A NEW CONCEPT FOR HARDWOOD REGENERATION

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Thomas Jay Stadt

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ABSTRACT

A NEW CONCEPT FOR HARDWOOD REGENERATION

By

Thomas Jay Stadt

Hardwood seedlings have been conventionally grown in nursery beds which are always under the influence of climatic uncertainties. A new approach advocated here is to optimize the plant system to produce large seedlings in the shortest time possible. This Accelerated-Optimal-Growth (AOG) concept uses extended photoperiods under programmed environmental conditions.

Twenty economically important hardwood species were examined for their general response to supplemental light. Five fold increases in height between the greenhouse grown, 24 hour photoperiod and nursery grown seedlings were not uncommon.

The response of six hardwood species was then studied at different spacings with either restricted or non restricted root development. The spacings ranged from 5 cm. to 14 cm. in .03 cubic meter plastic cases. The restricted root development was produced by inserting plastic coated cardboard plant bands into the plastic cases. Most species showed no significant height or diameter differences between spacings. However, there were significant differences between seedlings with and without plant bands. Seedlings without plant bands were 28 to 30 percent

taller than seedlings with plant bands. Analysis of growth parameters was performed on three of the six species in the spacing study and showed no significant reduction in the growth at the different spacings and root restrictions studied.

Survival of AOG hybrid cottonwood outplantings were compared to plantings with unrooted cuttings. Survival between clones varied greatly, however planting large, full leaf AOG cottonwoods in mid-summer can be performed satisfactorily. The Quickwood Tree Planter is introduced as the newest and probably most automated intermittent furrow planter useful in containerized planting.

A NEW CONCEPT FOR HARDWOOD REGENERATION

By

Thomas Jay Stadt

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INTRODUCTION

Current problems in hardwood regeneration

Hardwoods are becoming increasingly important to the timber industry because of the increased demand for high quality sawtimber and high yielding fiber production systems. Hair (1974) projects that the demand for paper and paperboard will more than double between the years of 1970 and 2000, while projections for lumber and pulpwood also show substantial increases.

Hardwood seedlings, in the past, have been produced in outdoor nursery beds by seeding, growing the seedlings for several years, then often transplanting and growing to the desired height and caliper, perhaps after a second transplant. There are, however, many inherent problems associated with growing seedlings, especially hardwoods, in outdoor nurseries. These problems can be divided into two general categories.

The first problem concerns the slow growth of seedlings due to climatic uncertainties. These impositions on the seedlings include unseasonable frosts, torrential rains and flooding, damaging wind and extremes of heat and cold which result in slow periodic growth, deformation, or death of trees.

The second problem deals with the cultural procedures of undercutting, lifting and bare-rooting. This drastic reduction of root volume has been shown to have detrimental effects on the seedling after outplanting. In most bare-root operations, for example, survival rates of 50 percent are considered acceptable, and very often much lower rates are obtained.

The low survival rate commonly accepted by growers is due mainly to a lack of knowledge of proper hardwood regeneration techniques resulting primarily from the emphasis on production of conifers in the past. Abbott (1973) points out that this lack of knowledge must change or hardwoods will soon be in short supply.

Other stresses are routinely imposed on seedlings in addition to root disturbances which give low survival. The potentially rapid growth of hardwoods during the juvenile phase of growth is sometimes decreased substantially when bare-root practices are used. Walnut and oak species, for example, have a characteristic taproot that is drastically cut back during lifting procedures. After these bare-root seedlings are outplanted they are expected to put on little or no growth the first year after outplanting or they are cut back and allowed to sprout from the root system (Bey, 1972). This has a tendency to produce undesirable multiple stemmed and forked trees.

An alternative method for regenerating hardwoods successfully which is advocated here is to grow and plant larger yet less disturbed seedlings than is now done. By establishing larger seedlings, other problems such as weed competition and snow and rodent damage may also be minimized.

As the demand for short rotation increases, the need for a better way to put land into production as soon as possible increases. This should bring about a willingness among nurserymen to use protective culture and minimize seasonal constraints which now limit the use of bare-root stock.

A new approach to hardwood regeneration

A new approach for producing large seedlings with high outplanting survival rates in being developed at Michigan State University. The approach centers around the concept of optimizing the plant system to produce large seedlings of outplanting size in the shortest time possible. This Accelerated-Optimal-Growth (Accel-O-Gro or AOG) concept (Hanover et al, 1976) combines the use of extended photoperiods under programmed environment conditions with genetically superior seed. Under these conditions, large seedlings suitable for outplanting with minimal amount of root disturbance are being produced. The basic elements of Accel-O-Gro are listed in Table 1 and were used as a basis for this study.

The objectives of this study were:

1. To test the feasibility of Accel-O-Gro methods to produce large containerized hardwoods suitable for large scale regeneration.
2. To test the effects of container spacing on tree growth.

Factors to consider in protective culture of hardwood species

The concept of the protective culture system is to grow trees in an environment that is programmed for the optimum growth of a particular

Table 1. Basic elements of the Accel-O-Gro concept.

1.	Use of genetically superior seed and propagules.
* 2.	Produce trees economically in protected environments such as greenhouses.
* 3.	Growth of trees in plantable containers.
4.	Use of programmed environments for year-round tree culture.
* 5.	Rapid production of substantially larger than normal trees for outplanting.
6.	Production of non-native and difficult to grow species.
* 7.	Minimal hand labor from seeding to final planting.
8.	Maximum use of techniques that minimize power requirements.
* 9.	Planting methods that assure high survival after trees are established.
*10.	Extension of planting seasons by using large seedlings in full leaf.
11.	Establishment of planting methods to minimize weed competition and animal damage.

* Elements focused on in this study.

species. To achieve optimum growth, Larson (1974) states that the genetic constitution of the seedlings must be pushed to its upper limits and this is one of the areas in which knowledge is severely lacking.

Even though exact optimum conditions are not yet known for each tree species, there are major environmental factors that can be manipulated to promote better growth. The main factors have been discussed extensively by many authors (Hanover, et al, 1976; Krizek, et al, 1970; Larson, 1974) and are listed below:

1. Photoperiod
2. Light intensity
3. Light quality
4. Soil and air temperatures
5. Carbon dioxide concentrations
6. Water relations
7. Mineral nutrients
8. Air movement
9. Insects and disease control
10. Endogenous and exogenous hormone levels

When viewing a programmed environment for trees from an economic standpoint, optimum conditions that are feasible and yet productively possible have not been achieved. Besides supplemental light in a controlled environment situation, the objective of this study was to determine growth and development patterns of several hardwood species grown in a container system at different spacings.

Containers

Proper shoot to root ratios are important to optimal seedling development. This ratio could be a key factor in the duration of continual growth a seedling undergoes. Borchert (1973) proposes that rhythmic growth of trees results from feedback interactions between the shoot and root which in themselves are potentially linear processes. He suggests that the slower process is rate limiting for the faster one. The importance of limiting factors was first proposed by Blackman in 1905, who stated that "when a process is controlled by a number of separate factors, the rate of the process is limited by the rate of the 'slowest' factor." This concept has been proven to be true in many cases and probably is also pertinent to the relative role of root and shoot development in tree growth (Eliasson, 1968; Richardson, 1953). The container, therefore, should not limit root growth appreciably while in the greenhouse and it should allow free expansion of the roots after outplanting.

Spacing

The optimal development of root and shoot is also affected by the spacing at which containerized seedlings are grown. Shading and consequent reduction in effective leaf surface area will result when seedlings are grown too close to one another. Desired height and caliper of seedlings should first be determined and then the desired spacing considered. Uniformity of growth is of primary importance when growing seedlings at close spacings. The use of genetically superior, relatively uniform seed and techniques to assure uniform germination should produce uniform stock. Such uniformity of growth not only allows faster growth due to decreased competition for light, but also reduces grading and handling costs.

PART II. A MODEL SYSTEM: ACCEL-O-GRO

Introduction

The Accel-O-Gro system includes all factors and procedures pertaining to optimum growth conditions and successful regeneration of tree species. This study began under the previously stated assumption that little is known about optimum growth conditions for hardwood species. Using AOG techniques, a progression of studies was conducted to further pinpoint conditions needed for optimal growth of certain hardwood species.

Garner and Allard (1920) were instrumental in showing that environmental factors such as extended photoperiods increased growth and decreased the length of time to flowering in many plants. It was not until the 1950's that this concept was applied to woody plants. Early work in this field was accomplished by such workers as Vaartaja (1959), Nitsch (1957), and Downs and Borthwick (1956).

The early photoperiodic work with trees opens up new possibilities in hardwood regeneration. The first application of Accel-O-Gro was used by Hanover and Reicosky (1972) for early testing of spruce seedlings. They showed that a favorable response by trees to extended photoperiods could be used to further increase growth by completely bypassing dormancy cycles that occur in the natural environment.

The first experiment described here was conducted to possibly add more hardwood species to the list of those that are known to respond favorably to extended photoperiods. Twenty economically important hardwood species, either for timber or ornamental purposes, were evaluated under a programmed environment as to their response to continuous light.

The effects of different seedling spacings and root volumes have been studied in coniferous species (Hocking and Mitchell, 1975; Scarratt, 1972). However, hardwood species have received little attention in this regard. This problem was focused upon in the second experiment which was concerned with the determination of a shoot spacing and root volume system that was optimal and yet feasible in hardwood production situations. Growth and development patterns were studied for six hardwood species in a container system at different shoot spacings and root volumes.

Light Response

Materials and Methods

To determine their general responses to supplemental light, twenty hardwood species were compared in three environments: (1) Greenhouse, 24 hour photoperiod; (2) Greenhouse, natural photoperiod; (3) Nursery grown. Greenhouse and nursery facilities were located at the Michigan State University Tree Research Center near East Lansing, Michigan.

Greenhouse temperature was maintained at approximately 22°C day and night throughout the six-month growth period. Supplemental light was provided by VHO, cool white fluorescent lights which produced 700-800 ft-c two feet above the trees.

In March, 1974, 1-0 nursery stock was planted in 18 cm. diameter x 23 cm. deep polyethylene pots, whereas nursery seedlings were grown directly in the ground. The seedlings were watered regularly as needed, and fertilizer was applied regularly to the greenhouse and nursery stock to maintain adequate levels of nutrients.

Three replications of five trees each were represented in a treatment. Height growth of the seedlings was measured 10 weeks and 20 weeks after planting. Poor nursery stock resulted in poor survival for some species. Therefore, measurements were taken of the eight tallest trees in each treatment. The heights of these trees were used for the analysis of treatment differences.

Results and Discussion

In most cases the greenhouse grown, 24 hour photoperiod treatment gave a greater height increment than other treatments (Table 2, 3).

Due to the decrease in natural photoperiods from June to September, the largest differences between the 24 hour photoperiod treatment and the other treatments showed up in the September measurements. The September measurements also showed statistical significance that could be separated into two major categories.

Category 1

In this category were species in which the height growth in the supplemental light treatment was statistically greater than in natural photoperiods of either greenhouse or nursery. Most of the species fit into this category including: red quince, Russian olive (Fig. 1), hackberry, tartarian honeysuckle, smoke tree, tulip poplar, sycamore, black cherry, eastern cottonwood, autumn olive, and Norway maple.

Table 2. Mean height increment (cm.) of hardwood species in greenhouse light trial after 10 weeks. All species were one-year-old transplants at beginning of test in April, 1974.

Species	Treatment 1/			
	I	II	III	$\frac{I - III}{III}$ x 100
				Percent
Pin oak	5.5 a 2/	2.3 b	5.3 a	0
Red quince	20.1 a	10.1 b	7.9 b	150
Russian Olive	18.3 a	6.1 b	3.4 b	440
Hackberry	12.7 a	7.1 b	7.6 b	70
Tartarian honeysuckle	18.7 a	7.6 b	5.5 b	240
Smoke tree	1.5 a	1.5 a	1.4 a	0
Tulip poplar	4.3 a	2.1 a	1.4 b	230
Sycamore	22.5 a	13.7 b	7.7 c	190
Sugar maple	11.4 a	4.2 b	4.0 b	190
Honeylocust	22.0 a	6.0 b	2.9 b	660
White birch	49.9 a	60.1 b	11.9 c	320
Black cherry	62.9 a	27.4 b	20.9 b	200
Green ash	32.8 a	8.5 b	6.7 b	390
E. Cottonwood	43.4 a	34.6 ab	17.4 b	150
Rose of Sharon	13.4 a	6.1 b	3.4 c	290
Silver maple	15.9 a	7.8 b	6.3 b	150
Autumn olive	14.9 a	11.9 b	5.5 c	170
Red dogwood	28.1 a	22.7 b	13.9 c	100
Norway maple	3.3 a	2.2 b	2.4 ab	0
Hawthorne	21.1 a	24.2 a	25.0 a	0

1/

I = Greenhouse grown, 24 hour photoperiod provided by fluorescent, VHO, cool white which provided about 700-800 ft. candles 2 feet above the trees. Greenhouse seedlings grown in 7" x 9" polyethylene pots.

II = Greenhouse grown, natural photoperiod.

III = Nursery seedlings grown directly in the ground.

2/

Any two means for a species are not significantly different at the LSR 5 percent level if followed by the same letter.

Table 3. Mean height increment (cm.) of hardwood species in greenhouse light trials after 20 weeks. All species were one-year-old transplants at beginning of test in April, 1974.

Species	Treatment [1/]			
	I	II	III	$\frac{I - III}{III} \times 100$
				Percent
Pin oak	10.4 a [2/]	2.3 b	11.8 a	0
Red quince	52.5 a	25.3 b	22.0 b	140
Russian olive	74.4 a	42.3 b	34.3 b	120
Hackberry	67.6 a	20.4 b	14.1 b	380
Tartarian honeysuckle	74.1 a	12.1 b	15.9 b	370
Smoke tree	57.9 a	1.5 b	6.2 b	830
Tulip poplar	40.6 a	8.1 b	9.3 b	340
Sycamore	92.1 a	54.6 b	38.8 b	140
Sugar maple	27.1 a	8.9 b	14.6 ab	90
Honeylocust	75.8 a	45.1 b	21.5 c	250
White birch	128.4 a	123.3 a	26.6 b	380
Black cherry	118.3 a	63.4 b	41.6 b	180
Green ash	58.5 a	19.9 b	35.4 ab	60
E. Cottonwood	163.9 a	99.0 b	90.3 b	80
Rose of Sharon	54.2 a	34.0 b	16.3 c	230
Silver maple	111.6 a	48.9 b	24.0 c	360
Autumn olive	61.1 a	37.2 b	28.3 b	120
Red dogwood	79.5 a	38.3 b	46.3 c	70
Norway maple	36.8 a	2.3 b	6.4 b	470
Hawthorne	21.1 a	24.2 a	25.0 a	0

1/

I = Greenhouse grown, 24 hour photoperiod provided by fluorescent, VHO, cool white which provided about 700-800 ft. candles 2 feet above the trees. Greenhouse seedlings grown in 7" x 9" polyethylene pots.

II = Greenhouse grown, natural photoperiod.

III = Nursery seedlings grown directly in the ground.

2/ Any two means for a species are not significantly different at the LSR 5 percent level if followed by the same letter.

Figure 1. (A) Russian olive grown for 20 weeks in outdoor nursery.

(B) Russian olive grown for 20 weeks in the greenhouse under natural photoperiod.

(C) Russian olive grown for 20 weeks in a greenhouse under 24 hour photoperiod.

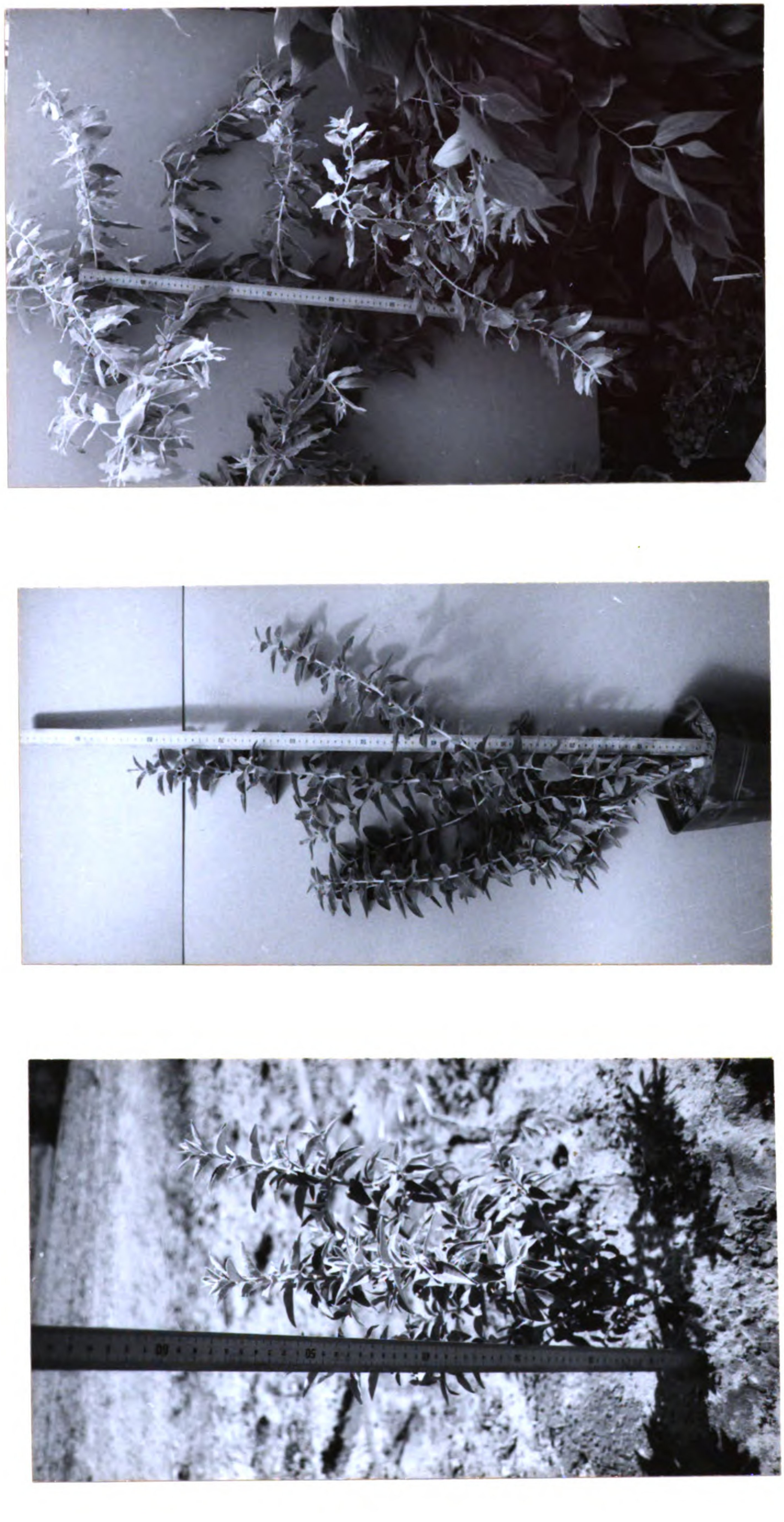


Figure 1. (A) (B) (C)

Category 2

Trees included in this category showed significant height growth differences between all three treatments. A greater height growth over nursery stock was obtained by using a programmed environment and still greater using a programmed environment with continuous light. Species included in this category were: honeylocust, rose of sharon, silver maple (Fig. 2), and red dogwood. White birch also showed this trend, but differences were not significant. Apparently white birch depends more on optimum temperature than extended photoperiods for increased growth.

Irregular growth between, as well as within, species caused shading and overtopping effects to occur in the greenhouse. Despite this uneven growth, five fold increases in height between the 24 hour photoperiod and nursery stock were not uncommon.

Spacing

Materials and Methods

Seedlings of European white birch (*Betula pendula* Roth), hybrid aspen (*Populus canescens* x *grandidentata*), European black alder (*Alnus glutinosa* 1. Garetn.), sugar maple (*Acer saccharum* (Marsh), black walnut (*Juglans nigra* L.), and ailanthus (*Ailanthus altissima* Mill.), were grown at Michigan State University's Tree Research Center under a 24 hour photoperiod using supplemental fluorescent light. Other greenhouse conditions were the same as the Hardwood Light Response study. Seeds

Figure 2. (A) Silver maple grown for 20 weeks in outdoor nursery.

(B) Silver maple grown for 20 weeks in the greenhouse under 24 hour photoperiod.

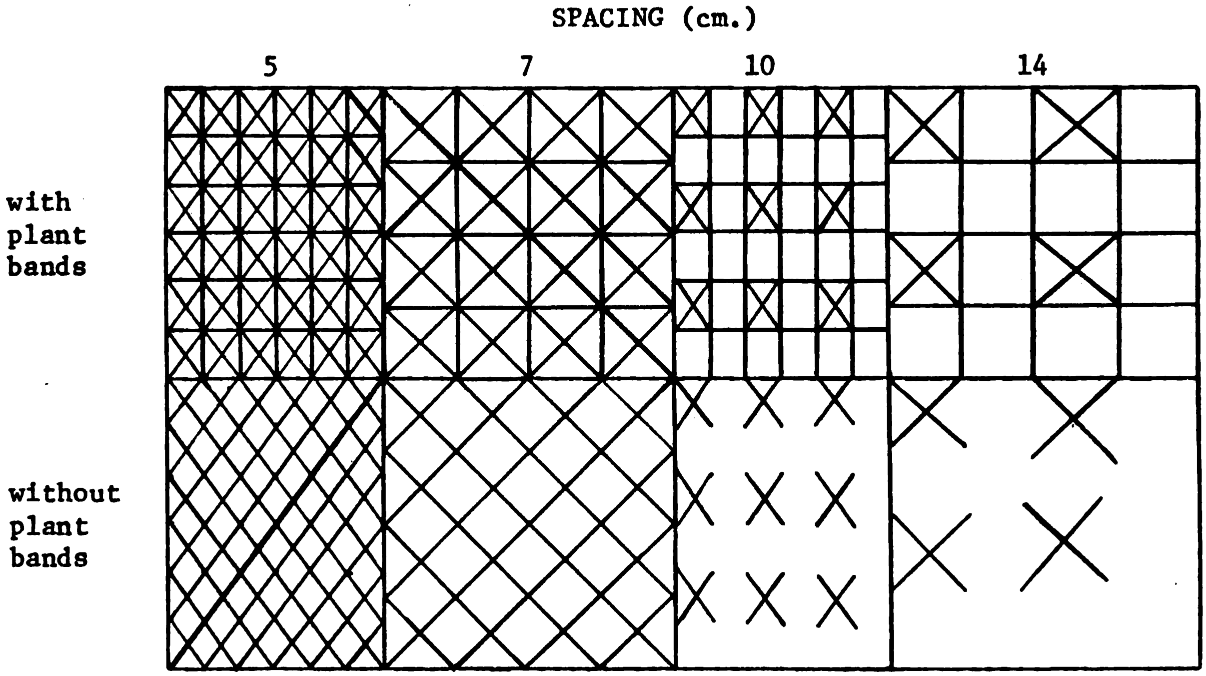
Figure 2. (A) (B)

were sown on March 29, 1975, in .03 cubic meter plastic cases with either restricted or non-restricted root development. The spacings, based on possibilities for practical use in greenhouses were 5, 7, 10, and 14 centimeters.

The restricted root development was produced by inserting polyethylene coated paperboard plant bands into the plastic cases (Fig. 5. (B)). The 10 and 14 centimeter spacings in restricted root treatments were obtained by sowing alternate 5 and 7 centimeter plant bands, respectively. Potting mixture consisted of 1:1, peat:vermiculite. Fertilization began three weeks after sowing. A weekly alternation of Peters 20-20-20 and a modified Hoaglands solution was used until harvest. Experimental design consisted of the basic split plot. Main plot and subplot treatments were spacings and restricted vs. nonrestrictive root development, respectively. Treatments were replicated four times. The number of trees per treatment varied because of different spacings within each case. Because of poor germination, hybrid aspen was condensed to three replications and black walnut to three treatments (5, 7, and 10 centimeters).

Analysis of variance was performed on height and diameter of the four tallest trees in each treatment 12 weeks after sowing. Mean separation of significant treatments was performed by the Least Significant Difference Test. An analysis of variance was not performed on European black alder because of poor survival and slow, erratic germination.

Below is a diagram of the experimental layout showing how spacings were obtained with and without plant band restrictions.



Results and Discussion

The major emphasis of this study was directed toward the potential height in each spacing with and without plant band restrictions. Overall height differences for different spacings are summarized in Table 4. An overall trend existed showing that the closer spacing produced the taller seedling. These compensatory growth trends existed in ailanthus, black walnut, and white birch, while statistical differences showing this same trend occurred in sugar maple and hybrid aspen.

Table 4. Mean height of five hardwood species grown for 12 weeks from seed at several spacings.

Root Development	Spacing (cm.) 5	7	10	14
	cm.			
Ailanthus [1]				
W [2]	39.8 a [4]	38.9 a	29.4 b	26.1 c
WO [3]	45.1 a	45.9 a	41.2 b	44.9 a
$\bar{x}$	42.5 a	42.4 a	35.4 a	35.5 a
Black walnut				
W	49.4 a	48.9 a	32.4 b	---
WO	58.3 a	62.1 a	49.5 a	---
$\bar{x}$	53.9 a	55.5 a	40.9 a	---
Sugar maple				
W	29.6 a	27.1 a	17.9 b	14.5 b
WO	29.1 a	23.6 a	26.9 a	13.1 b
$\bar{x}$	29.4 a	25.3 ab	22.4 b	13.8 c
White birch				
W	24.7 a	24.7 a	8.2 a	17.3 a
WO	26.0 a	23.3 a	13.0 a	13.3 a
$\bar{x}$	25.3 a	24.0 a	21.1 a	15.3 a
Hybrid aspen				
W	62.4 a	62.2 a	53.8 a	52.7 a
WO	88.8 a	74.0 b	72.2 bc	60.6 c
$\bar{x}$	75.6 a	68.1 b	63.0 bc	56.7 c

1/ Four measurements per rep.; three reps = mean for hybrid aspen. Four measurements per rep.; four reps = mean for all other species.

2/ W = paperboard plant bands inserted into .03 meter plastic cases for restricted root development.

3/ WO = seeds sown directly in plastic case without plant band restrictions.

4/ Means within rows followed by the same letter are not significantly different at LSD (.05).

Table 5 shows no difference in diameter at the different spacings. Therefore taller more slender plants were produced at the closer spacings.

Non-restricted root development produced larger seedlings for both height and diameter (Table 6) in all species analyzed except sugar maple and white birch. In these two species full utilization of the soil volume by the roots, especially in plant bands, was probably not obtained during the length of this study.

In the past, very little emphasis has been put on the importance of adequate root volumes. In this study, root volume was a primary limiting factor. After only 12 weeks, trees without plant band restrictions grew between 28 and 32 percent more than restricted roots based on height. Trees without restricted roots also had between 26 and 43 percent greater diameters than restricted roots. This will be discussed further in relation to the biomass of the shoots and roots in the following section.

When seeking optimum growing conditions for tree species, small spacings should also be considered as a possible way to increase height growth. Evidence suggests, in this study, that height increases can be obtained at the closer spacings with little difference in diameters.

Growth Analysis of Hardwood Seedlings

Materials and Methods

Growth functions were calculated after 14 weeks for ailanthus (*Ailanthus altissima* Mill.), black walnut (*Juglans nigra* L.), and hybrid

Table 5. Mean diameter of five hardwood species grown for 12 weeks from seed at different spacings.

Root Development	Spacing (cm.) 5	7	10	14
	---------- cm. ----------			
Ailanthus [1/]				
W [2/]	.53 a [4/]	.54 a	.50 a	.54 a
WO [3/]	.61 a	.70 ab	.65 a	.81 b
$\bar{x}$	.57 a	.62 a	.57 a	.68 a
Black walnut				
W	.56 a	.57 a	.54 a	---
WO	.67 a	.73 a	.70 a	---
$\bar{x}$	.62 a	.65 a	.62 a	---
Sugar maple				
W	.31 a	.33 a	.30 a	.26 a
WO	.29 ab	.29 ab	.33 a	.22 b
$\bar{x}$	.30 a	.31 a	.31 a	.24 a
White birch				
W	.29 a	.27 a	.16 a	.22 a
WO	.31 a	.32 a	.17 a	.16 a
$\bar{x}$	.30 a	.30 a	.16 a	.19 a
Hybrid aspen				
W	.47 a	.52 a	.47 a	.50 a
WO	.78 a	.68 a	.67 a	.69 a
$\bar{x}$	.62 a	.60 a	.57 a	.59 a

1/ Four measurements per rep.; three reps = mean for hybrid aspen. Four measurements per rep.; four reps = mean for all other species.

2/ W = paperboard plant bands inserted into .03 meter plastic cases for restricted root development.

3/ WO = seeds sown directly in plastic cases without plant band restrictions.

4/ Means within rows followed by the same letter are not significantly different at LSD (.05).

Table 6. Mean height and diameter of seedlings of five species grown for 12 weeks under accelerated conditions.

Species	Root development		
	W 1/	WO 2/	$\frac{WO - W}{W}$ x 100
	cm.	cm.	Percent
Height			
Ailanthus	33.6 a 3/	44.3 b	32
Black walnut	43.9 a	56.6 b	29
Sugar maple	22.3 a	23.2 a	0
White birch	18.7 a	18.9 a	0
Hybrid aspen	57.8 a	73.9 b	28
Diameter			
Ailanthus	.53 a	.70 b	31
Black walnut	.56 a	.70 b	26
Sugar maple	.60 a	.56 a	0
White birch	.47 a	.49 a	0
Hybrid aspen	.50 a	.70 b	43

1/ W = paperboard plant bands inserted into .03 meter plastic cases for restricted root development.

2/ WO = seeds sown directly in plastic cases without plant band restrictions.

3/ Means within rows followed by the same letter are not significantly different at (.01) by the F-statistic.

aspen (Populus canescens x grandidentata) from the spacing study. Dry weights were obtained for leaves, shoots, and roots as well as total leaf area for each of four trees per treatment. Because there were no significant height or diameter differences for ailanthus and black walnut in the spacing study, the two plant band sizes (5 and 7 cm), and the corresponding treatments without root restrictions, were sampled. For hybrid aspen all four spacings were sampled because of significant height differences due to spacings.

Seedling roots were gently sprayed and washed and the entire seedling was photographed. The Lamda Leaf Area Meter was used to obtain total leaf area for each seedling. Leaves, shoots, and roots were dried at 80°C for 92 hours and weighed individually.

Results and Discussion

The following growth parameters were calculated and analyzed for differences between species:

1. Specific Leaf Area: SLA = LA/LW
2. Leaf Area Ratio: LAR = LA/W
3. Leaf Weight Ratio: LWR = LW/W
4. Shoot to Root Ratio: SRR = SW/RW
5. Net Assimilation Rate: NAR = (W)(lnLA)/LA(t)
6. Relative Growth Rate: RGR = (SLA)(LWR)(NAR)

where LA = Leaf area

LW = Leaf weight

W = Total plant dry weight

SW = Shoot dry weight

RW = Root dry weight

ln = natural log

t = time in weeks (14.3)

The response of each species in terms of these parameters and spacings are shown in Tables 7 and 8.

Juglans nigra

All growth functions except RGR showed no significant differences between treatments sampled for black walnut (Fig. 3). RGR can be partitioned into SLA, LWR, and NAR, which allows a closer examination of the variation (Table 7).

SLA and NAR did not vary significantly, however, LWR differences between the 7 cm. treatments with and without root restrictions (Table 7) were significantly different at the 10 percent level. This could give a clue as to where most of the significant differences might occur in RGR. Since LWR is an indication of the productive investment in photosynthetic tissue, the larger LWR's without root restrictions could indicate a larger investment in photosynthetic than non-photosynthetic tissue.

The growth parameters for black walnut suggest that there are no significant reductions in physiological efficiency of seedlings grown with or without root restrictions at 5 and 7 centimeter spacings in this study, as reflected in mean dry weights (Table 8) the 7 cm. and 5 cm. spacings without root restrictions contributed to a larger and significant increase in dry weight than comparing the two spacings. Also of interest is the largest total dry weight in the study was obtained from black walnut at the 7 centimeter spacing without root restriction.

Figure 3. (A) Black walnut grown for 14 weeks in the greenhouse under continuous fluorescent light in a 5 cm. polyethylene coated cardboard plant band.

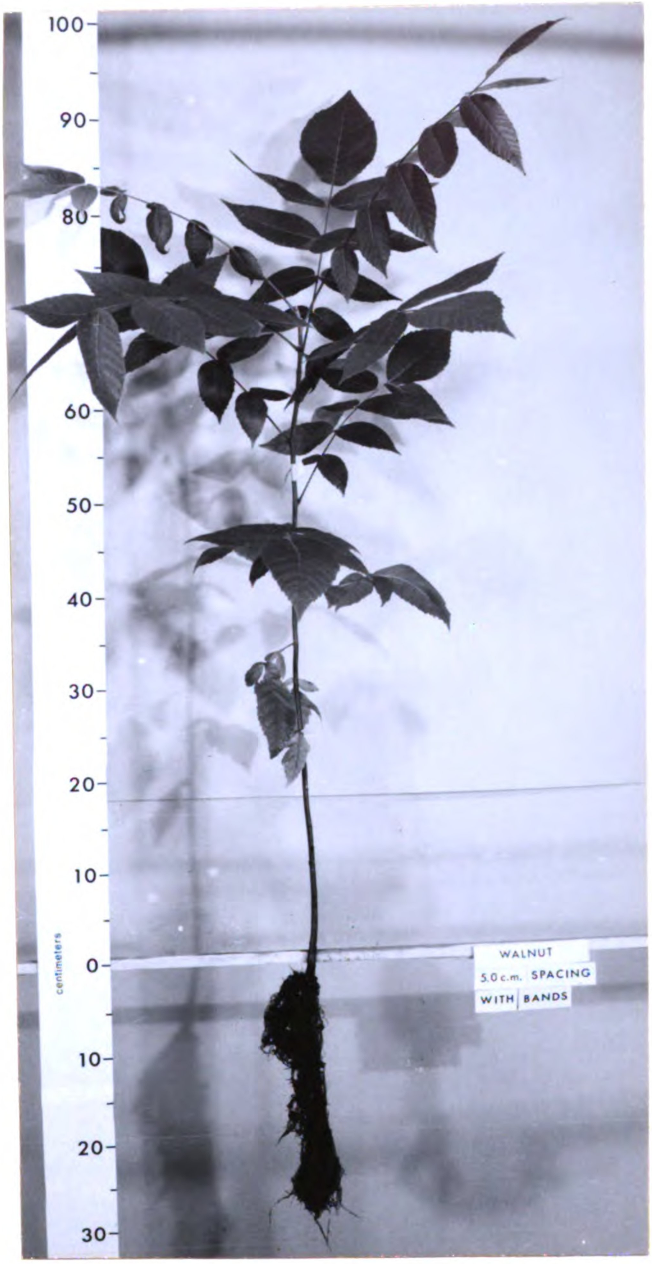

100
90
80
60
50
40
30
20
10
0
10
20
30
centimeters
WALNUT
5.0 c.m. SPACING
WITH BANDS

Figure 3. (A)

Figure 3. (B) Black walnut grown for 14 weeks in the greenhouse under continuous fluorescent lighting at a 5 cm. spacing in a .03 meter plastic case.

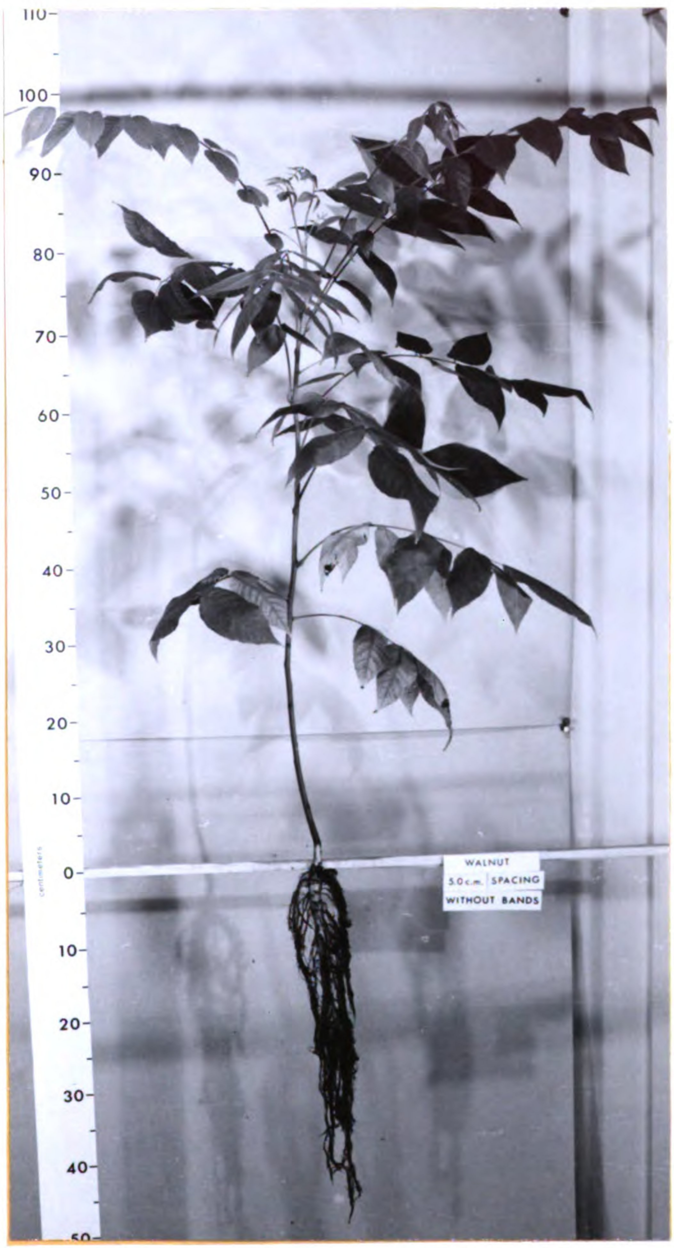


Figure 3. (B)

Table 7. Mean growth parameters for seedlings of black walnut, ailanthus, and hybrid aspen from spacing study. All species were 14 weeks old from seed at harvest.

Spacing (cm.)/ root restriction	Growth Functions [1/] SLA [2/]	LAR	LWR	SRR	RGR	NAR
Black walnut [3/]						
5 / W	413 a [5/]	85.7 a	.20 a	1.4 a	52.5 ab	66.7 a
7 / W	333 a	60.6 a	.18 a	1.1 a	51.0 b	85.4 a
5 / WO [4/]	330 a	77.1 a	.26 a	1.6 a	55.6 a	78.3 a
7 / WO	326 a	80.9 a	.25 a	1.3 a	59.0 c	74.8 a
Ailanthus						
5 / W	349 a	10.7 a	.30 a	4.4 a	49.9 a	43.2 a
7 / W	649 b	14.3 ab	.13 b	4.4 a	55.5 b	41.3 a
5 / WO	293 a	5.6 c	.21 b	2.8 a	52.5 ab	102.7 a
7 / WO	765 b	15.6 b	.21 b	4.0 a	55.9 b	35.9 a
Hybrid aspen						
5 / W	359 a	10.9 a	.30 a	5.3 ab	53.2 a	39.6 a
7 / W	373 a	12.3 a	.33 a	3.8 a	55.3 a	47.7 a
10 / W	568 a	17.2 a	.30 a	4.0 a	54.4 a	39.5 a
14 / W	392 a	11.0 a	.29 a	3.7 a	53.2 a	50.6 a
5 / WO	403 a	13.4 a	.33 a	3.4 a	54.0 a	43.5 a
7 / WO	361 a	12.5 a	.34 a	4.5 a	59.7 a	51.3 a
10 / WO	399 a	12.3 a	.31 a	7.1 b	55.4 a	50.8 a
14 / WO	302 a	8.8 a	.30 a	3.2 a	56.1 a	65.0 a

1/ Specific Leaf Area = $cm.^2/gm.$, Leaf Area Ratio = $cm.^2/gm.$, Leaf Weight Ratio, Shoot Root Ratio, Relative Growth Rate = $week^{-1}$, Net Assimilation Rate = $gm.\ cm^{-2} week^{-1}$.

2/ Leaf weights for SAL and LWR are excluding rachis for Ailanthus and Black walnut.

3/ W = with plant band restrictions.

4/ WO = without plant band restrictions.

5/ Any two means for a growth parameter within species is not significantly different at the LSD 5 percent level if followed by the same letter.

Table 8. Mean dry weights for seedlings of black walnut, ailanthus, and hybrid aspen from spacing study. All species were 14 weeks old from seed at harvest.

Spacing (cm.)/ root restriction	Dry Weight [1/]			
	LW [2/]	SW	RW	W
	----------------grams----------------			
Black walnut				
5 / W [3/]	6.6 a [5/]	6.6 a	10.8 a	24.0 a
7 / W	6.3 a	6.4 a	13.1 a	25.8 ab
5 / WO [4/]	12.2 b	8.4 a	17.2 b	37.8 b
7 / WO	19.2 c	12.9 a	26.0 b	58.1 c
Ailanthus				
5 / W	5.5 a	4.2 a	2.4 a	12.1 a
7 / W	8.8 a	8.5 b	4.1 a	21.4 a
5 / WO	12.7 b	12.5 c	10.8 a	35.9 b
7 / WO	8.9 a	7.0 ab	4.4 a	20.3 a
Hybrid aspen				
5 / W	6.0 a	10.4 a	3.3 a	19.7 a
7 / W	8.0 a	11.7 a	5.3 a	25.1 a
10 / W	4.6 a	7.0 a	3.0 a	18.6 a
14 / W	6.2 a	14.2 a	4.5 a	21.2 a
5 / WO	7.4 a	10.8 a	4.8 a	22.9 a
7 / WO	15.6 a	22.9 a	7.9 a	46.4 a
10 / WO	8.7 a	15.7 a	4.2 a	28.6 a
14 / WO	11.1 a	17.1 a	9.6 a	37.6 a

[1/] Leaf Weight, Shoot Weight, Root Weight, Total Weight.

[2/] Leaf weights include rachis for black walnut and ailanthus.

[3/] W = with plant band restrictions.

[4/] WO = without plant band restrictions.

[5/] Any two means for a growth parameter within species is not significantly different at the LSD 5 percent level if followed by the same letter.

While buds were just beginning to develop at the time of harvest, tap roots were noticed to extend the length of the container and were constricted due to the contact with the plastic mesh at the bottom of the cases. A relationship could exist between the constriction of the roots and the physiological state of the shoot. However, no conclusions can be made here except to suggest that the tap root of black walnut may be involved in hormonal control over the amount of continuous shoot growth.

Ailanthus altissima

NAR and SRR showed no significant differences between treatments, mainly due to the large variability in root weights within spacings. The large NAR for seedlings in the 5 centimeter spacing without root restrictions could be partially due to a small leaf area to total weight (LAR). Aside from this variability, ailanthus showed large shoot to root ratios mainly due to the small fibrous root system and rapid growth rate characteristics of this species.

Spacing alone is shown to have an effect on leaf distribution and photosynthetic capacity under continuous light in ailanthus. Seedlings in the 5 centimeter spacing produced more leaf weight per leaf area (SLA) than the 7 centimeter spacing. This was attributed to more leaf expansion taking place in the large spacing. This trend also existed in LAR where a greater amount of leaf area to total weight was obtained in the 7 centimeter spacing versus the 5 centimeter spacing.

Populus canescens x *grandidentata*

Because of the significant height difference of hybrid aspen in all the treatments of the spacing study (Table 3), all eight treatments were sampled for biomass differences. The variation, however, between spacings with and without root restrictions for the different growth functions was very small. The only growth function showing significant differences between treatments was shoot to root ratios.

Similar to black walnut, the growth functions for hybrid aspen (Fig. 4) suggest no significant reductions in the physiological efficiencies at the spacings and root restrictions studied even though height differences did occur in the spacing study.

Outplanting of AOG Hardwoods

Containerized seedlings have been shown to be superior in many ways over other methods of reforestation. Reasons for this are numerous (Stein, et al, 1975; Tinus, 1974), however, the primary cause for the continuing use of container stock is the improved survival and rapid initial growth of seedlings under this system. Root contact with the soil is not disturbed in containers, whereas re-establishment before growth can resume.

Containerized conifer seedlings have shown better survival and initial growth than bare-root seedlings in many cases (Owston and Stein, 1972; Miller and Budy, 1974). Because of the attention given to conifer seedlings in the past, knowledge of containerized hardwood regeneration is lacking severely. Information is needed in this area for determining

Figure 4. Hybrid aspen grown for 14 weeks in the greenhouse under continuous fluorescent light in a 7 cm. polyethelene coated cardboard plant band inserted in a .03 meter plastic case.

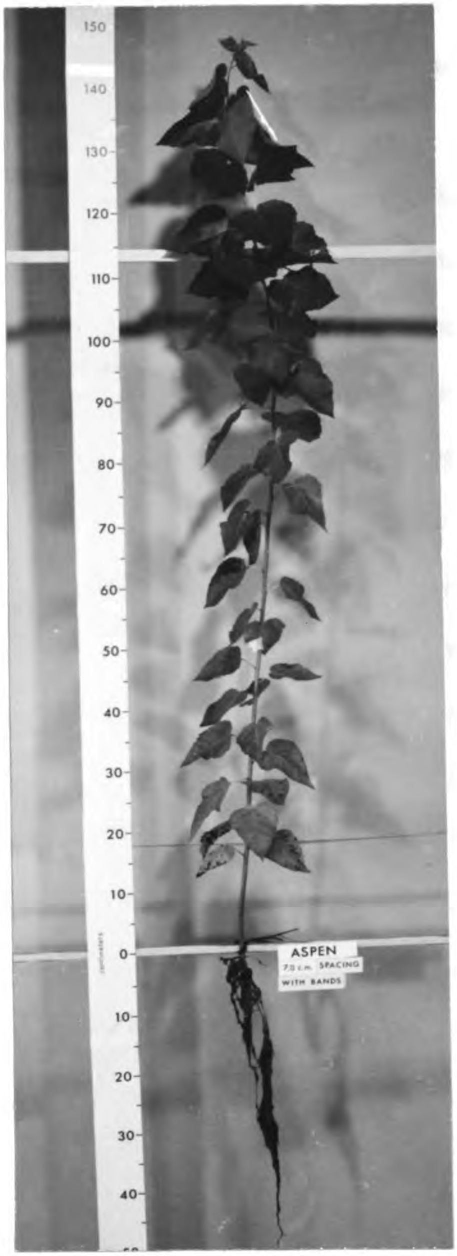

150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
10
20
30
40
ASPEN
7.0 c.m. SPACING
WITH BANDS

Figure 4.

correct physiological requirements needed to obtain high outplanting survival. Forbes and Barnett (1974), pointed out that work in the area of producing containerized hardwoods in controlled environments is still in the pilot production stage. Further work is needed before any large scale hardwood container seedling operations are initiated.

Programmed environments present a challenge primarily to the physiologist. The most critical factor in preparing AOG hardwood seedlings for outplanting is the manipulation of their environment.

These problems were examined in developing a system of planting AOG hardwoods in full leaf throughout the summer months. Hybrid cottonwood cuttings were grown for 12 weeks in 7 centimeter cardboard containers in the greenhouse using the same procedures as the spacing study. The seedlings averaged approximately 100 centimeters and were hand planted along with the plant band in mid-July, 1975. The planting site was very harsh, consisting of extreme weed competition and sandy soil. Fall survival rates varied greatly between clones averaging 42 percent with particular clones receiving as high as 92 percent survival. Over winter survival rates were also good with root development extending beyond bottom of plant band showing well established root systems.

This pilot test shows that planting large full leaf AOG hardwood seedlings in mid-summer can be obtained. Williams (1970) showed that large caliper (10/32", 12/32") black walnut seedlings survived better than small caliper trees (< 8/32"). With further testing, the planting of large AOG hardwoods could be a superior method for reasons of survival, weed competition, animal damage, and growth rate.

CONCLUSION

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As the demand for high yielding, optimally stocked hardwood stands increases, new approaches are being examined to put lands into production rapidly and shorten the rotation period. Accelerated-Optimal-Growth, using containerized seedlings subjected to a programmed environment with extended photoperiods is proving to be a successful method of producing large seedlings with high rates of survival after outplanting.

Research on accelerating the growth of hardwoods and conifer seedlings has shown that many species respond favorably to extended photoperiods (Hanover et al, 1976). The initial study presented here showed that many other species can respond to extended photoperiods with increases in height and duration of growth. Because of the addition of optimum environmental conditions in a programmed environment, it is likely that all hardwood and coniferous species will eventually be shown to respond favorably to accelerated conditions.

As demonstrated in the spacing study, various hardwood species can be grown to large, outplanting size in as little time as 12 weeks. Also, the planting season is extended for these seedlings because there is a minimal amount of root disturbance by using degradable containers.

Correct seedling spacing in the greenhouse is important to allow for maximum growth yet obtain the greatest number of seedlings per square foot. Spacings as close as 5 centimeters for six hardwood species had little detrimental effect on the growth and in some cases actually increased height growth. Root volume, however, was shown to be an important limiting factor in height and diameter growth. The correct shoot to root ratio is also important when outplanting large trees. Johnson (1974) points out the need for a good shoot to root ratio when planting containerized oak seedlings. If the roots are restricted too much they cannot take up enough water to support the shoot, and dieback will occur. While seedlings are growing in the greenhouse, air pruning of the roots helps to minimize outplanting shock and produces a more fibrous root system capable of taking up water in a smaller space.

To help minimize outplanting shock the latest intermittent furrow planter called the Quickwood is introduced here as a superior method for planting large containerized hardwood seedlings. This intermittent furrow planter can plant containerized seedlings in full leaf by inserting the container in the planting arm and mechanically allowing the arm to plant the seedling at desired spacings (Fig. 5).

The Quickwood Tree Planter proves to be very advantageous and versatile in planting containerized as well as bare-root seedlings (Edwards, 1974; Strehlke, 1974) and will be used extensively in the planting of AOG hardwoods at Michigan State University.

Manipulation of the seedling development and physiological status sometimes requires special programming before outplanting. Care must be taken to fulfill any preconditioning requirements when scheduling crop rotations in the greenhouse. For example, if scheduling required outplanting dormant seedlings in the spring, adequate time must be allowed to program for the formation of the buds and chilling requirements must be met before growth can resume at spring outplanting.

The advantages and disadvantages of growing trees in accelerated, programmed environment have been discussed by many authors (Stein, 1974;

Figure 5. (A) Quickwood tree planter in operation.

(B) Hardwood seedlings are planted in full leaf by inserting the polyethylene coated cardboard plant band into planting arm sleeve.

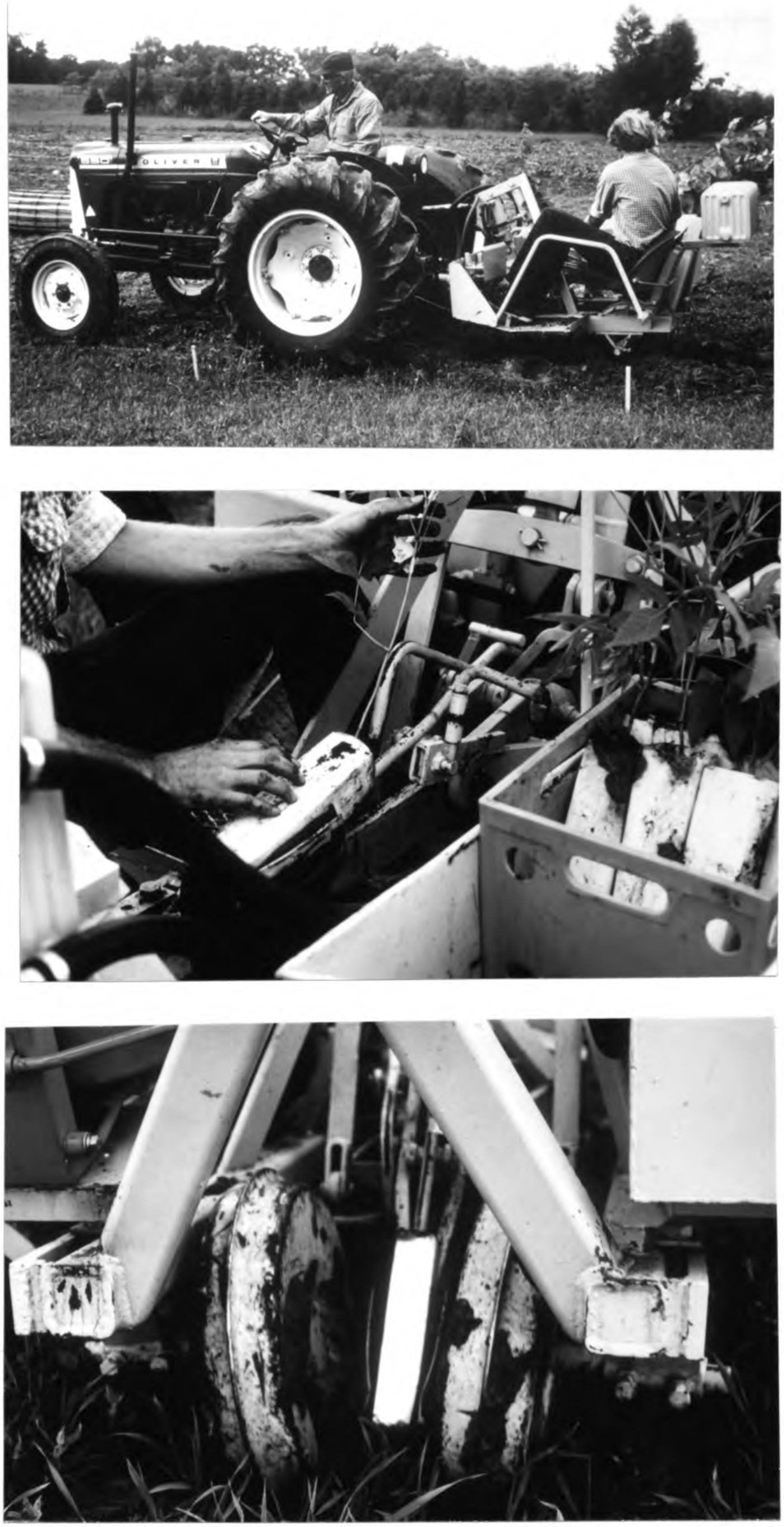
(C) By pushing the foot petal, the arm is lowered between the packing wheels and plants seedling. The planting arm is then returned, by using foot petal, to accept the next seedling.

Figure 5.

(A)

(B)

(C)



Balmer, 1974; Greffenius, 1974; Harris, 1968) and are summarized along with personal observations in Table 9.

Even with the increased technical knowledge required and higher cost per seedling, greenhouse techniques are being used by many small and large nursery operations, and are proving to be economically feasible. Colby and Lewis (1973) analyzed the economics of container grown ponderosa pine in a greenhouse versus nursery bare-root and potted stock. Their findings showed that greenhouse stock had the lowest cost per surviving seedling and that production of containerized greenhouse seedlings appears to be economically favorable in light of current trends.

Accelerated, containerized tree seedling production should receive more consideration by commercial nurserymen engaged in all areas of seedling production. By adopting these concepts seasonal constraints now incurred by conventional nurseries would no longer be a major drawback and improved seedlings could be produced in a fraction of the time normally required.

Table 9. Advantages and disadvantages of Accel-O-Gro.

Advantages	Disadvantages
1. Containerized production is a rapid, flexible means to increase seedling demand.	1. Increased cost per tree may be greater than the benefits of shorter production time.
2. The time needed to produce plantable seedlings is shortened.	2. Occurence of disease and insect problems can be increased.
3. Container production requires less space than nursery operations and site is not a critical factor.	3. Reliance on supplemental energy sources can become critical.
4. Survival and growth rates are improved.	4. A high level of technical knowledge is necessary.
5. Planting season is extended.	5. Day to day attention is needed.
6. Entire root system is retained at outplanting.	6. Problems associated with containers (e.g. root constrictions and overwintering).
7. Production of species slow or difficult to grow in bare-root operations.	7. Different optimum conditions may be needed for different species.
8. Species that are not native to the area can be produced.	8. Increased trucking space along with careful handling is needed for containerized seedlings.
9. Greater production and planting efficiency can be achieved.	
10. The whole production system is more suitable to mechanization.	
11. Production may be adjusted to meet fluctuating seedling demand.	
12. Fertilizers, herbicides, and insecticides can be easier and more efficiently used.	
13. Genetically improved seed can be used more effectively.	
14. Genetic screening can be done more effectively because of uniform conditions.	
15. A more uniform stock can be produced.	

RECOMMENDATIONS FOR FUTURE STUDIES

RECOMMENDATIONS FOR FUTURE STUDIES

The major problem in growing seedlings at a close spacing under accelerated conditions is uniformity in growth. Slow erratic germination of many species used in this study resulted in overtopping, and irregular growth.

A pre-germination treatment was tried for black walnut and should be further examined as a way to produce more uniform germination. After the nuts germinate they can be put directly into a cooler which slows radicle extension considerably. When enough nuts have germinated and placed into cooler they then could be planted, in bulk, to produce rapid, uniform germination and growth.

Other pre-germination treatments should also be considered for different species which could consist of mechanical stratification or hormone treatments. The use of genetically superior seed will also aid in obtaining uniform growth in a controlled environment.

Another problem in growing tap rooted species in containers is container depth. It was observed in this study that growth decreased as the tap roots of black walnut became constricted when they extended into the bottom of the plastic case in which they were grown. A correlation could exist between tap root constriction and termination of shoot extension.

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