CONTAINER SEEDLING PRODUCTION:
INFORMATION NEEDED AND HOW TO GET IT.

by Richard W. Tinus, Principal Plant Physiologist
Rocky Mountain Forest and Range Experiment Station
Bottineau, North Dakota 58318

ABSTRACT.--General principles and examples are given of information needed to successfully operate a greenhouse container nursery. Form and size of container, seed germination requirements, response to temperature, mycorrhizae, dormancy prevention, and hardening procedures, are the factors discussed, but there are many others that need consideration.

Dr. Hanover has given you an excellent overview of the potential and advantages of the greenhouse container nursery system and the strategy for growing seedlings more rapidly than most people thought possible a decade ago (Read and Bagley 1967). I will try to fill in that framework with examples of and information on some key factors in the growing schedule. Much of this applies only to certain species, but I want to show you the kind of information you need and how to obtain it.

SELECTING A CONTAINER

A good container should (1) produce a root system a tree can live with, (2) be large enough to prevent the container from seriously limiting growth before the tree reaches the desired size, (3) not limit root growth after outplanting, and (4) be suitable for handling from arrival at the nursery until outplanting.

There are many kinds of containers on the market, but the ones that best meet the above objectives have the following characteristics:

They have rigid walls with vertical grooves or ribs, no sharp horizontal corners, and a hole at the bottom for root emergence and air pruning. That configuration prevents spiralling and produces a parallel root system (Hiatt and Tinus 1974). Whether or not it yields a desirable root system is a subject of continuing research. The worst container is a standard round horticultural pot. The need for root configuration control varies with the species. All pines I have tried need it badly. On the other hand, Douglas-fir and western hemlock on the west coast seem to recover well from a balled up root system.

Flexible walled containers such as the Alberta sausage and the Japanese paperpot are not as good, because it is hard to maintain a shape other than circular. Degradable and no-wall containers have problems with roots penetrating from one container to the next. No harm is done to small trees whose roots are not lignified. When the containers are separated, they will usually break cleanly. However, when the roots are large and lignified, much damage is done, and it takes too much physical effort to separate the containers. In addition, root penetration of cavity walls limits flexibility in time of outplanting. The trees must be planted when they reach that stage; they can not be stored longer.

I like the principle of a degradable container, but there are some major problems with them. They begin to degrade in the nursery as soon as they are planted. By shipping and planting time either they have lost too much strength to handle well or else they continue to restrict root growth after outplanting. What needs to be invented is a way to keep them from degrading at all in the nursery until their degradation is deliberately triggered, and they must then become freely permeable to roots within days, a couple of weeks at the most.

There are a number of biologically suitable containers on the market that have the characteristics I mentioned. The choice among them is generally based on how well it fits the rest of the nursery operation, the shipping, and outplanting. When making a selection the questions to be answered include:

How many are needed, 10 thousand or 10 million? What sizes are needed? How is the labor supply? What kind of mechanized handling will there be? What is the cost of an empty container? How will they be shipped? Will the container be reused? Will planting be by hand or machine? How rough is the terrain?

There are so many variables to consider that each nursery will have to make its own decision. There are no pat answers that will fit everyone.

For information on size of container required to produce a given size tree, see Tinus (1974) for ponderosa pine and Scarratt (1973) for white spruce and jack pine.

SEED GERMINATION

Although germination methods are available for most tree species, the greenhouse container nursery is much more demanding than the outdoor bare root nursery. In the bare root nursery, fall seeding is one way to give seed a long stratification. Very low viability seed can be used by increasing the seeding rate to obtain the desired stand density. However, nobody seeds a spring crop in the greenhouse in the fall. The time and space cost too much. Furthermore, you must end up with exactly one tree per cavity, and the number of seeds required to insure less than a given percent of empty cavities becomes very large with low germinating seed (Space and Balmer 1976).

Consider North Dakota sources of bur oak for example. Their problems were: (1) slow and incomplete germination, (2) it was infested with weevils, and (3) it has a large seed that can only be planted one per cavity. The procedure we developed to overcome these problems is:

1. Collect the seed from the ground or shake the tree, but do not pick it green.
2. Immediately float test the seed in water. Keep the sinkers and discard the floaters.
3. Place the wet acorns in a plastic bag.
4. Store them for 120 days or more in a cooler just above freezing, but do not freeze them.
5. When ready to plant, spread the acorns one layer deep in trays in a warm room or greenhouse.
6. Plant germinating acorns.

This procedure yields prompt germination and insures an almost 100 Percent stand.

Green acorns will ripen and germinate, but are a colossal nuisance to pick from the tree. It is far easier to collect them from the ground. Acorns lose viability rapidly as they dry out (fig. 1), so the float test at time of collection does three things: it eliminates the low viability acorns (0-30% for floaters vs. 80-90% for

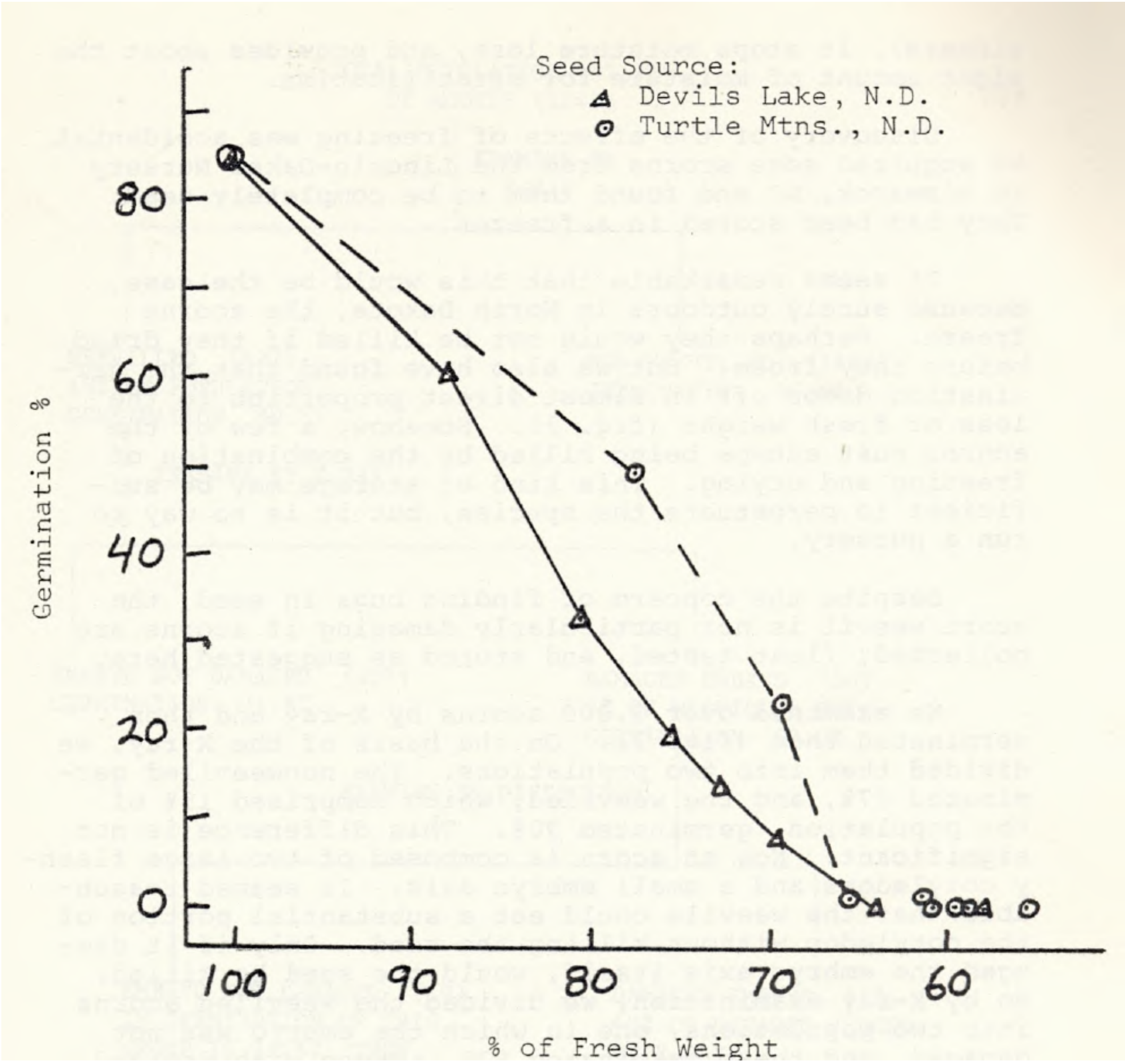


Figure 1.--Germination of Quercus macrocarpa acorns as a function of weight loss due to drying.

sinkers), it stops moisture loss, and provides about the right amount of moisture for stratification.

Discovery of the effects of freezing was accidental. We acquired some acorns from the Lincoln-Oakes Nursery in Bismarck, ND and found them to be completely dead. They had been stored in a freezer.

It seems remarkable that this would be the case, because surely outdoors in North Dakota, the acorns freeze. Perhaps they would not be killed if they dried before they froze. But we also have found that the germination drops off in almost direct proportion to the loss of fresh weight (fig. 1). Somehow, a few of the acorns must escape being killed by the combination of freezing and drying. This kind of storage may be sufficient to perpetuate the species, but it is no way to run a nursery.

Despite the concern of finding bugs in seed, the acorn weevil is not particularly damaging if acorns are collected, float tested, and stored as suggested here.

We examined over 2,800 acorns by X-ray and then germinated them (fig. 2). On the basis of the X-ray, we divided them into two populations. The nonweeviled germinated 87%, and the weeviled, which comprised 15% of the population, germinated 90%. This difference is not significant. Now an acorn is composed of two large fleshy cotyledons and a small embryo axis. It seemed reasonable that the weevils could eat a substantial portion of the cotyledon without killing the seed. Only if it damaged the embryo axis itself, would the seed be killed. So by X-ray examination, we divided the weeviled acorns into two populations, one in which the embryo was not damaged, and these germinated 92%. Those with damaged embryos comprised only 7% of the weeviled nuts, and the germination of this group was 60%.

Unless you X-ray an acorn from two directions, you can not tell whether the damage that you see and the embryo axis are in the same plane. The damage may be above or below the embryo. When we dissected acorns that appeared to have damaged embryos, we found only 40% of those judged to be damaged by X-ray actually were damaged. We were not able to germinate the dissected acorns for obvious reasons, but if we assume that the weeviled acorns whose embryos appeared damaged by X-ray, but were not, had the same germination rate as those that appeared not damaged by X-ray, then the calculated germination of the ones with the truly damaged embryos was 14%. In oth-

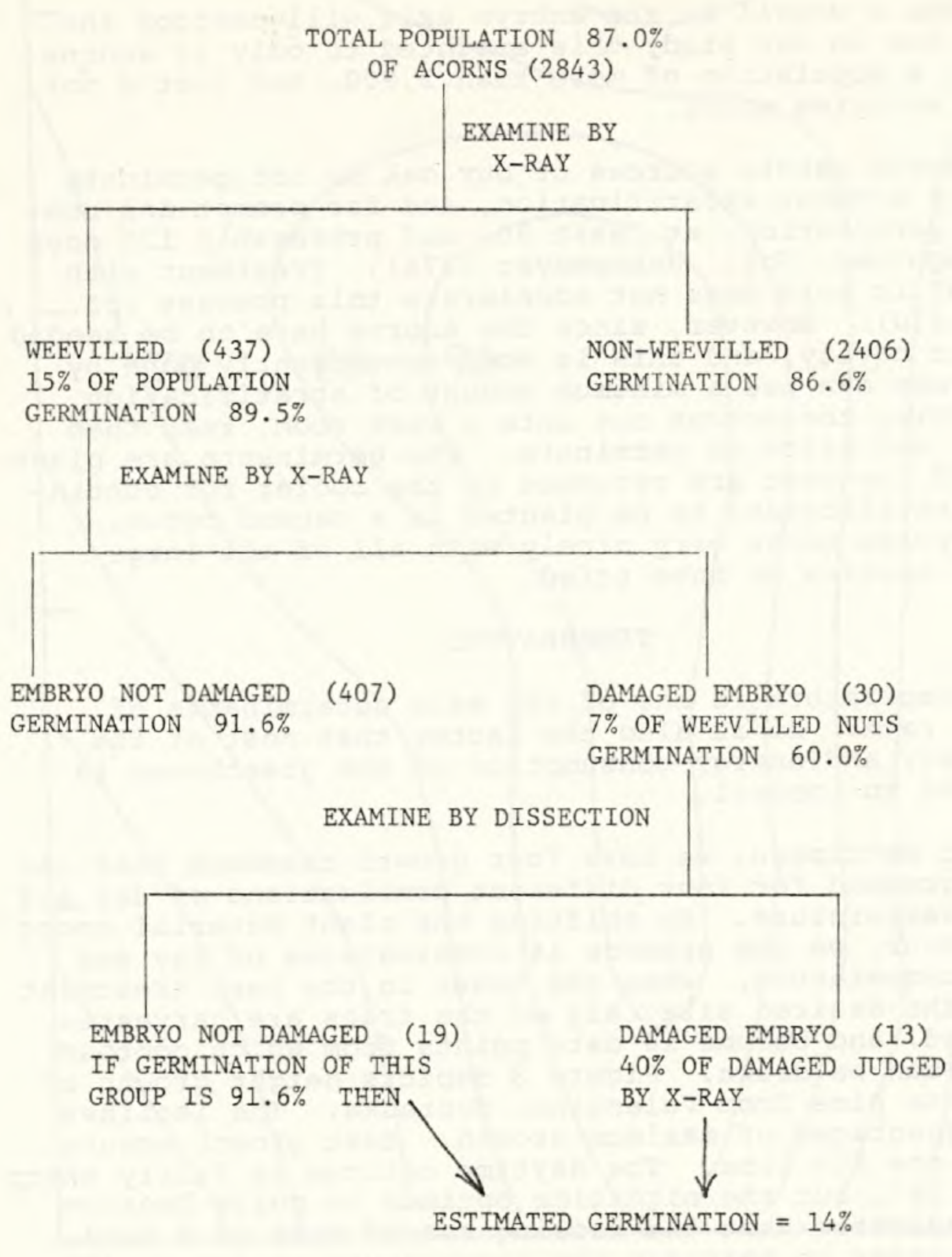


Figure 2.--Effect of weevils on germination of *Quercus macrocarpa* accorns.

er words a weevil in the embryo axis will destroy the seed, but in our study this amounted to only 13 acorns out of a population of more than 2,800, and that's not worth worrying about.

North Dakota sources of bur oak do not germinate readily without stratification, and for prompt and complete germination, at least 90, and preferably 120 days are required (cf. Schopmeyer 1974). Treatment with giberellic acid does not accelerate this process (cf. Vogt 1970). However, since the acorns have to be seeded one per cavity, and this is most conveniently done by hand, one can use a minimum amount of stratification, then bring the acorns out into a warm room, keep them moist, and allow to germinate. The germinants are planted, and the rest are returned to the cooler for continued stratification to be planted in a second batch. This system works very nicely with all of the large seeded species we have tried.

TEMPERATURE

Temperature is one of the main determinants of growth rate. It is also the factor that most of the machinery and energy consumption in the greenhouse is designed to control.

At Bottineau, we have four growth chambers that can be programmed for four different combinations of day and night temperature. By shifting the plant material among these four, we can produce 16 combinations of day and night temperature. When the trees in the best treatment reach the desired size, all of the trees are harvested, measured, and become 16 data points from which contour graphs can be drawn. Figure 3 depicts height growth of ponderosa pine from Valentine, Nebraska. The isolines are percentages of maximum growth. Best growth occurs within the 90% line. The daytime optimum is fairly sharp around 25°, but the nighttime optimum is quite broad. This indicates that the cooling system must be a good one in order to maintain the temperature as low as 25°, but fuel can be saved by letting the temperature fall at night. It's not that simple, however, because the growth of the tree depends in part on how it is measured. Figure4 shows that cool nights reduce dry weight of ponderosa pine. The graph for blue spruce height (fig. 5) is similar, but growth rate drops suddenly at higher day temperatures. This means maintaining suitable day temperatures is especially important. On the other hand, bur oak growth is promoted by high day temperatures and warm night temperatures (fig. 6).

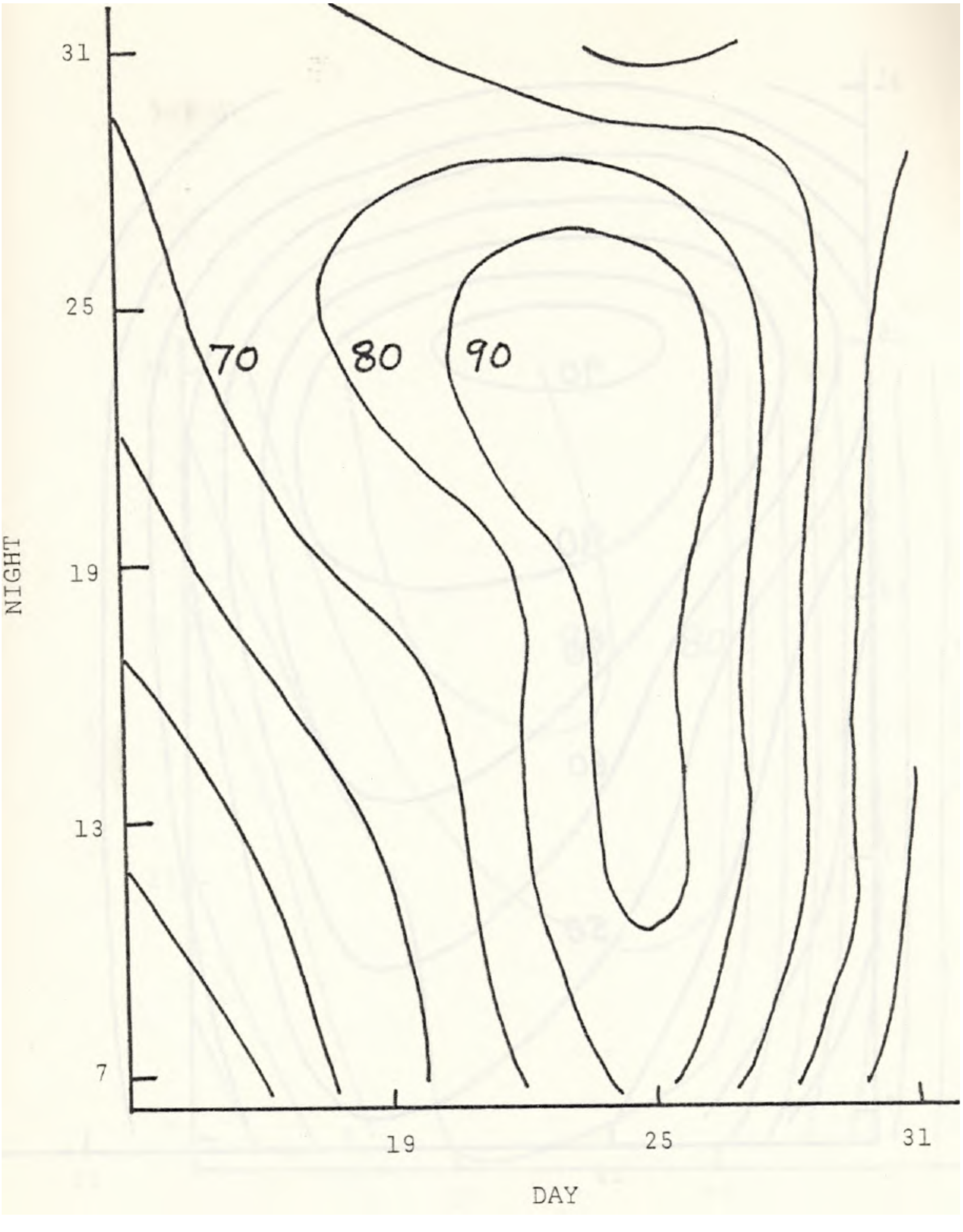


Figure 3.-- Pines ponderosa height growth in percent of maximum as a function of day and night temperature (°C). Maximum height - 147 mm. Coefficient of variability - 5.4%

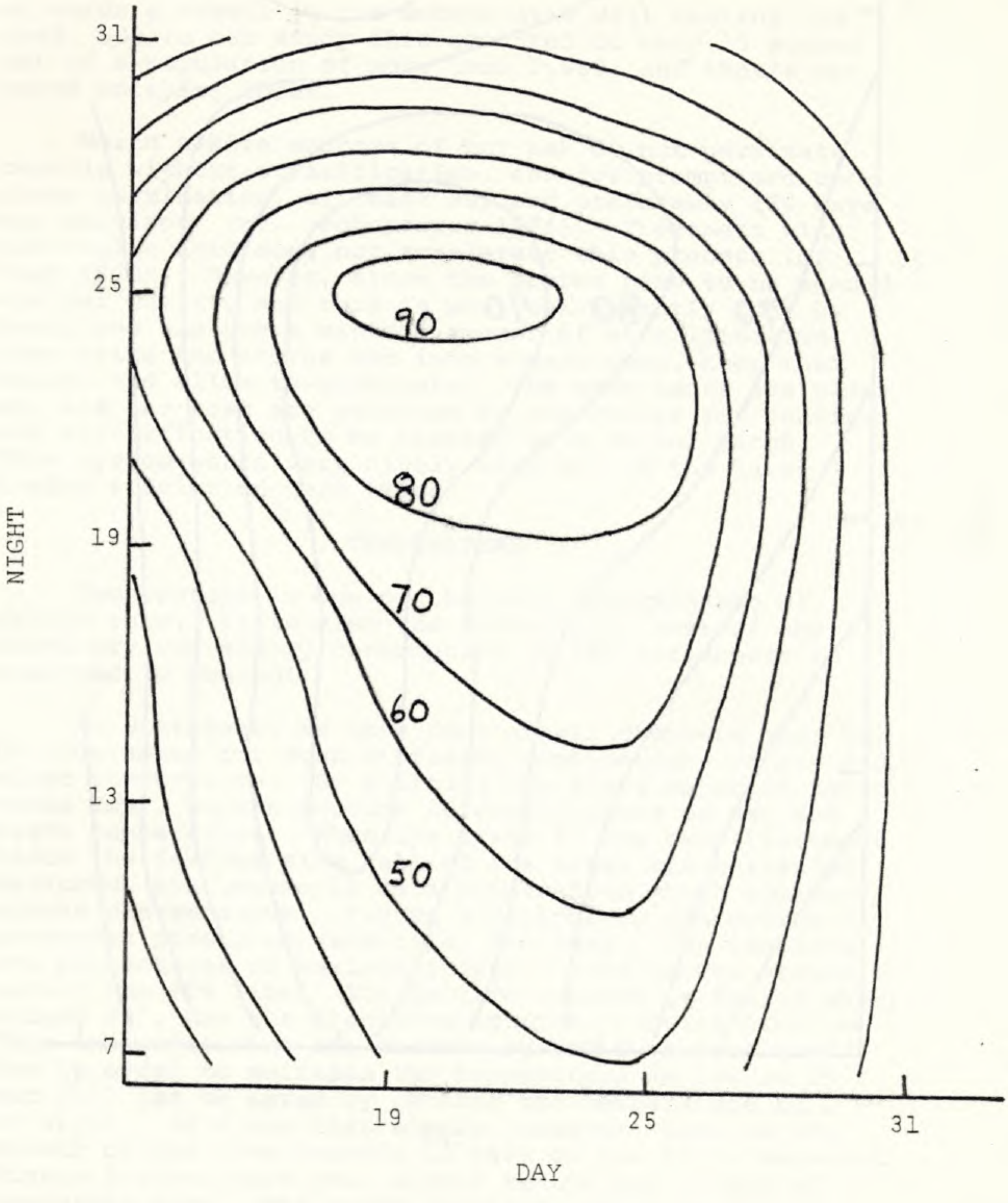
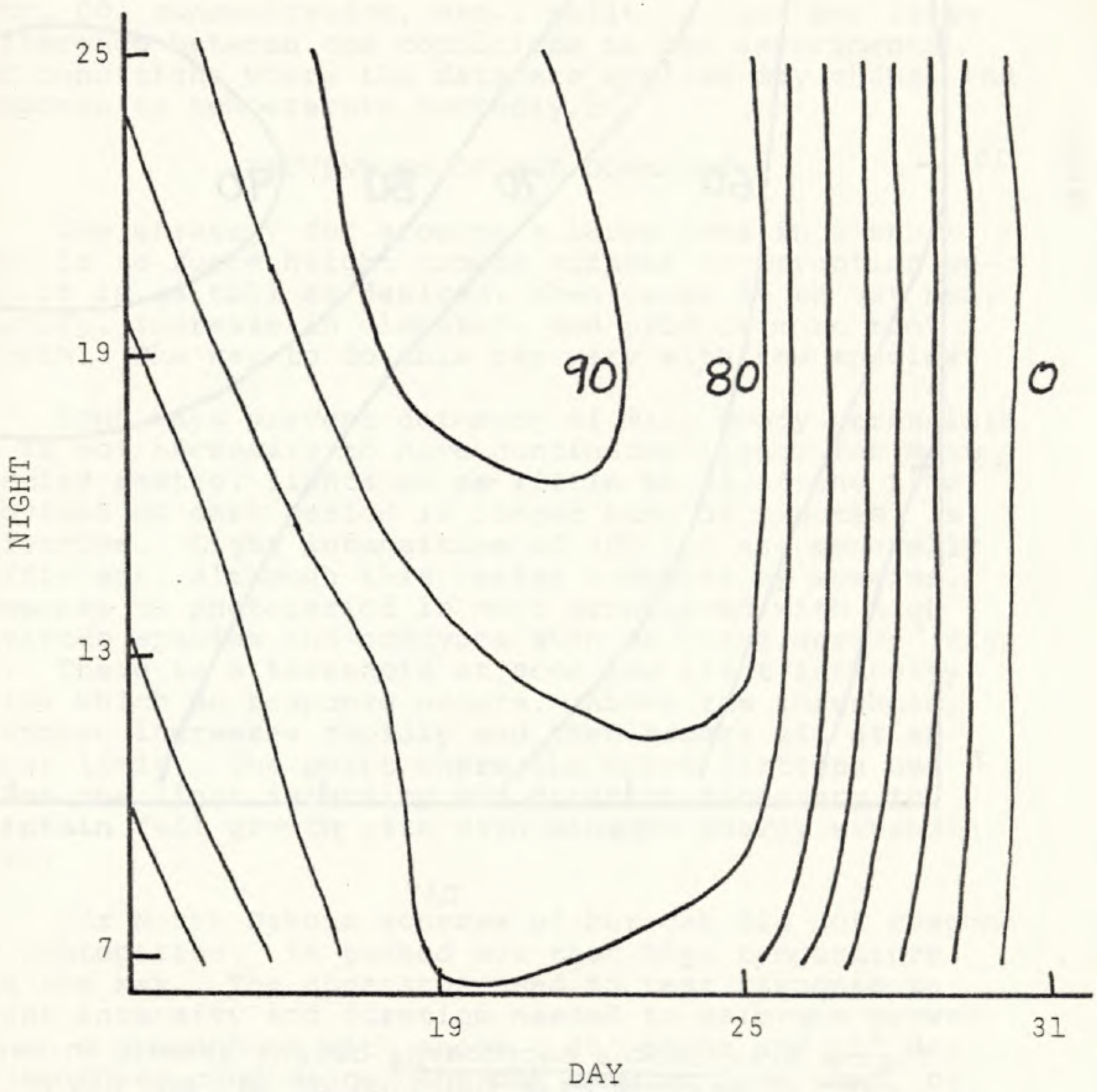


Figure 4.--*Pinus ponderosa* dry weight growth in percent of maximum as a function of day and night temperature (°C). Maximum dry weight - 16.2 gm. Coefficient of variability - 9.6%



Picea punens height growth in percent of maximum as a function of day and night temperature (°C). Maximum height - 274 mm.

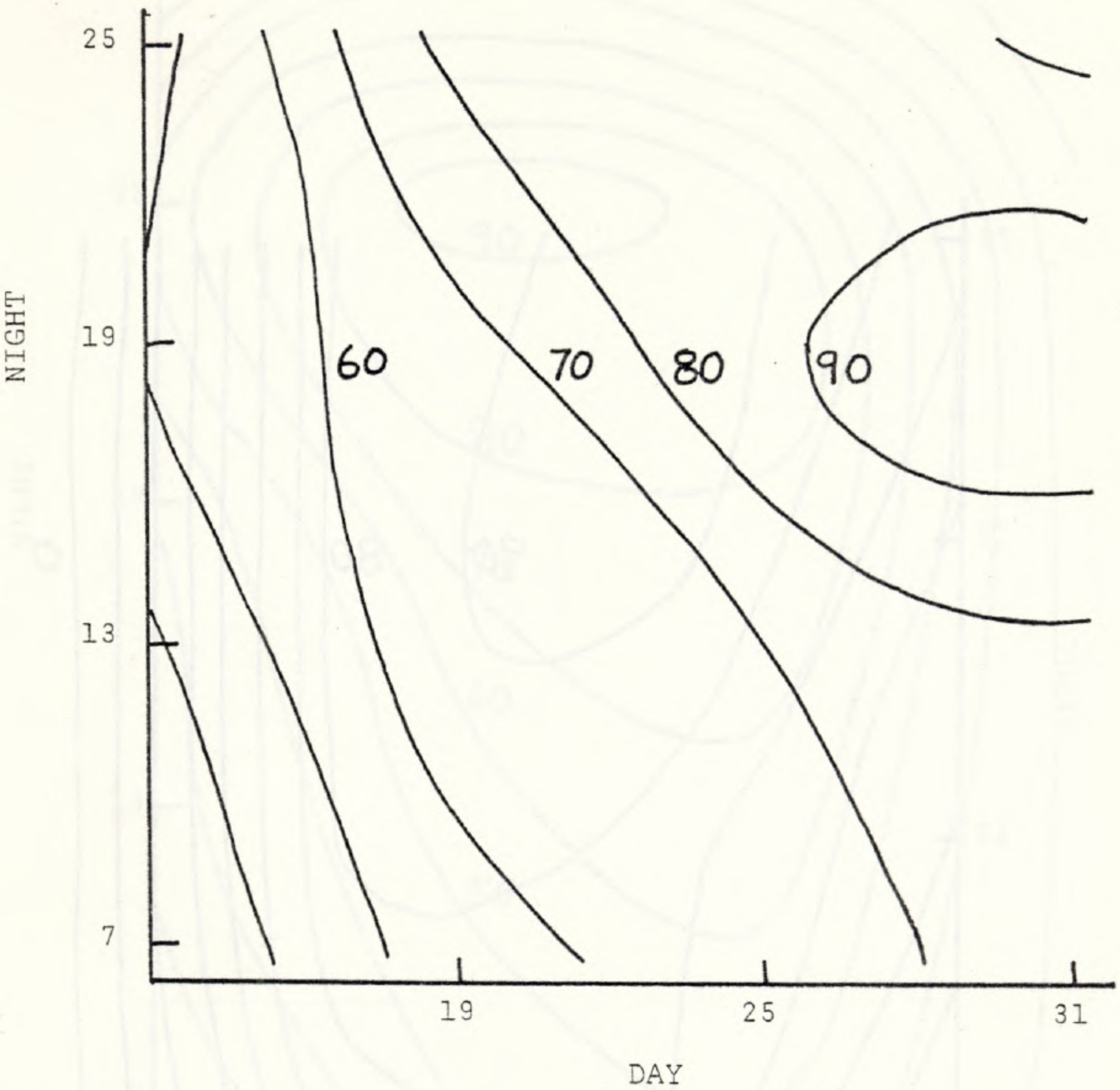


Figure 6.--Quercus macrocarpa height growth in percent of maximum as a function of day and night temPerature (°C). Maximum height - 354 mm. Coefficient of variability - 5.6%

We now have detailed temperature information of this kind on 17 species (table 1). On the basis of these experiments, we have made recommendations to full scale nurseries, and they have verified our results by producing excellent crops on their first try. One caution, however: in these experiments we have tried to make conditions other than temperature as nearly the same as they would be in the greenhouse nursery in which the data was to be used. There are assumptions about container size, pot mix, day length, light intensity, CO_2 concentration, etc., built in, and any large difference between the conditions in the experiments and conditions where the data are applied may change the response to temperature markedly.[1/]

PREVENTION OF BUD DORMANCY

The strategy for growing a large tree in a short time is to force height growth without interruption until it is as tall as desired, then cause it to set bud, lignify, increase in diameter, and produce more root growth. The way to do this may vary with the species.

Long days prevent dormancy of many woody perennials. It is not necessary to have continuous light; for most species tested, lights on as little as 3% of the time, provided no dark period is longer than 30 minutes, is effective. Light intensities of 400 lux are generally sufficient, although this varies somewhat by species. Response to photoperiod is most pronounced with high latitude species and ecotypes such as white spruce (fig. 7). There is a threshold at some low light intensity below which no response occurs. Above the threshold, response increases rapidly and then tapers off at an upper limit. The point where the curve flattens out gives the light intensity and duration necessary to maintain full growth rate with minimum energy expenditure.

Our North Dakota sources of bur oak did not respond to photoperiod. It turned out that high temperature was the key. The apparatus used to test response to light intensity and duration needed to maintain growth is in a greenhouse with about a 20° night and 25° day. Under these conditions, the oak came up from seed, put out one spray of leaves, and set bud. However, when the night temperature was raised to 25°, and day temperature to 30° to 35°, the oak flushed several times, tripling and even quadrupling in height. This worked not only with bur oak, but also with northern red and black oak.

Table I.—Recommended temperature settings (°C) for maximum growth of tree seedlings from end of germination to dry weight indicated when all other environmental conditions are optimized.

		Max. Dry	Day Temperature		Night Temperature		
Species	Seed Source	Wt.(gm)	Set Point	Allowable Range	Set Point	Allowable Ramie	Authority
Abies ougnifica (A.Murr.)	North Coast, Calif., 1800w	1.7	17	16-19	5	4-10	Hellmers (1966a)
CeitiS occidentalts L.	Bismark, N.D.[1] 1	7.2	31.	25-32	19	18-26	Tinos
Juglans nigra	Manhattan, Kans.	18.4	28	26-30	22	19-28	Tinos
Juniperus scopulocum Sarg.	Denbigh, N.D.1	5.6	25	21-28	18	12-26	Tinos
Juniperus virginiana L.	Towner, N.D.1	11.9	24	21-26	21	19-26	Tinos
Larix sibirica Ledeb.	Denbigh, N.0.1	6.3	25	24-28	22	16-26	Tinos
Picea engelmannil (Parry)	Larimer Co., Colo., 3140m	8.3	19	17-23	23	22-24	Helimers, et al(1970)
Picea glauca (quench) vows	Central Alberta	0.37	22	21-25	19	16-20	Tinus
	Fairbanks, Alas.	0.39	22	20-24	16	13-22	Tinus
	Kenai, Alas.	0.43	22	20-25	19	16-26	Tinos
Picea pungens (Engelm.)	Ft. Collins, Colo.	9.4	20	18-25	22	19-26	Tinus
	Indian Head, Sask.'	8.9	22	18-25	19	17-23	Timis
Pious contorta var.	Central Alberta	0.56	25	22-28	16	14-19	Tinos
latifolia Engelm.	Whitehorse, Y.T.	0.50	22	20-24	19	16-20	Tinos
Pious ponderosa var.	Ruidoso, N.M.	19.1	22	18-26	24	18-25	Tinos
scopulorum Engelm.	Safford, Ariz., 2770m	0.5	17	16-19	22	21-23	Callaham (1962)
	Valentine, Neb.	15.6	22	20-25	24	20-25	Tinus
	Black Hills, S.D.	0.12	23	20-24	23	20-24	Larson (1967)
	Moon, S.D. 1890m	0.5	23	20-27	22	21-23	Callahan (1962)
Pilots radiata D. Dun	Cambria, Calif.	12.9	20	19-23	5 or 20	4-7;17-23	Hellmers,et al (1973)
Pious syivestris var.uralensis	W. Ural Mins., Russia	9.1	19	18-21	28	25-31	Tinus
var. balcanica	Central Russia	7.1	19	18-22	25	22-31	Tinus
Pseudotsuga menziesii var. menziesti (Mirb.) Franco.	Vancouver Is., B.C.	2.4	22	17-25	18	13-22	Brix (1971)
iluercus macrocarpa Michx.	Devils Lake, N.D.	7.2	31	26-32	19	17-26	Tinos
Sequoia sempervirens (D.Don) Endl.	Klamath, Calif.	29	19	18-20	16	15-17	Helimers (1966b)
Tsuga heterophylla (Raf.) Sarg.	Vancouver Is., B.C.	1.4	18	17-20	18	13-20	Brix (1971)

Location from which seed was obtained, not the origin of native stand.

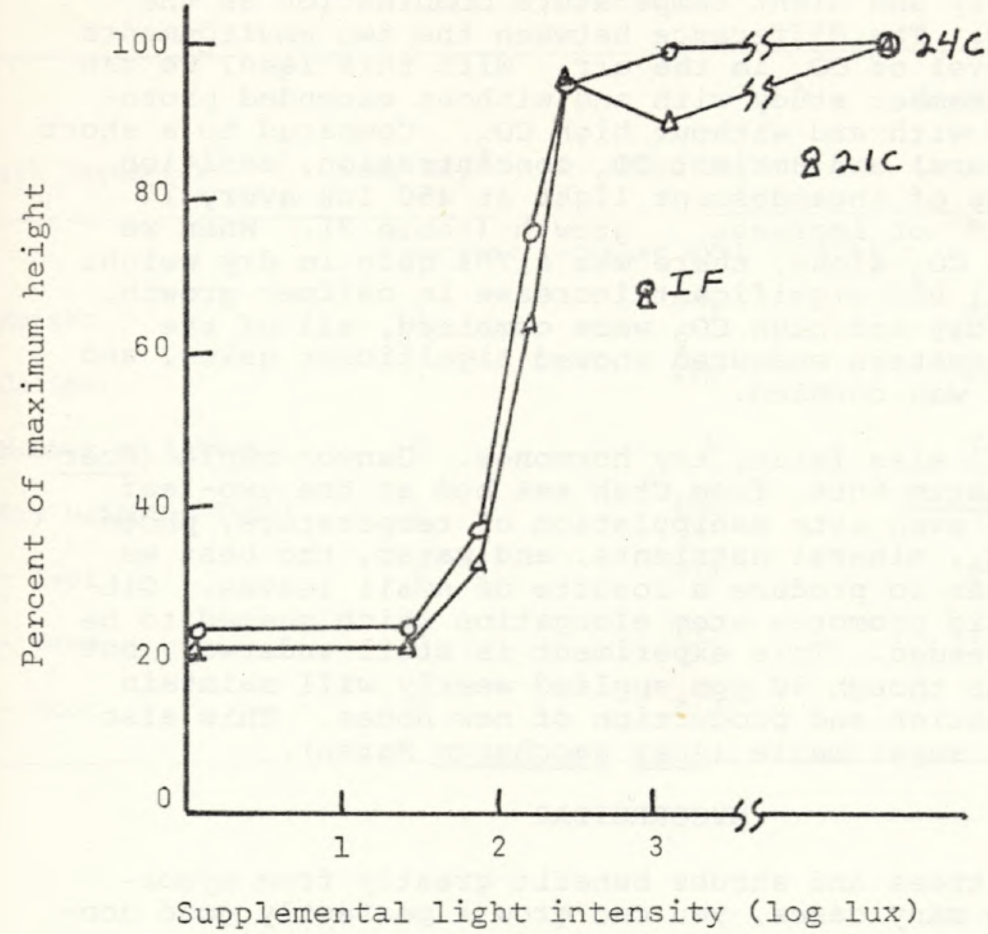


Figure 7.--Height growth response of white spruce to different intensity, duration, and quality of supplemental light. Triangles and circles represent two different seed sources from central and northern Alberta. Unlabeled points are different intensities of incandescent light given 1 minute out of every 15 during the night. IF indicates intermittent fluorescent light on the same schedule. 21C was continuous incandescent light at 1200 lux with a 3 hr dark period. 24C was the same as 21C with no dark period.

If neither photoperiod nor temperature seem to maintain growth, perhaps an interaction between several factors is involved. We noticed that black walnut did not respond to photoperiod in our greenhouse but grew much larger in our growth chamber temperature experiments at the same day and night temperature combination as the greenhouse. The difference between the two environments was the level of CO_2 in the air. With this lead, we ran a growth chamber study with and without extended photoperiod and with and without high CO_2. Compared to a short day (14 hours) and ambient CO_2 concentration, addition of 1 minute of incandescent light at 450 lux every 15 minutes did not increase growth (table 2). When we added high CO_2 alone, there was a 70% gain in dry weight and a small but significant increase in caliper growth. When long day and high CO were combined, all of the growth parameters measured showed significant gains, and dry weight was doubled.

If all else fails, try hormones. Canyon maple (*Acer grandidentatum* Nutt. from Utah set bud at the two-leaf stage, and even with manipulation of temperature, photoperiod, CO_2, mineral nutrients, and water, the best we could do was to produce a rosette of small leaves. Giberellic acid promotes stem elongation which seemed to be what was needed. This experiment is still underway, but it looks as though 50 ppm applied weekly will maintain stem elongation and production of new nodes. This also works with sugar maple (*Acer saccharum* Marsh).

MYCORRHIZAE

Most trees and shrubs benefit greatly from mycorrhizae. In many cases, you can grow a perfectly good non-mycorrhizal tree, but the margin for error in disease control and mineral nutrition is smaller, and the seedling will be at a disadvantage when it goes to the field. In the past, a nurseryman never had to worry about mycorrhizae, because his nursery practices were never clean enough to exclude them. Most bare root conifer nurserymen still do not have to worry, because in humid areas like the East the fungi reinvade quickly after fumigation. Many hardwood trees and shrubs, however, have endomycorrhizae. These organisms do not produce airborne spores and, therefore, do not spread rapidly. So, the nurseryman must be very careful not to kill them out.

The container nurseryman generally uses a sterilized mix and must inoculate his seedlings, if they are to be assured of mycorrhizae. This is especially true in dry climates, where airborne inoculation is not reliable.

Table 2.--Interaction of long day and high CO_2 in the growth percent increase over control of black walnut seedlings. Least significant difference at 5% level is 14%.

Growth Parameter	Long Day	High CO2	High CO2 + Long Day
	- percent increase over control -		
Height	0	0	+40
Caliper	0	+16	+29
Number of leaves	0	0	+14
Dry Weight - Total	0	+70	+102
- Leaf	0	+74	+86
- Stem	0	+51	+151
- Root	0	+75	+99

Currently, the only feasible means of inoculation is to add forest duff to the pot mix. But whether from airborne or duff inoculation, the tree may not be getting the fungus that will do it the most good, and duff inoculation risks introducing pest organisms. The answer is to inoculate with a pure culture of the best possible fungus. This process is in the development stage, and commercially produced mycorrhizal inoculum should be available in a few years.

HARDENING

When growing conditions are optimized for rapid height growth, a spindly, succulent seedling with a high shoot-root ratio is frequently produced. Such trees may be suitable for outplanting under highly favorable conditions, but usually a tougher tree is needed.

I recognize two stages of hardening. The purpose of Stage I is to stop height growth, develop dormant buds, and increase caliper and root growth. The procedure is to leach out the mineral nutrients and then briefly drought stress. This stops height growth and initiates budset. When the seedlings are rewatered, use a nutrient solution with only 10% as much nitrogen as before. At the same time, shorten the photoperiod (turn off the lights at night), lower day temperature about 5°C below optimum, and lower night temperature 5-10°C below optimum. (This may not be possible at all seasons.) This combination of conditions will promote development of dormant buds and continuation of caliper and root growth, for most species tested. The least cooperative species are ones with sympodial growth, such as cottonwood and elm.

During stage I evergreens may be kept under high CO2 which promotes caliper and dry weight growth, but for deciduous trees it must be turned off, as it inhibits leaf drop and may promote bud break and renewed height growth.

The purpose of stage II is to develop cold hardiness and satisfy the bud chilling requirements so they will break promptly. After stage I is completed, which may take 5 weeks, turn off the high CO (if it is not already off), and lower the day and night temperature to 1-3°C. The day temperature may be allowed to reach 10° or more, but the night temperature should not exceed 5°. Do not allow anything to freeze for the first 2 weeks. After that, occasional freezing will not hurt, but the rootballs must not stay frozen for long periods of time unless the tops are covered with snow or are well mulched.

Trees can be hardened conveniently either in a lathhouse or greenhouse, but not in a cooler. Hardening is a very active process that takes photosynthetic energy. If the seedlings do not get enough light, they will not harden. 3-5 kilolux is enough, but most coolers are not designed for that much heat load.

The time required for each stage of hardening depends on the planting season and the site harshness. For late spring and summer planting on favorable sites, perhaps no hardening is required. For less favorable sites or fall planting I recommend 1-5 weeks of stage I. For spring planting, I recommend 5 weeks of stage I followed by 5 weeks of stage II.

CONCLUSION

I have given you some detail on containers, seed germination, temperature requirements, mycorrhizae, how to prevent dormancy, and how to harden. I have not covered all of the aspects that need to be considered.

There are many advantages and great potential for greenhouse container nursery systems. But it should be be realized that success in building and operating these systems requires a high degree of biological knowledge and engineering skill.

[/] For example see Tinus, R. W. (1976) Growth of white spruce and lodgepole pine under various temperature and light conditions. Unpublished report to Alberta Dept. of Energy and Natural Resources, Edmonton, Alta. under cooperative agreement 16-573-CA with USDA-Forest Service, 49 pp.

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