ACCELERATED GROWTH OF HARDWOOD SEEDLINGS

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ABSTRACT

Seedlings of numerous hardwood species have been produced in plantable containers under accelerated growth conditions and established in plantations. These species include *Betula verrucosa*, *B. papyrifera*, *B. alleghaniensis*, *Juglans nigra*, *Prunus serotina*, *Acer saccharum*, *Quercus robur*, *Alnus glutinosa*, *Populus tremuloides*, *P. grandidentata*, *Populus* hybrids, and *Ailanthus altissima*. The systems used to grow hardwoods rapidly and efficiently in the greenhouse are described. Data on survival and growth after outplanting are presented for several species. These new methods offer many advantages over conventional nursery techniques for researchers and commercial nurserymen.

INTRODUCTION

Methods for accelerating the growth of tree seedlings by greenhouse culture are now well established for coniferous species. Nurserymen have been using the accelerated growth concept for several years to produce planting stock in containers more rapidly than is possible in a typical outdoor nursery. Although there is still much opportunity for improvement in techniques, there now is an annual greenhouse production capacity of close to 100 million trees throughout the United States.

In contrast to conifers, the production of hardwood seedlings in containers and greenhouses is rare. Because hardwood species are generally considered more difficult than conifers to establish in plantations, the application of accelerated-optimal-growth methods (Hanover and Reicosky, 1972; Hanover, et al. 1976; Hanover, 1976; Hanover, 1977) seems particularly appropriate. Here we will describe the components of such a system developed at Michigan State University and give some representative results from its application to establish hardwood plantations in a tree improvement program.

COMPONENTS OF ACCELERATED-OPTIMAL-GROWTH

The concept of accelerated-optimal-growth (AOG) of woody plants is based upon the programmed control of growth by the use of light and temperature regimes that prevent growth cessation and dormancy. Control of other environmental factors including water, nutrients, carbon dioxide, and growing media is also necessary to assure that optimum plant development occurs in terms of root-shoot ratio, resting bud quality, stem stiffness, cold hardiness, and storage carbohydrate for regrowth after outplanting. Each of the major environmental factors is listed in Figure 1 (Hanover, 1976) along with other components of our system for producing genetically and culturally superior trees.

Select seed

An essential feature of our program is the use of the best seed sources or clonal materials available whenever possible. Because our primary goal is the breeding and development of improved strains of many species our material is usually destined for progeny test plantations or seed orchards (Hanover and Bongarten, 1977). In either research or commercial applications of AOG this is an important consideration to assure maximum response to the environmental factors imposed.

Container growing system

In order to achieve complete control over tree seedling growth they must be grown in some type of container unit. Containers for this purpose vary greatly and most of those now available have several deficiencies. When we began our work in Michigan, we established the following design criteria for a container system:

1. Flexibility - available in a wide range of sizes; allow movement of individual plants without root disturbance.

2. Durability - to provide support without root egress during greenhouse phases of various durations from 3 to 18 months.

3. Growability - deep, rectangular configuration, open bottom, to allow maximum root development and air pruning of roots.

SELECT SEED OR VEGETATIVE PROPAGULES
(GENETICALLY SUPERIOR)

↓

EFFICIENT, CONTAINER GROWING METHODS

↓

PROTECTIVE CULTURE (GREENHOUSES, ETC.)

↓

PROGRAMMED GROWTH CONTROL
THROUGH THE YEAR:

LIGHT
TEMPERATURE
MINERAL NUTRIENTS
WATER
CARBON DIOXIDE
GROWTH REGULATORS
MYCORRHIZAE
GROWING MEDIA
COMPETITION
PESTS

↓

PRODUCTION OF LARGE "SEEDLINGS"
IN MONTHS RATHER THAN YEARS

↓

ACCLIMATION TO NATURAL CONDITIONS,
SITE PREPARATION, AND PLANTING

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GENETIC SELECTION, HYBRIDIZATION, AND PROPAGATION
OF SUPERIOR GENOTYPES.

Figure 1. Components of the Michigan State accelerated-optimal-growth system.

4. Transportability - fit into a larger unit for support and easy movement in the greenhouse by hand or conveyor; removeable for commercial shipping.

5. Plantability - container may be planted with tree or removed before planting; adaptable to conventional tree planting machines.

6. Biodegradability - to break down in soil after planting allowing free root development.

7. Storability - compact for storage when not in use.

8. Costability - per unit cost under a few pennies.

9. Availability - dependable, long term source, in variable quantities, rapid delivery.

Based upon these criteria we decided upon the square paper plant band made from milk carton stock. These units can be made in any dimension from 2.5 to 15 centimeters square and from 10 to 60 centimeters deep in a range of material thickness. They last in the greenhouse, breakdown in the field, allow good drainage and root development, and they are inexpensive and available from several sources. The plant bands are placed snuggly in plastic cases which are 30 cm. square and have a small mesh bottom to prevent growing media from falling through, yet allow for air pruning of the roots. Our experience with this container system over the past six years leads us to believe that it is the most versatile and suitable one available.

Protective culture

The tree seedling containers must themselves be "contained" in some type of protective culture or controlled environment facility. In most cases this is a greenhouse although we also grow in well-insulated buildings using artificial light only (Hanover et al. 1976). There are numerous strategies for using the greenhouse in combination with other facilities such as shade houses to minimize energy costs and condition plants but they will not be discussed here.

Programmed growth control

Light: Light has two functions in the AOG system, (1) provide energy to drive photosynthesis to substain rapid growth, and, (2) provide the trigger or regulatory mechanism to prevent dormancy of the seedlings. Photosynthetic light must be of relatively high intensity (50 to 1500 $\mu E\ m^{-2} s^{-1}$) and sufficient duration to maintain a high net photosynthetic rate for dry matter accumulation. The regulatory light may be of very low intensity (5-10 $\mu E\ m^{-2} s^{-1}$) in the red or 660 mμ wave length for brief periods during the night. The plant pigment phytochrome is responsible for mediating dormancy prevention through the light energy (Downs and Borthwick, 1956; Hanover 1976). In order to control tree growth with light it is important to know the specific responses shown by each species of interest because there is much genetic variation in their reactions to both light types.

There are several choices as to source of supplemental light in an AOG system. However, to activate phytochrome and thereby prevent inception of dormancy in seedlings it is important to maximize the ratio of red (666 mμ) to far red (730 mμ) light in the source. We use cool white fluorescent lighting because it provides this balance more effectively than do incadescent sources as shown in data below from Holmes and Smith (1975):

Light Source	Red/Far-red	Active Phytochrome / Total phytochrome ratio in plant
Mid day daylight	1.08	0.60
Incandescent	0.71	0.55
Fluorescent	13.5	0.76
Red light	20.1	0.80
Far-red light	0.002	0.04

Temperature: Although supplemental light predisposes tree seedlings to continuous growth, temperature regimes of both the aereal and root environment are important for optimal development at all stages. Thus, a growing facility must provide a reasonable degree of day-night temperature control for the germination, free growth, bud set, cold hardiness induction, and chilling phases of production. A constant day-night temperature near 22°C during the germination, growth and bud set phases is suitable for some but not all species. Temperatures above 30°C for prolonged periods should be avoided.

Mineral nutrients: A deficiency in a given mineral nutrient will not only result in growth reduction but can also counteract the long day supplemental light regime and induce temporary dormancy of seedlings (Young and Hanover, 1978).

The mineral nutrient status of tree seedlings produced in containers is relatively easy to control once species optima are determined. As an example and general guideline, the optimum proportions of nutrients both in the tissue and the starting solution for birch setting N at 100 ppm have been determined by Ingestad (1971) as follows:

Macronutrients		Micronutrients	
N	100	FE	0.7
K	65	Mn	0.4
P	13	B	0.2
S	9	Cu	0.03
Ca	7	Zn	0.03
Mg	8.5	Cl	0.03
		Mo	0.007
		Na	0.003

These proportions of nutrients will vary somewhat with species and even seed source. In addition, the availability of nutrients to the seedling depends on pH of the growing media which, for conifers, should be in the range of 4.5 to 5.5. Less is known about hardwood pH requirements but they are generally above that of conifers, up to pH 7. Further information about mineral nutrition of seedlings is given by Brix and Van den Driessche (1974).

Water: Maintenance of proper water levels in container-grown trees is one of the most crucial and difficult tasks. This is especially true when hardwood seedlings attain a full leaf complement making water penetration to the container media difficult. In our experimental greenhouses we water completely by hand but still experience some difficulty maintaining uniformity. Use of moisture probes and systematic container weighing schedules help to prevent temporary desiccation or overwatering. Either of these situations may lead to growth reduction and induce dormancy of the trees (Young and Hanover 1978).

Carbon dioxide: Atmospheric levels of CO_2 are usually limiting to photosynthesis and growth of plants. Therefore, greenhouse culture systems offer an excellent opportunity to increase growth by CO_2 "fertilization". In atmospherically controlled experiments with black walnut (*Juglans nigra*) we have measured an 80% increase in total dry weight and 93% increase in height at 12 weeks by exposing seedlings to a 2000 ppm CO_2 atmosphere compared with ambient levels in the greenhouse (Table 1).

The effects of CO_2 on seedling growth are multiple. It not only is rate limiting as a reactant in photosynthesis but in tree species high levels of CO_2 depress photorespiration thereby further increasing net photosynthesis (Goldsworthy, 1976). Moreover, an increase in CO_2 concentration usually allows the tree to utilize light more efficiently than at ambient CO_2 levels.

Although enriched CO_2 atmospheres are hard to achieve when greenhouse vents are open, efforts should be made to accomplish this control because of its benefits to tree growth.

Growth regulators: In contrast to ornamental flowering plants, relatively little research or practical application has been done with chemical growth regulators on tree seedlings in greenhouses. This situation should change as more sophisticated control of tree growth is sought because of the great potential of growth regulators for modifying elongative growth, bud set, leaf abscision, and cold hardiness.

Table 1. Effects of carbon dioxide fertilization on growth of black walnut seedlings in a greenhouse.

CO_2-Conc. (ppm)	Total Dry Weight (g)	Root/Shoot ratio	Height (cm)			Leaf Area (cm^2)
			4 wks	8 wks	12 wks	
ambient (500-700)	10.5 a[1/]	1.76 a	21.3 a	24.6 a	25.7 a	812 a
1,000	15.4 b	1.65 a	21.2 a	36.5 b	37.1 b	1740 b
2,000	18.9 c	1.20 b	25.0 a	49.4 c	50.6 c	1457 b

[1/] Values in columns not followed by the same letter are significantly different at the 5% level of probability.

Mycorrhizae: There is general agreement among growers that mycorrhizal inoculation of tree seedlings in containers is desirable. Mycorrhizae could reduce the quantities of fertilizer required in the greenhouse. But more importantly, they allow the tree to be more effective in nutrient uptake once the trees are planted on sites which are often depleted of nutrients. At this time it is difficult to inoculate in a greenhouse where fertility levels are high and the appropriate mycorrhizal associates of a species are unknown.

Growing media: Selection of the proper rooting media for containerized seedlings is vital to the AOG system. Adequate moisture retention, aeration, bulk density, and cation exchange capacity are requisites of the media to prevent low vigor and mortality of the trees. We use a mixture of coarse sphagnum peat moss, vermiculite, and perlite (1:1:1, V:V:V) in our hardwood program. Other choices include various combinations of soil, bark, sand, sawdust, etc. However, most growers use the peat-vermiculite combinations and commercial preparations of these materials are also readily available in sterile form. Because of its low cost, availability, and potential antibiotic properties, ground bark may become a common replacement or additive for peat in the future.

Competition: Weeds and neighboring tree seedlings provide competition for containerized hardwood seedlings. Our growing medium is virtually free of weed seed so occassional hand weeding is an effective control. Tree seedlings in adjacent cells are a definite problem. The problem is accentuated with species like black walnut and the oaks which often do not germinate in synchrony thereby leading to shading as the early germinats overtop late ones in a case. Initial seed spacing for most of our hardwoods is 36 per square foot in a 5 cm square plant band. This spacing usually results in 20 to 36 trees for planting, depending upon species.

Pests: Greenhouse pests include insects, fungi, rodents or nematodes. Rodents are rare and are easily controlled. We have also had no problem with nematodes. The pests most damaging to containerized trees are fungal disease organisms and insects. Root rot fungi are insidious and devasting to a greenhouse crop. Therefore, it is essential that a systematic drenching schedule be maintained using Benlate plus Dexon, Banrot, or other effective fungicides even when sterilized media are used. Occassionally, insects will build up in damaging numbers but these too are controlable by the judicious use of insecticides.

Production of large seedlings

There is growing evidence that the use of large rather than small seedlings for planting stock results in better survival and the lowest total cost per living tree (Newton, 1976; Phares and White, 1972). Larger seedlings are also likely to grow more rapidly than small ones which can mean shorter rotations. For ornamentals and high value hardwoods decreasing the time required to produce a salable tree would justify higher initial seedling costs.

The main disadvantage to large seedlings is their bulkiness which makes transporting and planting more difficult. However, these problems can be overcome at a cost and, of course, the cost must be overbalanced by the increased return from better survival and shorter rotation ages.

Our AOG program for both hardwoods and conifers is based on producing large seedlings without sacrificing high for low root-shoot ratios. To accomplish this our containers have a minimum volume of 700 cu. cm. and height of 27 cm. By growing in the large containers we are able to stimulate rapid shoot growth yet maintain stem stiffness and massive root systems for most hardwood species. Those species with a taproot develop the main root which is naturally airpruned when it reaches the bottom. Then a fibrous root system forms off the main root resulting in a balanced root system. Thus, the damage and subsequent shock associated with undercutting seedlings in a bare root nursery is avoided.

Acclimation to natural conditions, site preparation and planting

Greenhouse growing conditions usually provide much higher humidity, lower wind speed, and lower light intensity and different spectrum than exist in the outdoor nursery. When greenhouse-grown trees are moved outside, there is likely to be an increase in transpiration rate and bleaching of the leaves. We have found that some species such as the oaks, birches, alders, and poplars can be outplanted directly from the greenhouse without serious shock. Species such as black walnut, however, require an acclimation period in a protected shadehouse facility to prevent immediate leaf fall and mortality. In general, all hardwood species benefit from a conditioning treatment of at least several weeks to make the transition from greenhouse to the field.

It is almost axiomatic that the key to successful establishment of hardwood plantations is some site preparation prior to planting (McGee, 1977; Phares and White, 1972; Dickmann, Heiligmann, and Gottschalk, 1977; Shipman, 1974). Site preparation may range from complete cultivation and use of herbicides to no cultivation or chemical treatment for weed control. Our methods for old field plantings usually do not include cultivation although on many sites this would be desirable to increase soil aeration. We remove tall vegetation by mowing followed by spraying planting strips with amitrol-T at 8 l/ha (3 qt/ac), simazine at 2.2-5.6 Kg active ingredient per ha (2-5 lb/ac), or Roundup at 5.4 l/ha (2 qt/ac) depending upon time of the year, soil conditions, species, and planting time (fall, summer, or spring). Post-planting weed control is also recommended whenever competition is severe but this step is minimized through use of large seedlings.

Our procedures for the planting phase in establishing hardwood plantations include use of a Cannon auger planter, a Quickwood hydraulic interval planter, and a more conventional machine which creates a furrow into which the tree is placed followed by packing wheels. Each of these machines is suitable for planting large seedlings with or without the plant band around the roots. Which machine is used depends largely on the terrain and amount of ground debris. Both the Cannon and Quickwood can be used on rough ground whereas the furrow planter is suited only for relatively level, open fields.

Genetic selection and hybridization in hardwood plantations

Once a hardwood planting is successfully established it constitutes a progeny test, breeding arboretum, or seed orchard for our genetic improvement program in Michigan. Recently, we have begun research on hardwood plantings that are to serve as energy plantations to provide animal feed, fiber, and chemical feedstocks. Although the end use of our hardwood plantations is for research purposes we attempt to develop the biological and mechanical methodology in such a way as to be directly applicable to commercial operations.

SURVIVAL AND GROWTH OF AOG HARDWOODS

Greenhouse phase

We have grown many hardwood species under a standard set of accelerated-growth conditions. Few of these species fail to show substantially more rapid and substained growth than can be achieved in the outdoor nursery (Hanover, et al. 1976; Hanover, 1977). The few instances when growth stimulation did not occur, such as pin oak and hawthorne, may have been caused by imposition of non-optimal growing conditions for these species. When the optimum conditions are worked out for each species the AOG methods will probably be applicable to all woody plants.

Each hardwood species possesses an inherent pattern of primary shoot growth (Zimmerman and Brown, 1971) which governs their response to accelerating conditions after germination. These patterns vary from a single flush followed by formation of a dormant bud (determinate type, e.g., black walnut) to those exhibiting a sustained flush of growth as long as conditions permit (indeterminate-type, e.g., northern white birch).

There are many intermediate types of response among hardwood species. For example English Oak (*Quercus robur*) and sugar maple (*Acer saccharum*) grow in a series of recurrent flushes in the greenhouse. Any of the hardwoods can be induced to enter dormancy if stresses are applied during the growth phase but some like walnut and sugar maple are more prone to growth cessation than others. An important aspect of the AOG system for hardwoods is to know the specific requirements of each growth factor for a species in order to optimize development in the greenhouse.

In our production system we attempt to grow a hardwood to heights of from 40 cm to 100 cm in a period of 12 to 20 weeks depending upon species. The trees are programmed for planting anytime between April 15 and September 15 and may be actively growing or dormant. Growing schedules for many species are being developed but are too detailed to cover here.

An example of optimum growth and development of a hardwood species, black walnut, under AOG conditions compared with that obtained in two outdoor nurseries is given in Table 2. After 12 weeks of greenhouse culture, growth and development of the seedlings exceeded those grown in the nurseries for the entire growing season. In general these results are typical of those obtained for other species in our program including *Betula verrucosa, Betula papyrifera, Betula alleghaniensis, Prunus serotina, Acer saccharum, Quercus robur, Alnus glutinosa, Populus tremuloides, Populus grandidentata, Ailanthus altissima, Plantanus occidentalis, Gleditsia triacanthos, Fraxinus pennsylvanica, and Liriodendnon tulipifera* as well as many other exotic species.

Plantation phase

After the seedlings produced in the greenhouse have been properly conditioned in a windbreak or shadehouse they are transported in the plastic containers to our test plantations and planted in the previously prepared strips. Planting is done as described above in replicated designs.

During the course of developing the AOG system for hardwood species we have experienced many failures or partial successes. Usually, poor success in the plantation establishment phases can be attributed to improper site or species selection, inadequate weed control before or after planting, animal damage, drought, or improper condition of stock prior to planting. Other workers have arrived at similar conclusions in establishing plantations with bareroot stock (von Althen, 1977). When losses due to each of these factors are minimized a successful hardwood plantation results with use of AOG planting stock.

Although our oldest AOG hardwood plantations are only 3-years-old some have been successful (Table 3.). When the trees were planted without removing them from the plant bands no detrimental effects were evident other than a slight restriction of upper lateral root development. To overcome any possibility of container affects in the future we use bands that have several random holes on each side or we remove the band at planting.

Table 2. Mean growth and development from seed of black walnut seedlings under accelerated growth conditions for 12 weeks versus two outdoor nurseries for one growing season.

Trait	Container dimension (cm)				Outdoor Nurseries	
	Depth		Width			
	28	56	5	10	#1	#2 1/
Height (cm)	58 a2/	76 b	61 a	76 a	21	52
Days to budset	69 a	76 a	70 a	72 a	41	-
Total dry weight (g)	63 a	94 b	65 a	88 a	10	16
Leaf area (cm^3)	4908 a	7396 b	5316 a	6965 a	595	934
Root/Shoot ratio	0.59 a	0.45 a	0.63 a	0.75 a	0.49	0.60
Tap root dry weight (g)	17 a	26 b	18 a	27 a	2.3	4.5

1/ Nursery No. 1 was Michigan State University with a bulked Michigan/Indiana seed source; Nursery No. 2 was a commercial nursery using a southern Indiana seed source.

2/ Means followed by the same letter are not significantly different within a comparison of depths and widths.

Table 3. Growth and survival of several hardwood genetic plantations established with stock produced in containers in the greenhouse. Spacing of trees is usually 2.4 m x 2.4 m.

Species	Location of Plantation	Year Planted	Survival (%)	Mean Height in 1978 (m)	Range in Height (m)
Ailanthus	Augusta, Mich.	1976	96	1.2[1/]	up to 2.3
Ailanthus	Dowagiac, Mich.	1976	82	1.0[1/]	up to 2.6
Trembling aspen	Dowagiac, Mich.	1976	38	0.6	0.2 to 1.0
Bigtooth aspen	Dowagiac, Mich.	1976	38	0.5	0.3 to 0.9
White birch	Dowagiac, Mich.	1976	63	1.7	0.3 to 4.5
Yellow birch	Augusta, Mich.	1978 (April)	59	0.6	0.2 to 0.9
Sugar maple[2/]	Augusta, Mich.	1978 (April)	74	0.7	0.2 to 1.2
Walnut	St. Clair, Mich.	1977	71	0.3	0.1 to 0.6

1/ All shoots were killed during hard frosts in 1976 and 1977. Further details on this plantation are in Dickmann, Lemmien, and Kowalewski (1976).

2/ Stock produced by W. Gabriel, Northeast Forest Experiment Station, U.S.F.S., using similar AOG system.

It is evident from the survival data in Table 3 that there is still room for improvement in our techniques. It should also be emphasized that most of these test plantings are composed of a diversity of seed sources which tends to decrease overall survival and growth compared with what might be expected using the best adapted source for the planting area.

From the positive results obtained with a range of hardwood species we conclude that the AOG concept can be applied to both research and commercial operations. By so doing and with further refinement in procedures for each species these methods should expedite genetic or cultural testing of hardwoods and allow commercial nurserymen to produce higher quality seedlings more rapidly.

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