mechanical injury, disease, or insects often is followed by severe water deficits in the tops.

The arborist should be constantly aware that the decreased absorbing capacity of root systems of transplants can be compensated for by decreasing transpiration capacity. Probably the most useful, least expensive, and easiest way of assuring decreased transpirational loss of transplants is by pruning 15 to 40% of the bud-bearing branches. The amount of pruning will depend on the condition of the tree when it is moved and on the care it will receive after transplanting. Trees up to 10 feet high require less pruning and withstand transplanting better than do larger trees. Trees in containers or balled and burlapped trees require less pruning than bare-rooted trees. Well prepared balled and burlapped trees, especially evergreens, often do not require pruning. When trees are pruned, only secondary branches should be removed so the shape of the tree will not be changed.

Many examples are available of the importance of top-root ratios to survival and only a few will be cited. Hermann (1964a) found that *Pseudotsuga* seedlings with high top-root ratios showed low survival when outplanted. According to Allen (1955), most outplanted *Pinus palustris* trees died simply because they lost water faster than their recently disturbed and damaged roots could supply it. Reducing the amount of needle surface by clipping affected the top-root balance and it decreased transpiration. Plants clipped to a needle length of 5 inches lost 30% less water than did unclipped seedlings. Average increases in survival following clipping varied from 10 to 30% and sometimes they exceeded 50%. However, clipping was most beneficial on good sites and in years of average rainfall. In one test planting in February during a dry spring on a sandy site, only 63% of the unclipped seedlings survived by late March as against 82% of the clipped seedlings. By June survival had dropped to 4% for unclipped seedlings and 11% for clipped ones. Nevertheless the overall advantages of clipping were so definite that the practice was widely recommended. Altering top-root ratios by removing leaf surface may also inhibit growth through reduction of photosynthetic surface, but usually this is less important than ultimate plant survival.

Antitranspirants

Two main types of antitranspirants (antidesiccants) are recognized:

1) film-type antitranspirants which form films on leaves, thereby blocking stomatal pores, or coating the cells inside the leaf with a waterproof film. These include waxes, wax-oil emulsions, high alcohols, silicones, plastics, latexes, and resins.

2) metabolic antitranspirants which chemically close stomatal pores. These include succinic acids, phenylmercuric acetate, hydroxysulfonates, the herbicides Karsil and Atrazine, sodium azide, and phenylhydrazones of carbon cyanide. When applied to roots certain metabolic antitranspirants (e.g., succinic acids) have been reported to increase permeability of roots to water.

A major consideration in the use of antitranspirants is that green plants require carbon dioxide (CO_2) for photosynthesis. This gas is taken up through stomatal pores as water vapor is lost through them. An ideal situation would be one in which loss of water vapor by plants is reduced while CO_2 uptake by leaves continues at a high level. Film-type antitranspirants unfortunately are more permeable to water vapor than to CO_2. Thus complete leaf coverage with an antitranspirant film will reduce CO_2 uptake (photosynthesis) more than plant water loss. However, many film-type compounds are applied in a thick film that covers only parts of plants or parts of leaves. Where the film is present it is essentially impermeable to both CO_2 and water vapor, and therefore transpiration and CO_2 exchange are reduced by about the same amount, with the percentage reduction depending on the extent of coverage of the plant.

Desirable properties of a film-type antitranspirant are: 1) persistence of the film over a limited period, followed by breakdown of the film and resumption of unimpeded CO_2 uptake, 2) nontoxicity to plants, and 3) favorable sticking and spreading properties.

With these considerations in mind we evaluated the effects of a large number of film-type and metabolic antitranspirants, applied at various dosages to foliage, on transpiration, photosynthesis, growth, and injury to different species. Experiments were conducted in the field, greenhouse, and in environmentally controlled growth chambers (Davies et al., 1972; Lee and Kozlowski, 1974; Davies and Kozlowski, 1974; Olofinboba et al., 1974). Experiments were also conducted on effects of antitranspirants applied to soil on seed germination, loss of water from soil, and uptake of the antitranspirants by plants (Chaney and Kozlowski, 1973a, 1973b). Antitranspirants tested included TAG, Adol, Geon Vinyl Latex, Wilt Pruf, Improved Wilt Pruf, Rhoplex, Foligard, CS-6432, Keykote, Folicote, Aqua Gro, Vapor Gard, Clear Spray, Epolene, succinic acids, phenylmercuric acetate, atrazine, and abscisic acid. This paper will present a brief overview of the results of these experiments and make some recommendations for use of antitranspirants. For details on effects of individual antitranspirants applied under various conditions the reader is referred to the Final Report on *Effect of Transplanting on Physiological Responses and Growth of Shade Trees* submitted to the International Shade Tree Conference.

Many examples have been cited of beneficial use of antitranspirants. For example, antitranspirants improved water balance in transplanted citrus trees, increased fruit growth in established olive and peach trees, and reduced transpiration of transplanted ornamentals (Davenport et al., 1971).

In considering whether or not to use antitranspirants the arborist should be aware of possible toxicity of these compounds, especially at high dosages. A number of our experiments emphasized that some antitranspirants were toxic to plants and for a very long time. The toxicity, which varied with the antitranspirant, its dosage, and species to which applied, was evident in reduced photosynthesis, altered metabolism, lesions on leaves, chlorosis and browning of leaves, leaf fall, reduced growth, and plant mortality (Lee and Kozlowski, 1974; Olofinboba et al., 1974). Toxicity sometimes was apparent early and, at other times, late after the compounds were applied. In one experiment toxicity was apparent after the physical effects of the antitranspirant had worn off. Toxicity symptoms may be particularly apparent at high temperatures. Significant increases in leaf temperature were observed when compounds particularly efficient in reduction of plant water loss were used. Some problems could be encountered with high leaf temperature, particularly at high ambient air temperatures.

Because of the likelihood of promoting injury by application of some antitranspirants under certain conditions, it is suggested that each grower experiment with these compounds on a few plants of the species which are to be transplanted on a large scale. Climatic and soil conditions should be as similar as possible to those experienced by plants in the commercial operation. Comparisons with untreated plants should be used as a basis for wider use of the antitranspirant during the following year.

If used, antitranspirants should be applied *conservatively* at low dosages to only some of the leaves on a plant so that if these are injured there will be other leaves to carry on the photosynthetic function. Covering only part of the shoot system with an antitranspirant may significantly reduce water loss, maintain a favorable plant water balance, and allow CO_2 exchange to continue at a reasonable level. Such treatment may enable a plant to survive the period between transplanting and resumption of root growth.

Antitranspirants can be used advantageously during the dormant season to prevent winter desiccation injury of established and recently transplanted shrubs and trees. The compounds should be applied only to the sides exposed to sun and wind.

Application of antitranspirants by spraying is much less toxic than dipping of leaves. For example, *Robinia pseudoacacia* seedlings sprayed with 20% Geon Vinyl Latex were not injured whereas leaves dipped into the same antitranspirant turned yellow or brown.

We conducted experiments on absorption of antitranspirants by plants from the rooting medium and translocation to leaves to form a water-impermeable film around mesophyll cells in the interior of the leaf. Some antitranspirants incorporated in soil reduced evaporation of soil moisture. CS 6432 was most effective, followed by cetyl alcohol and Dow Latex. TAG was very inhibitory to seed germination. Geon Vinyl Latex and Foligard also reduced seed germination and seedling survival whereas Adol (cetyl alcohol) did not. Growth of *Robinia pseudoacacia* seedlings was reduced by incorporation of cetyl alcohol in the soil. Leaves were chlorotic and smaller than those of plants growing in untreated soil. On the basis of our present knowledge, we do not recommmend applying antitranspirants to the soil. However, because this method offers an attractive possibility for easy control of transpiration and because some success has been achieved with herbaceous plants (Abdalla and Flocker, 1963), expansion of research along these lines is recommended.

Our review of the literature emphasized the unsatisfactory status of research on antitranspirants. Many compounds are known to reduce plant water loss by blocking or closing stomata or coating the internal surface of the leaf. Short-time observations of antitranspirant efficiency are made, reported, but not followed up. Many reports on antitranspirants do not provide any indication of the effects of the compounds on physiological processes such as photosynthesis. Antitranspirants are reported as being x% effective in reducing transpiration, with no reference made to the species studied or to prevailing environmental conditions. For these reasons we have emphasized some important interactions between the antitranspirant, plant, and environment.

Under moderate environmental conditions, the effects of film-type antitranspirants were particularly long-lived on *Pinus resinosa*. The reduction of plant water loss on both *Pinus resinosa* and *Pinus strobus* apparently was the result of the antitranspirant combining with waxes in the stomatal pores and forming impermeable plugs. A number of compounds reduced water loss in pines by as much as 90%, *but they also drastically reduced photosynthesis and for a very long time.* It seems unlikely that stomatal plugs in pines could be washed from pores by rain or by irrigation, and if this is the case, permanent reduction of plant metabolism may result with damaging consequences. At best, needles will be suffocated and suffer severe toxicity symptoms. Survival of plants will thus depend on production of new needles, which are likely to be reduced in size due to reduction of current-year photosynthiesis.Hence, film-type antitranspirants may be unsuitable for use on gymnosperms which have wax in or around stomatal pore (e.g., *Pinus resinosa, P. strobus*].

In a moderate (nonstressed) environment, antitranspirants were effective in reducing water loss of broadleaved species, namely *Fraxinus americana* and *Acer saccharum*. However, various compounds were effective to different degrees (see Final Report for details). This variation apparently was traceable to species stomatal anatomy, cuticular structure, and surface tension and spreading properties of the compounds, on the two types of leaf. This result points out the mistake of evaluating an antitranspirant compound on one species and extending the results to a recommendation of its use on another species.

One environmental effect that was particularly noticeable was a decrease in efficiency of film-type antitranspirants on plants subjected to high temperatures and high levels of insolation. While some cracking of the antitranspirant film was apparent under moderate environmental conditions, high temperatures apparently caused rapid drying and cracking of the film. Partial leaf coverage in this situation proved to be very significant since the stomatal closure that occurred in control plants was prevented by the film, due to increase in leaf water content. At high temperatures, cumulative transpiration from those stomata that were exposed was greater than from untreated plants. This demonstrated dramatically the very different results that can be obtained with a given antitranspirant under varying environmental conditions, i.e., a variation from a 50% reduction in transpiration to a 50% increase in transpiration, as a result of an increase in ambient temperature and exposure to high levels of insolation. Hence, we strongly reemphasize that the environmental conditions under which an antitranspirant is tested should be evaluated.

A less obvious, but nonetheless significant effect of environment on antitranspirant efficiency, is that of wind. One compound (silicone) proved significantly less effective as wind speed was increased. Wind speed should be controlled or recorded during antitranspirant evaluations. In the field, high wind may disrupt antitranspirant films. As a result, the leaf suffocation attributed to antitranspirant films may be avoidable.

Under conditions where antitranspirants would prove most useful, i.e., low water availability, the metabolic (stomatal closing) antitranspirant, abscisic acid (ABA), was very effective. As soil moisture stress increased, photosynthesis in control plants decreased, primarily as a result of stomatal closure. ABA initially reduced transpiration and photosynthesis, but maintained plant turgor as the soil dried. Eventually CO_2 uptake of treated plants was greater than that of control plants, since stomatal opening of treated plants was maintained by increased plant turgor. ABA had a significant effect on soil moisture status. In a similar situation, a silicone film very significantly reduced transpiration, with a positive effect on plant water potential. However, photosynthesis of treated plants was reduced to such an extent by silicone, that photosynthetic levels of treated plants did not compare favorably with those of untreated plants until the stomata of the latter were nearly closed. *This emphasizes that the antitranspirant compound that reduces transpiration most may not necessarily be the most satsifactory compound in the long run.*

Our results provide a basis for future evaluation of antitranspirant compounds. The importance of defining all variables in an antitranspirant evaluation or recommendation is reemphasized. Despite problems of toxicity, suffocation, and inefficient reduction of transpiration, some of the compounds evaluated may be used to good advantage. On balance CS 6432 appeared to be useful (see also Final Report for comparisons of toxicity of compounds and effects on water loss and photosynthesis under certain environmental conditions).

Our experiments with metabolic antitranspirants (atrazine, phenylmercuric acetate, succinic acids, and abscisic acid) were variable. Atrazine did not show marked usefulness in promoting stomatal closure. Although we were able to induce stomatal closure with phenylmercuric acetate, we observed toxic side effects (Waisel et al., 1969). The experiments with succinic acids were, on balance, disappointing. Evidence of transpiration reduction of these compounds was not impressive. Sprays of decenylsuccinic acid at concentrations of 1×10^{-1}M or higher applied to *Pinus resinosa* trees in the summer injured leaves and adversely affected late-summer development of buds. Shoot growth in the year after treatment was greatly reduced. Many trees were killed (Kozlowski and Clausen, 1971). On the other hand, abscisic acid (ABA) was a very efficient, nontoxic metabolic antitranspirant. Unfortunately this compound is not yet available to commercial use. Because of the demonstrated success of ABA as an antitranspirant, it is hoped that this compound or others with similar properties, will be available for commercial use in the near future.

Our studies underlined the difficulty of making specific recommendations for antitranspirant use. Compound and dosage, species, and environmental variables are important in determining the physiological responses of trees to antitranspirant application. The growth stage of the plant will also be an important variable. Antitranspirant application to a growing plant will produce a different result than application to a plant that has completed shoot growth for the season. Reduction of photosynthesis by antitranspirants may have an important influence on current year's growth, or on accumulation of reserves (Olofinboba et al., 1974). In addition, growth stresses may crack antitranspirant films and reduce their effects.

Root Growth and Survival of Transplants

The shock of transplanting generally is least for trees transplanted from containers, intermediate for balled and burlapped trees, and greatest by far for bare-rooted trees. This is because of differences among the three groups in loss and drying of the fine absorbing roots during the transplanting process. This consideration is especially important when trees in full-leaf are transplanted.

The capacity to resume root growth rapidly often is critical to survival of transplanted trees. The most efficient zone of water absorption usually is near the root tips, and both the number of growing tips and their growth rate determine how efficiently water is extracted from the soil. On both theoretical and experimental grounds it is clear that capillary movement of water from moist to dry regions in soils at or below field capacity is very slow. If little or no capillary water moves towards roots, continuous root extension becomes essential for absorption of enough water to meet transpiration demands and maintain a favorable internal water balance. Hence, trees with an inherent capacity to develop rapidly growing root systems are most likely to extract water from a given soil mass and thereby maintain a favorable internal water balance.

Because the success of field planting often depends on how fast trees begin root growth and absorb available water, considerable variation may be expected among species in their survival ability. Woods (1959) found that appreciable root growth of *Pinus caribaea* began within 8 days after planting. He attributed the high degree of success in transplanting this species to the rapid initiation of root growth after transplanting.

Planting of species which show marked seasonal periodicity in root regenerating potential should be confined to the time of year when high capacity for root growth occurs. On sites with high availability of soil moisture, adjustment of planting schedules is less important (Kozlowski, 1971).

Particular attention is called to the useful physiological grading system of Stone and Jenkinson (1971) for pine nursery stock in California based on expected root growth following planting. They demonstrated that root growth capacity could be predicted once nursery cultural practices were standardized and the nursery climate was characterized. The system involved: 1) monthly tests of root growth capacity of seedlings lifted prior to and during the lifting and shipping season and 2) a cumulative record of the number of hours that air temperatures in the nursery were below 10°C.

As emphasized by Stone and Jenkinson (1971), root regenerating potential varies with nursery cultural practices, nursery climate, and cold storage. Fumigation, watering, fertilizing, and root-pruning practices differ from nursery to nursery, and they differ from year to year in the same nursery. For these reasons plants from different nurseries may differ widely in root regenerating potential. Hence, cultural practices should be standardized before root growth capacity can be predicted.

Climate also controls seasonal periodicity in root growth capacity. Thus, if the nursery climate varies greatly from year to year, the date on which root growth capacity reaches its peak will also vary. A shift in peak of root growth capacity is largely controlled by the number of hours that seedlings in the nursery are exposed to low air temperatures. For example, in a California nursery, a minimum exposure of 1500 hours of air temperature equal to or less than 10°C was required before the peak was reached.

When normal nursery practice involves 2 to 4 months of seedling cold storage after lifting, the effect of cold storage on root growth capacity can be evaluated in the same way as for newly lifted seedlings. The effect of cold storage depends on when the seedlings are lifted in the nursery., In California, root growth capacity was reduced by cold storage if seedlings were lifted in the early fall, increased by cold storage if the seedlings were lifted during early winter when the build-up in root growth capacity was underway, and reduced if the seedlings were lifted during or subsequent to the time that root growth capacity peaks.

Handling of Planting Stock

All the skill and understanding of producing plantable trees can be undone by improper handling of nursery stock. Culling of nursery stock with low potential for survival is desirable. Beyond this, close supervision is needed during transplanting to be sure that nursery plants do not dry out to critical levels. Use of polyethylene packaging is helpful in conserving moisture of planting stock.

Exposure of bare-rooted trees to drying for even short periods of time may have very serious effects on growth and survival, but this varies with species and with the physiological conditions of the plants at the time they are exposed. In one experiment, exposure of nursery stock for as little as 4 minutes reduced survival. In another experiment, Hermann (1964b) exposed 2 + 0 *Pseudotsuga menziesii* seedlings at 90°F and 30% relative humidity for periods up to 120 minutes. Survival by November of the year of outplanting was decreased with each added length of exposure. Exposures of 30 minutes influenced small seedlings more adversely than large seedlings but size of plants was unimportant, and survival of both sizes was very low following exposure of 30 minutes or more.

Critical limits of exposure varied considerably with the physiological condition of the nursery stock. Seedlings lifted in the autumn could not survive more than a few minutes of exposure while those lifted in the winter survived exposure up to 30 minutes. These differences probably were related to root regenerating potential. Prolonged storage also increased susceptibility to exposure. The importance of keeping exposure to a minimum was amply demonstrated. Even if long exposures did not reduce survival they caused slow growth of seedlings.

Dipping of roots of planting stock in water immediately on lifting often is beneficial to planting stock. Mullin (1971) showed that, at times of lifting and planting, dipping of *Picea glauca* roots in water increased survival and improved growth. Increased time of exposure of roots caused significant reduction in growth and survival.

Dipping of roots in compounds such as Agricol or Alginure also appears to have a favorable effect on absorption and water balance of transplants. Our data showed that dipping of *Pinus resinosa* roots in Alginure prior to transplanting increased survival and decreased the shock of transplanting. Dipping of roots in Agricol also has been useful in keeping bare rooted plants fresh during storage and transport. Dr. W. Tranquillini in Austria (personal communication to T.T. Kozlowski) found that in plants treated with Alginure or Agricol the new roots dried out less, regenerated faster, and gained faster contact with soil after transplanting. Best results were achieved with Agricol.

Our experiments indicated that dipping of roots in succinic acids to increase root permeability is *not* advisable. Although this treatment increased root permeability it also injured the roots.

Post Planting Practices

The bark of newly transplanted trees generally will benefit from wrapping with crepe paper or burlap to prevent drying and sunscald. Trees with a stem diameter greater than 1 inch should be braced to prevent swaying which sometimes impedes absorption of water through breaking of the soil-root contact.

Trees should be thoroughly irrigated after planting and regularly thereafter for at least the first few critical years or longer to insure that soil water deficit will not be an added barrier to maintaining a favorable internal water balance. Irrigation to a depth of 15 inches in well-drained soils, at approximately weekly intervals is advisable, or less often in tight soils.

Light waterings which wet the surface soil only are often wasted as the water evaporates rapidly from the soil surface and is not absorbed by deep-rooted trees. Watering should not be continued into late autumn in northern areas of the country that are subject to early freezes, since this may prolong growth and not give the tree enough time to harden.

Mulching of transplanted trees is beneficial in conserving soil moisture and stabilizing temperature. Trees planted in the autumn should be mulched when planted. Those planted in the spring should be mulched after the soil warms. Suitable mulches include peat moss, leaf mold, pine needles, ground cobs, straw, etc. (May, 1972).

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