(Table 9). Fewer eggs, less plant damage, and fewer larvae were found on them. No differences occurred among the commercial cultivars and progenies of the 'Slobolt' selections.

In summary, our survey of a broad sample of the gene pool of *L. sativa, L. serriola,* and *L. saligna* for plants unattractive to the cabbage looper for oviposition revealed 29 entries on which the moths deposited significantly fewer eggs when they were allowed a choice in screenhouse tests.

Oviposition varied on any 1 entry when the entry was compared with a standard. Plant age influenced oviposition and interfered with genetic tests and selections. Progeny tests of 'Slobolt' selections were inconclusive, although 1 selection showed higher oviposition in the screenhouse. However, as a majority of the plants from 'Slobolt' had low oviposition as evidenced by the average eggs/plant from 100-plant blocks (Table7), it may be difficult to select for lower oviposition.

Progenies from many more selections would be required to yield conclusive evidence on heritability. Differences among cultivars observed in the screenhouse did not seem effective in the field, but 1 Plant Introduction collection, each, of *L. serriola* and *L. saligna* were less attractive to looper moths in the field. These species may be valuable sources of looper resistance if it can be transferred to cultivars of *L. sativa* without their numerous, undesirable characters.

Literature Cited

1. Chalfant, R. B., and C. H. Brett. 1967. Interrelationship of cabbage variety, season, and insecticide on control of the cabbage looper and the imported cabbage worm. *J. Econ. Entomol.* 60:687-690.
2. Cochran, W. B., and G. M. Cox. 1957. Experimental Designs. (Second Edition). John Wiley & Sons, Inc., New York. 611 p.
3. Henneberry, T. J., and A. N. Kishaba. 1966. Mass rearing cabbage loopers. p. 461-478. *In* C. N. Smith [ed.] Insect Colonization and Mass Production. Academic Press, New York. 618 p.
4. Hoagland, D. R., and D. I. Arnon. 1938. Water-culture method for growing plants without soil. *Calif. Agr. Expt. Sta. Cir.* 347.
5. Radcliffe, E. B., and R. K. Chapman. 1966. Varietal resistance to insect attack in various cruciferous crops. *J. Econ. Entomol.* 59:120-125.
6. Schoonhoven, L. M. 1968. Chemosensory basis of host plant selection. *Ann. Rev. Entomol.* 13:115-136.
7. Snedecor, George W. 1956. Statistical Methods. (Fifth Edition). The Iowa State College Press, Ames, Iowa. 534 p.
8. Steel, Robert G. D., and James H. Torrie. 1960. Principles and Procedures of Statistics. McGraw-Hill Book Company, Inc., New York. 481 p.

Comparative Growth of Birch Seedlings Grown in the Greenhouse and Growth Chamber[1, 4]

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Abstract. The growth of paper birch (*Betula papyrifera* Marsh.) seedlings was greatly accelerated by high light intensity applied in a growth chamber at the cotyledon stage and continued for the next 8 weeks. At the end of the 8-week period, seedlings grown in a growth chamber under 2500 ft-c (26.9 klx) of cool-white fluorescent and supplemental incandescent light, a 16-hour photoperiod, and 25/18°C day/night temperature weighed over 40 times more than those grown in the greenhouse under natural daylight supplemented by 200 ft-c (2.16 klx) of cool-white fluorescent light, a 16-hour photoperiod, and 24/18°C day/night temperature. Compared with plants grown under low light intensity, plants grown for 8 weeks under high light intensity were 6 times taller, had twice as many leaves, and produced lateral shoots containing 17 times as much dry matter. These findings indicate the feasibility of using high light intensity alone at the seedling stage in the commercial production of planting stock of this species.

The feasibility of using controlled environments to accelerate the seedling growth of selected woody plants has been reported in several studies (1, 2, 7, 8, 9, 11). Relatively few detailed studies have been conducted, however, on the comparative growth of woody plants under greenhouse and growth chamber conditions (4).

In a preliminary experiment Krizek et al. (7) found that the growth of European white birch seedlings (*Betula pendula* Roth) was greatly stimulated by growing them for 4 weeks from seed in a growth chamber at elevated day/night temp (30/24°C), high light intensity (2500 ft-c) (26.9 klx), and CO_2-enriched atmospheres (400 and 2000 ppm). After 4 weeks, seedlings grown under controlled environmental conditions were nearly twice as tall, had several more leaves, and had many more lateral shoots than those grown under greenhouse conditions. Subsequent experiments conducted in a custom-designed propagation unit (3) with high light intensity and only modest control of the environment (Krizek et al., unpublished results) revealed that careful control of all of the environmental factors used previously is not needed to accelerate the growth of paper birch seedlings.

The present study was conducted to determine the growth of young paper birch seedlings after 2, 4, 6, and 8 weeks of high light intensity in the growth chamber as compared with growth of plants in the greenhouse under natural days and supplemental low light intensity for 16 hr a day.

Materials and Methods

Plant material. Seeds of paper birch were planted on September 7, 1971, in petri dishes under approximately 1000 ft-c (10.8 klx), cool-white fluorescent light at 25°C. Seven days later, when the cotyledons were visible, the seedlings were transferred to 7.5 cm plastic pots containing a peat-vermiculite

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[5]Mention of trademark name or a proprietary product does not imply its approval by the USDA to the exclusion of other products that may also be available.

mix (commercially available as Jiffy-Mix[5]) and allowed to remain overnight in the laboratory under artificial light.

Experimental treatment began on September 15 and lasted 8 weeks. The newly potted plants were selected for uniformity and divided at random into 8 groups of 4 plants each. Four groups were grown under low light intensity in a greenhouse with closely controlled temp for 2, 4, 6, or 8 weeks; the other 4 groups were grown under high light intensity in a growth chamber. Temperature, CO_2, moisture, and fertility conditions were comparable in the 2 locations.

Environmental conditions. Plants in the greenhouse received a 16-hr photoperiod supplementing natural daylight with 200 ft-c (2.16 klx) of cool-white fluorescent light from 4:00 AM to 8:00 PM; a day/night temp of approximately 24/18°C; and ambient CO_2 (about 350 ppm). The seedlings were watered and fertilized automatically for 4 minutes, 3 to 5 times daily, enough for the excess water or nutrient solution to drip from the pots. The nutrient solution was a 20-20-20- water-soluble fertilizer containing essential macronutrients and micronutrients and was applied at a concn of 0.5 g/liter, for the first 4 weeks and 1.0 g/liter for the next 4 weeks.

Plants in the growth chamber were grown under the following conditions: 2500 ft-c (26.9 klx) of light, provided by 1500 ma cool-white fluorescent lamps, and 60 watt (120 volt) incandescent lamps, the latter providing about 20% of the input wattage; a 16-hr photoperiod; day/night temp of 25/18°C; 65% relative humidity, day and night; air velocity across the chamber at about 20 m/min; and ambient CO_2 (about 350 ppm). The plants were fertilized as described above. At least once a week the soil was leached with distilled water to prevent excess salt accumulation. After 4 weeks of treatment all plants were transferred to 12.5-cm pots.

Environmental measurements. The CO_2 levels in the greenhouse and the growth chamber were monitored periodically by means of a Beckman[5] model 215A infrared analyzer but were not controlled. They remained near ambient level of about 350 ppm. Light levels were set and measured at plant height by means of a Weston[5] model 756 light meter. Relative humidity was recorded by means of a hygrothermograph. Air velocity was measured with an Anemotherm[5] anemometer. Total daily radiation in the growth chamber (ca 270 langleys/16 hr day), as measured by a Lintronic pyranometer, was comparable to average daily solar radiation outdoors as calculated for the months of September, October, and November (295 langleys/11.24 hr day). For the same period, however, the total radiation in the natural day greenhouse was only ca 34.5 langleys/day on a basis of 6.6 hr of mean daily sunshine and 58.7 langleys/day on a basis of 11.24 hr mean daylength. (Liu et al., unpublished results).

Growth measurements. Stem growth above the cotyledonary node and number of leaves were measured after 2, 4, 6, and 8 weeks of treatment from the time the seedlings were placed in the greenhouse or growth chamber. Fresh and dry wt of the main shoot and the roots were determined after 2, 4, 6, and 8 weeks and of the lateral shoots after 6 and 8 weeks. The top-root ratio was calculated on the basis of dry-wt values.

Results

Overall growth. After 2 weeks of treatment, differences in overall growth between greenhouse- and growth-chamber-grown seedlings were discernible (Tables 1, 2). After 4 weeks, growth differences were even more marked, especially in leaf size and in the extent of lateral growth (Fig 1). After 8 weeks, the size of growth-chamber-grown seedlings far surpassed that of greenhouse-grown plants (Fig 2).

Height of the main shoot. Birch seedlings grown in the growth chamber for 8 weeks elongated at an average rate of 1.2 cm/day; those grown in the greenhouse elongated at an average rate of approximately 0.2 cm/day (Table 1). The greatest increase in plant height was between week 6 and week 8. During this period, seedlings in the growth chamber elongated at an average of 2.7 cm/day; those in the greenhouse at an average of 0.6 cm/day. At all harvests, seedlings grown in the growth chamber were at least 6 times taller than those grown in the greenhouse. The greatest difference in rate of stem growth between plants in the greenhouse and those in the growth chamber was between week 4 and week 6 (Table 1).

Number of leaves. The rate of leaf initiation was greatly increased by high light intensity (Table 2), but not as markedly as the rate of stem elongation (Table 1). At all harvests, seedlings grown in the growth chamber had at least twice as many leaves as seedlings grown in the greenhouse. During the 8-week period, plants in the growth chamber produced an average of 3.5 leaves per week, whereas comparable plants in the greenhouse produced an average of 1.6 leaves per week (Table 2). The greatest difference in rate of leaf production between plants in the greenhouse and those in the growth chamber occurred between week 2 and week 4.

Fresh and dry wt. Differences in fresh wt of tops between greenhouse- and growth-chamber-grown seedlings were nearly 10-fold after 2 weeks of treatment and increased to over 40-fold after 8 weeks of treatment (Fig 3). Similar differences were found in dry wt of tops. Fresh and dry wt of roots were also 10 times greater after 2 weeks and were over 40 times greater after 4 to 6 weeks. In general, the rate of dry-matter accumulation in growth-chamber-grown seedlings was much more rapid than that

Fig. 1, 2. Comparative growth of paper birch seedlings after 4 weeks (Fig 1) or 8 weeks (Fig 2) of treatment in greenhouse (left) and growth chamber (right). Seedlings in Fig 1 are in 7.5-cm pots; those in Fig 2 are in 12.5-cm pots.

Table 1. Stem growth produced by paper birch seedlings during 8 weeks of treatment in the greenhouse and growth chamber.

Environmental treatment	Stem growth (cm) Week/0-2	Week/2-4	Week/4-6	Week/6-8	Week/0-8
Greenhouse	0	0.9	1.9	8.1	10.9 ± 0.5[z]
Growth chamber	0.3	6.0	24.6	37.5	68.4 ± 8.6
Ratio	–	6.6	13.0	4.6	6.3

[z]Mean ± standard deviation.

of greenhouse-grown seedlings (Fig 3).

Relative distribution of dry matter. The most striking difference in dry-matter distribution observed between birch seedlings grown in the greenhouse and those in the growth chamber was in the relative amount of dry matter of the lateral shoots as compared with that of the main shoot (Table 3). Lateral shoots were visible after 4 weeks of treatment in the growth chamber but were not large enough to be harvested until after 6 weeks of treatment. After 6 weeks, lateral shoots of seedlings grown in the growth chamber had 10 times as much dry matter as that of seedlings grown in the greenhouse under long-day conditions. After 8 weeks, this difference was 17-fold.

Table 2. Number of leaves produced by paper birch seedlings during 8 weeks of treatment in the greenhouse and growth chamber.

Environmental treatment	Number of leaves produced Week/0-2	Week/2-4	Week/4-6	Week/6-8	Week/0-8
Greenhouse	2	2	3.5	5.3	12.8 ± 1.0[z]
Growth chamber	3.8	7.2	7.8	9.7	28.5 ± 0.6
Ratio	1.9	3.6	2.2	1.8	2.2

[z]Mean ± standard deviation.

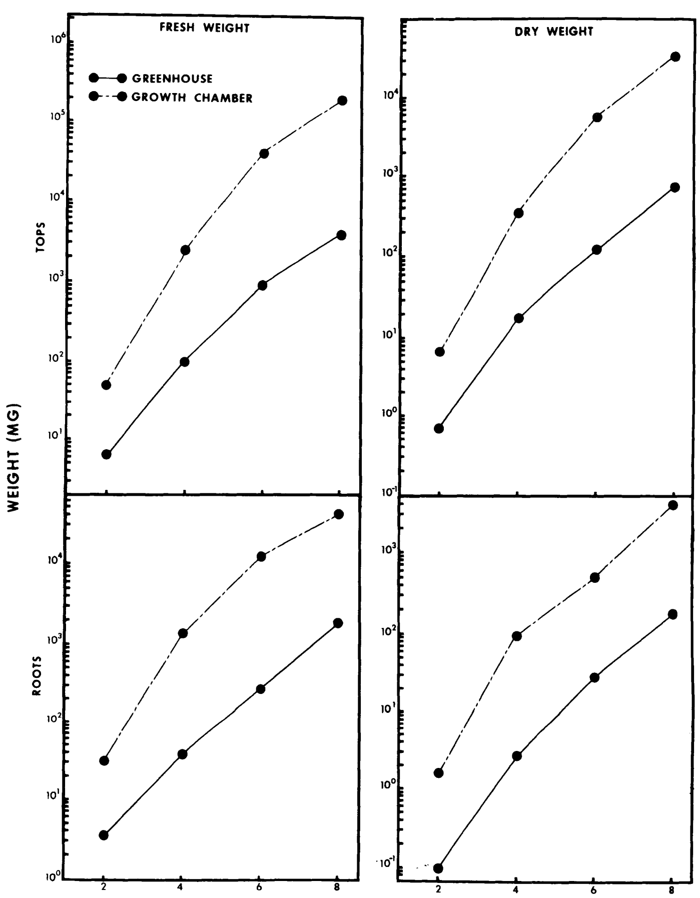

Fig 3. Fresh and dry wt of tops and roots of paper birch seedlings after 2, 4, 6, and 8 weeks of treatment in greenhouse and growth chamber.

The ratio of dry matter in the lateral shoots to that in the main shoot after 6 weeks in the growth chamber was 1:1.25, whereas the ratio in the greenhouse was approximately 1:22. After 8 weeks of treatment, these differences were even more pronounced; for example, growth chamber-grown plants had nearly twice as much dry matter in the lateral shoots as in the rest of the tops. The top-root ratio increased after 6 and 8 weeks of treatment in the growth chamber (Table 3).

Discussion

The importance of starting woody plants under a CO_2-enriched atmosphere in a controlled environment to accelerate seedling development has been shown in earlier studies with crabapple (7, 8, 9. 11) and European white birch (7). The present study demonstrates that the growth of paper birch seedlings may be greatly accelerated merely by using high light intensity alone during the first 8 weeks of the life of the seedlings.

Pinney and Peotter (10) have reported that under the best growing conditions outdoors in Wisconsin in mid-August, ***Betula papyrifera*** stems grew at a rate of 0.5 inches/day (1.2 cm/day), with an average rate at approximately 0.3 inches/day (0.8 cm/day). In the present study, we obtained a maximum rate of stem elongation of 2.7 cm/day during the 6th to 8th week of treatment and an average rate of 1.2 cm/day for the entire 8-week period. These values are considerably greater than those Pinney and Peotter reported for seedlings of the same age or the same size. It is possible that the total radiation that our seedlings received in the growth chamber was greater than that obtained under natural conditions in Wisconsin in the Pinney and Peotter studies.

Pinney and Peotter (10) reported that it took 4 months for paper birch seedlings to reach a height of 12 inches (30.5 cm) and nearly 6 months to reach a height of 30 inches (76.2 cm) under their conditions. In the present study and in other experiments conducted with this species under 2500 ft-c (26.9 klx) of light (Krizek et. al., unpublished results), comparable growth was obtained in less than 1/2 that time.

The stimulation of lateral growth was the most marked influence of high light intensity in the growth chamber. This is similar to the response obtained with herbaceous plants (5, 6)

Table 3. Relative distribution of dry matter in main shoot, lateral shoots, tops, and roots of paper birch seedlings grown for 2, 4, 6, and 8 weeks under greenhouse and growth chamber conditions.

Environmental treatment	Time of treatment weeks	% Distribution of dry matter Tops Main shoot	Lateral shoots	Total	Roots	Top root ratio[z]
Greenhouse	2	87.5	–	87.5	12.5	6.1 ± 3.2[y]
	4	80.6	–	80.6	19.4	4.4 ± 1.7
	6	77.9	3.8	81.7	18.3	4.5 ± 2.8
	8	77.7	3.5	81.2	18.8	4.4 ± 0.7
Growth chamber	2	81.0	–	81.0	19.0	4.6 ± 1.7
	4	78.7	–	78.7	21.3	3.7 ± 0.4
	6	53.3	40.8	94.1	5.9	17.9 ± 9.4
	8	28.7	61.3	90.0	9.9	9.1 ± 1.3

[z]Top/root ratio based on dry wt.
[y]Mean ± standard deviation.

when high light intensity was used in combination with elevated temp (30/24°C, day/night) and CO_2-enriched atmospheres (2000 ppm).

The large increase in dry-matter production as a consequence of controlled-environment treatment is consistent with prior results obtained under controlled environments with petunia and other herbaceous plants (5, 6).

Total radiation was apparently the chief determinant of the difference in growth observed because photoperiod, temp, CO_2, nutrition, and moisture status were comparable in the greenhouse and the growth chamber.

Because *B. papyrifera* is important both as a landscape specimen and as a potentially valuable source of wood fiber, a method of accelerating seedling growth of this tree species is economically important.

From our work, seedling growth of birch can be accelerated by increasing light intensity to 2500 ft-c (26.9 klx) for at least 16 hr per day, using a day/night temp of at least 25/18°C, and maintaining adequate levels of moisture and nutrition.

The actual number of weeks of light treatment that may be practical for the commercial production of paper birch remains to be determined. However, this species clearly is extremely sensitive to light intensity at an early seedling stage and even a minimum amount of light treatment may prove highly stimulatory to vegetative growth.

Literature Cited

1. Funsch, R. W., R. H. Mattson, and G. R. Mowry. 1970. CO_2-supplemented atmosphere increases growth of *Pinus strobus* seedlings. *Forest Sci.* 16:459-460.
2. Jarvis, P. G., and Margaret S. Jarvis. 1964. Growth rates of woody plants. *Physiol. Plant.* 17:654-666.
3. Klueter, H. H., W. A. Bailey, and D. T. Krizek. 1970. A propagation unit for accelerating growth of seedlings and cuttings. *HortScience* 5:137. (Abstr.).
4. Kozlowski, T. T. 1964. Shoot growth in woody plants. *Bot. Rev.* 30:335-392.
5. Krizek, D. T., W. A. Bailey, and H. H. Klueter. 1970. A "headstart" program for bedding plants through controlled environments. p. 43-53. *In* W. H. Carlson (ed.), Proc. Third Nat. Bedding Plant Conf. Michigan State Univ., East Lansing.
6. ______, ______, ______, and H. M. Cathey. 1968. Controlled environments for seedling production. *Proc. Int. Plant Prop. Soc.* 18:273-280.
7. ______, R. H. Zimmerman, H. H. Klueter, and W. A. Bailey. 1969. Accelerated growth of birch and crabapple seedlings under CO_2 enriched atmospheres. *Plant Physiol.* 44 (Suppl.):15. (Abstr.).
8. ______, ______, ______, and ______. 1970. Growth and development of crabapple seedlings in controlled environments: Effects of light intensity and CO_2 concentration. *Plant Physiol.* 46 (Suppl.):7. (Abstr.).
9. ______, ______, ______, and ______. 1971. Growth of crabapple seedlings in controlled environments. Effects of CO_2 level, and time and duration of CO_2 treatment. *J. Amer. Soc. Hort. Sci.* 96:285-288.
10. Pinney, T. S., Jr., and G. W. Peotter. 1966. The propagation of birch. *Proc. Int. Plant. Prop. Soc.* 16:193-202.
11. Zimmerman, R. H., D. T. Krizek, W. A. Bailey, and H. H. Klueter. 1970. Growth of crabapple seedlings in controlled environments: Influence of seedling age and CO_2 content of the atmosphere. *J. Amer. Soc. Hort. Sci.* 95:323-325.