LARGE TREES FOR THE ROCKIES AND PLAINS 1/

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Abstract.--Harsh site conditions require large trees in large containers for best survival. The strategy is to grow the seedling rapidly in its optimum environment, and design the growing cycle to deliver the desired size in proper outplanting condition at a specified time. Procedure for growing several species is outlined.

WHY LARGE TREES?

A "large" tree for us is one grown in a 5 x 5 x 21 cm container (410 ml) with a height between 15 and 30 cm, depending on species, and root collar caliper in the 6 to 8 mm class.

Large trees are needed because the site conditions on which they are planted are harsh. Mean annual rainfall ranges from 30 to 80 cm, and there is a great deal of fluctuation around the mean. If the ground surface is not dry when the trees are planted in the spring, Lt generally becomes dry during the summer. The deep container puts tree roots in contact with soil that does not dry nearly so fast. On the Plains we are planting trees where they have not been native in recent geologic history. To survive and grow, new plantings must be cultivated. If the trees are not visible above the weeds, they may suffer "cultivator blight." Many of the species we plant, such as ponderosa pine and blue spruce, are light demanding. If they are overtopped, they will lose vigor and eventually succumb. Trees adapted to the Rockies and Plains tend to he slow-growing ecotypes, and a 15 cm difference in height may represent 3 years of growth on a newly planted tree.

So large trees are used, because for a variety of reasons, large trees in large containers survive and grow better than small ones in small containers. In the forested areas of the Rockies, the economics of large trees may be debated, but on the Plains where we talk miles of row instead of acres of plantation, the number of trees planted is much smaller, but the value per tree is much higher. Shelterbelts are truly "people trees," and people don't mind paying for trees that establish and grow well.

TREE GROWING STRATEGY

Our strategy for producing trees has been first to learn everything we could about the physiology of the tree, how to manipulate its growth, and what the optimum growth environment is. Then we designed the growing cycle to deliver the desired size in the correct physiological condition ready for outplanting at a specified time. Finally, we designed and built a structure capable of producing the required environment.

THE OPTIMUM ENVIRONMENT: POT MIX AND CONTAINER

The criteria for pot mix were that it had to have a high water-holding capacity and yet be well aerated. It had to be light; this was a logistic consideration, not a biological one. It had to have adequate exchange capacity, and be chemically and biologically inert to the degree that mineral nutrition would not be adversely affected, the mix would not settle in the container, nor would it promote the growth of pathogens.

We tried everything we could lay our hands on, and finally settled on a 1:1 mixture of local peat and "attic fill" vermiculite. We found that a fairly large (3 to 5 mm diameter) vermiculite particle was necessary to keep the peat from settling and waterlogging in the 21 cm deep container we use. The local peat (Turtle Mountains, N.D.) has about the right physical structure but

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is salty and alkaline. However, the unwanted salts are quickly leached out by heavy watering. We do not add any mineral nutrients to the pot mix. We achieve greater control and flexibility by adding them to the watering system.

The first step in container development was to determine the best size. Since depth of rootball was an advantage, we chose 21 cm because that was as deep as our tree planter would reliably bury the entire rootball. Four sizes of square pot 21 cm deep were tested and dry weight of ponderosa pine at 8 months of age was found to be directly proportional to pot area (Figure 1). We chose a 5 x 5 cm size as being a good compromise between the largest possible tree and the economics of handling the large containers.

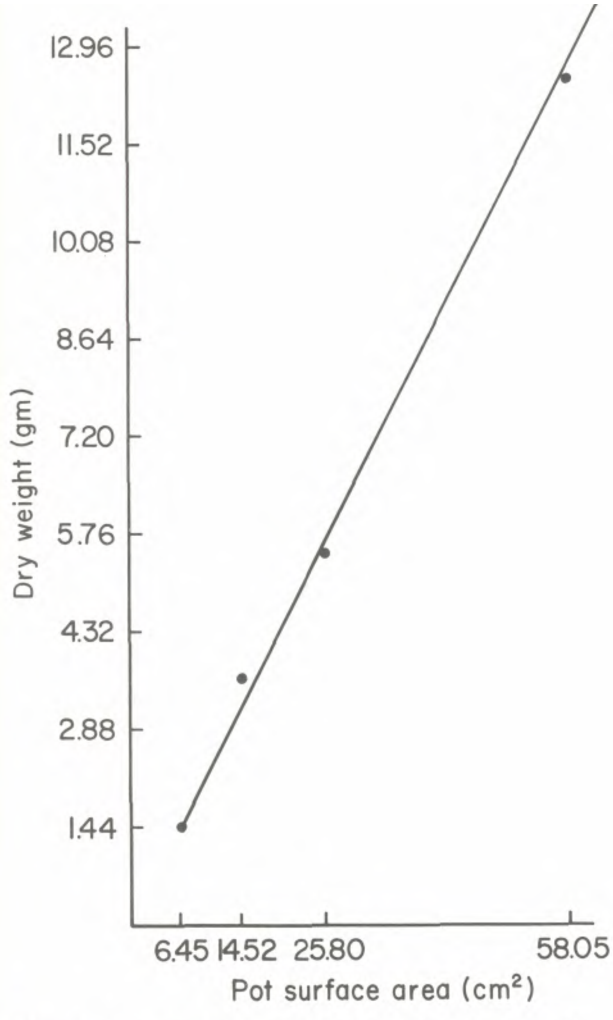


Figure 1.--Dry weight of ponderosa pine at 8 months of age was directly proportional to pot area.

The necessity for an opening at the bottom for root egress to prevent balling up was established very early by Walters (1969), Matthews (1971), and others. Observation of trees growing in a variety of containers led us to believe that root spiraling could be prevented by using rigid containers with vertical ribs or grooves and without sharp horizontal corners. Experiments over the last 2 years have shown that this is indeed the case (Tinus and Hiatt 1974).

We also decided to try a container with no taper. Roots tend to be more numerous near the bottom of the container, and lack of taper maximizes container volume near the bottom.

The container must be impermeable to roots while in the nursery, otherwise the seedling will lose part of its root system when removed from the container or when the containers are separated. In the case of large trees with strong, lignified roots, the damage caused by separation can be quite extensive and is highly detrimental to field survival (Tinus 1974).

The ideal container should be immediately permeable to roots upon outplanting, or better yet from a biological standpoint, the container should be removed. Since root development concentrates in the lower portion of the rootball, taper of the container is a disadvantage, although it does insure ease of plug removal from the container. However, container removal is not hampered by lack of a tapered container if root development is adequate and if the trees are thoroughly watered about 2 days before planting. Even without good root development or proper rootball moisture, intact rootballs can be extracted if the book planter we use is assembled in such a way that it coo still be opened.

CONTROL OF GROWTH

Young seedlings under optimum conditions will grow exponentially; that is, the bigger they get, the faster they grow. Therefore, Lie strategy for producing a large seedling quickie is to maintain height growth until it is as tall as desired. This gives the tree a large photosynthetic area. Leader growth is stopped and growth is then concentrated on lignification and diameter. Finally, the seedling is conditioned physiologically for outplanting.

PHOTOPERIOD

Height growth of many species can b, maintained by long days created with supplemental light at night (Kramer and Kozlowski 1960). Table 1 shows the effect of long lave

Table 1.--Effect of 86 watts m^{-2} incandescent light on 12 seconds every 6 minutes throughout the dark period

LD maintains continuous height growth	LD maintains intermittent height growth	LD fails to maintain height growth
Larix siberica	*Pinus ponderosa*	*Juglans nigra*
Picea glauca	*Pinus sylvestrus*	*Fraxinus pennsylvanica*
Picea pungens	*Pinus nigra*	*Quercus macrocarpa*
	Pinus divaricata	*Quercus rubra*
	Pinus contorta	*Quercus velutina*

on the species with which we have had experience. The use of intermittent light for extending the photoperiod was developed for greenhouse production of plants by Cathey and Borthwick (1961, 1962), Waxman (1961, 1963), Paleg and Aspinall (1970), and others, and adapted for forest tree seedlings by Tinus (1970a, 1970b, 1971) and Arnott (1974). For many species height growth can be maintained by as little as 86 watts m^{-2} of incandescent light on at least 3 percent of the time provided no dark period is longer than 30 minutes. Fluorescent light is 2 to 4 times more efficient than incandescent light, but tube life is short when cycled on and off. Continuous fluorescent light at night produces a 26 percent shorter pine or spruce than incandescent, probably because it is too efficient. Red light not only prevents dormancy but also retards stem elongation. Maximum growth is obtained when red and far red light, or red light and dark, are balanced so that dormancy is prevented with minimum retardation of stem elongation.

TEMPERATURE

Patterns of response to day and night temperature vary considerably with species, and for maximum growth it is important to know the optimum combination (Tinus 1971). This information is being developed at Bottineau for Plains-adapted species. Seedlings are grown to age 20 weeks. Sixteen combinations of day and night temperature are achieved by switching color-coded cans twice a day among four growth chambers. Day temperatures are 13°, 19°, 25°, and 31°C. Night temperatures are 7°, 13°, 19°, and 25°C. Sodium and mercury vapor lights provide up to 91 kilolux for a 16-hour day in an atmosphere of 1500 ppm CO_2.

Contour graphs are drawn for each seed source and species. Height, caliper, and weight were plotted on axes of day and night temperature, and isolines were drawn by linear interpolation in two dimensions between data points.

Detailed results will be published elsewhere, but in general, growth was more sensitive to day temperature than night temperature, and there was less difference among ecotypes within species than among species. For instance, bur oak (Quercus macrocarpa) grew best at the hottest combination tried: 31°C day and 25°C night, although germination was more rapid but less complete at high temperature (Figure 2).

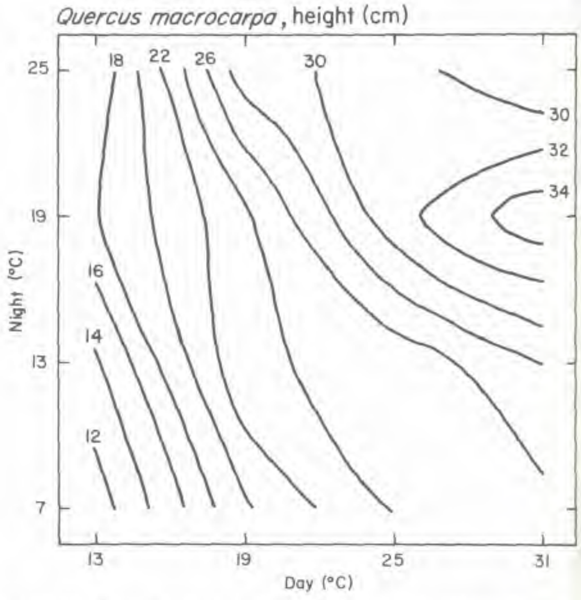
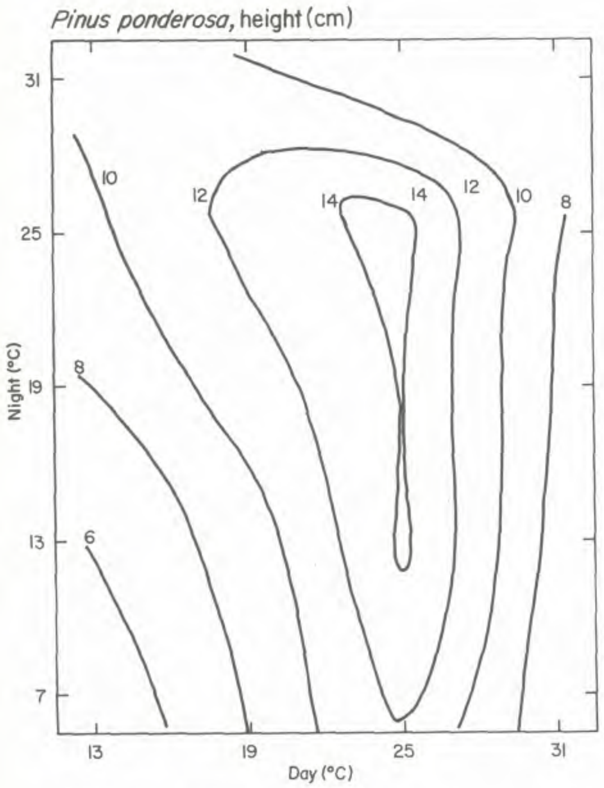


Figure 2.--Height (cm) of *Quercus macrocarpa* as a function of day and night temperature.

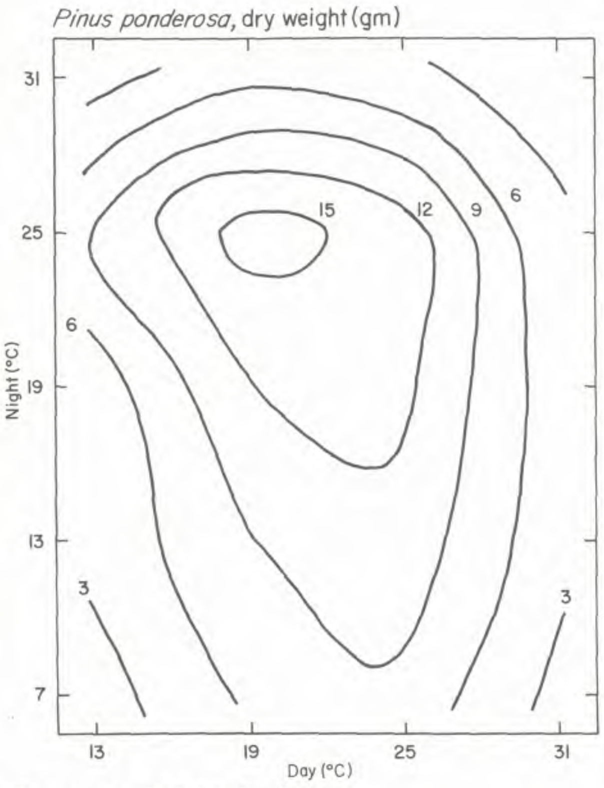
Pinus ponderosa grew best at day temperatures near 25°C. Night temperature could vary from 15 to 25° with little effect on height and caliper (Figure 3), but warm nights maximized dry weight (Figure 4).

Picea pungens could not tolerate high day temperatures. All trees at 31° day temperature died before the end of the experiment (Figure 5).

Temperature also may control dormancy. Bur oak (Quercus macrocarpa) does not respond to long days at moderate temperatures, but high day temperatures plus extended photoperiod and high CO_2 cause repeated flushing. High night temperatures promote height growth of Engelmann and blue spruce. However, it is

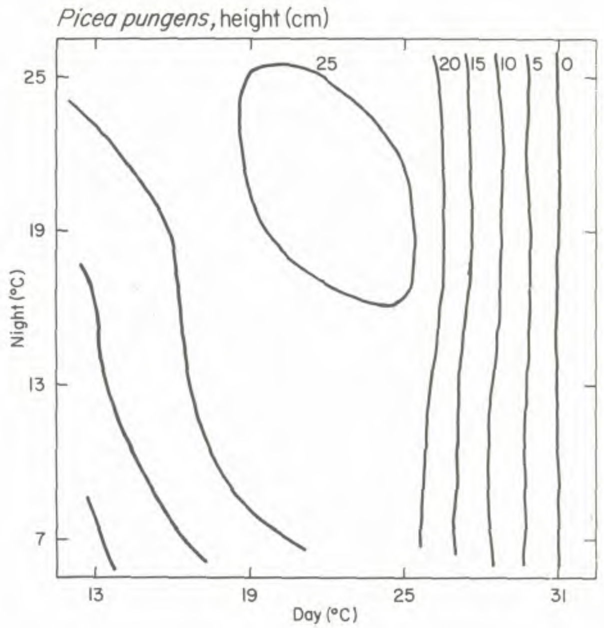


Pinus ponderosa, height (cm)



Pinus ponderosa, dry weight (gm)

Figure 3.--Height (cm), and
Figure 4.--Dry weight (gm) of *Pinus ponderosa*, Nebraska seed source, as a function of day and night temperature.



Picea pungens, height (cm)

Figure 5.--Height (cm) of *Picea pungens* as a function of day and night temperature.

not known whether temperature alone could sustain height growth without extended photoperiod or high CO2.

All green plants require carbon dioxide. In a closed greenhouse the C02 concentration may be increased from a normal atmosphere of 325 ppm to 1000 to 1500 ppm with an increase in dry weight growth of ponderosa pine and blue spruce of 50 to 70 percent (Tinus 1972). Judging from the horticultural literature a similar response should be expected from most other tree species, and I recommend that a CO2 generator be standard equipment in any greenhouse.

MYCORRHIZAE

Mycorrhizal fungi are an immense asset to many species (Mikola 1970), but comparatively little attention has been given to them. All seedlings from a well-managed bare-root nursery will be mycorrhizal because of resident fungi in the soil.

But container nurseries change soil every crop. Unless the pot mix is inoculated deliberately, there is no guarantee that each seedling will be mycorrhizal. In humid forested areas airborne spores may be an effective inoculant. In arid and non-forested areas they are not. In my experience differences between inoculated and uninoculated seedlings begin to show at age 3 to 4 months. If seedlings are outplanted before then into inocufated sites, perhaps there is no need for inoculation in the nursery. On the Plains and on sterile soils such as strip mine spoils, nursery inoculation is essential.

Currently, we recommend adding 2 to 5 percent forest duff to our pot mix, but this has the disadvantage that we risk adding back all the evils we sterilize the mix to remove. Studies are in progress to determine which fungi are most beneficial to ponderosa and Scots pine, how to mass produce the fungus in pure culture, and how to inoculate most efficiently.

MINERAL NUTRITION

Since nothing is added to the pot mix, a complete complement of mineral nutrients must be added through the watering system. The literature on mineral nutrient requirements of trees is fairly extensive (Table 2), but species vary in their requirements, and no one has reported optimum concentrations for the species we have been most concerned with. The composition of the nutrient solution we use is shown in Table 3 and has been found satisfactory, if not optimum.

Table 2.--Sources of information on mineral nutrient requirement of trees

Species	Source
tomato	Hoagland and Arnon (1938)
paper birch	Bjorkbom (1973)
European birch	Ingestad (1970, 1971)
white spruce	Etter (1971), Swan (1971), Hocking (1971)
red spruce	Swan (1971)
Norway spruce	Ingestad (1962)
Sitka spruce	van den Driessche (1969)
Eastern white pine	Schomaker (1969)
Scots pine	Ingestad (1962)
lodgepole pine	Hocking (1971)
Douglas-fir	van den Driessche (1969)
cottonwood	Phares (1970), Bonner and Broadfoot (1967)

GROEING CYCLE

The growing cycle in the greenhouse is planned according to the size of tree desired, and when it is to be outplanted. This determines how long it will take to grow and what condition the tree must be in for successful outplanting. Current container production in the Rockies and Plains is aimed at a spring planting season, and it takes close to 1 year to produce stock of the desired size and condition. Germination in the greenhouse is started April 1. During the first month no mineral nutrients are added to the water. The seedlings do not need them at that stage, and by keeping the medium sterile we reduce damping off without resorting to heavy doses of fungicides which might kill the mycorrhizal fungi. If seedlings are transplanted to fill vacant pots, it should be done as soon as possible after germination to minimize root deformities. Timing of thinning is not as critical, but should be completed by age 2 months. The best way, of course, is to plant 1 seed per container using very high quality seed. With many of the pines, carefully cleaned and properly stratified seed will germinate between 93 and 97 percent. This avoids the need for either transplanting or thinning, both of which are hand operations.

Table 3.--Concentration of mineral elements in nutrient solution used at several locations in the Rockies and Plains

Element	High N solution	Low N high PK solution	Element	High N solution	Low N high PK solution
	- -ppm- -			- -ppm- -	
N	225	40	Fe	2.5	2.5
P	27	80	Mn	.5	.5
K	155	120	Cu	.3	.3
Ca	60	60	Zn	.3	.3
Mg	48	48	Cl	.03	.03
S	63	63	Mo	.007	.007

The seedlings are grown under conditions as close to optimum as possible through the summer and early fall. By mid-November they have reached full height, and the hardening process begins. Supplemental light is shut off. The containers are leached with water to remove nitrogen and then allowed to dry until they reach the wilting point. Then they are rewatered with a low IN high PK nutrient solution (Table 3). The combination of short day and moisture and nutrient shock initiates bud set. However, growing temperatures must be maintained for an additional 5 weeks to allow for stem diameter growth, lignification, and bud development. The temperature is then reduced to just above freezing with maximum day temperature of 10 °C. The chilling requirements for spring bud break are satisfied, and full cold hardiness is developed in 5 weeks. The trees are ready to be removed from the greenhouse by February 1, and are best stored in a lathhouse until shipped to the field.

The above hardening regime has been under development for 8 years. The need for each step has been tested with blue spruce, ponderosa pine, and Scots pine. Height growth must cease before bud set can occur and the whole stem can become lignified. Adequate bud development is essential, otherwise the tree will not flush properly after outplanting, and bud development occurs best at moderate (not low) temperatures. Bud development is frequently slow under short days but high N conditions. Mositure stress and removal of nitrogen help initiate bud set promptly so that the growing cycle can be shortened as much as possible. The high PK solution is believed to increase cold hardiness (Arnott 1972, personal communication./), and at least some nitrogen must be available during hardening, otherwise chlorosis develops. Cold hardiness does not develop without short day and low temperature (Tanaka 1974, Tinus, unpubl.). Even if cold hardiness is not required, chilling is required for prompt bud break in the spring. If the terminal does not break, it is likely to die before the following spring and the seedling becomes leaderless for several years. We do not know how quickly the hardening process can be accomplished, but 5 weeks of each of the 2 stages is adequate. In March, 1974, our seedlings had been moved from the greenhouse to a lathhouse for about 2 weeks when they experienced -32 °C with no apparent damage.

This summary of a system for growing large trees for the Rockies and Plains for spring planting is based mainly on our work at Bottineau, N. D. But the potential has hardly been tapped. Each new nursery entering container tree production wants to grow different species to a different size to be outplanted at a different time. Describing container systems of the Interior West will soon become vastly more complex than it is today.

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Question: What is the basis for the practice of not fertilizing conifers during the first month? I note the chlorosis of young seedlings shown in your photos.

Tinus: The seed, especially a fairly large one such as ponderosa pine, carries with it a good complement of mineral nutrients. As long as the seed is still attached, the seedling should be able to draw upon these reserves. Second, my experience has been that damping off will occur in fertilized containers even when the pot mix has been sterilized unless fungicides are used. But damping off has not been a problem even without using fungicides, if the medium is unfertilized, especially if it is low in nitrogen.

Question: Were the roots exposed to -32°C in March without damage?

Tinus: The local weather station reported -32°C (-26°F). The trees were stored in a shade house, and the rootballs had been frozen for some time. I don't know what the temperature in the rootball was, but I am sure it was well below 0°F.