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Effects of Flooding on Silver Maple (*Acer saccharinum* L.) and American Sycamore (*Platanus occidentalis* L.) Seedlings: Implications for Biomass Production

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ABSTRACT

Silver maple and American sycamore were compared to determine their suitability for use in biomass plantations located on flooded sites. One-year old nursery stock of each species was subjected to various periods of inundation: early, late, and a combination of early and late in the growing season. Treatments were compared for leaf weight, stem weight, root weight, total weight, root weight/aboveground weight, and height. Biomass increment (final weight/initial weight) was evaluated for aboveground and belowground components. Early flooding caused greater reductions in the growth of silver maple than of sycamore. Late flooding caused slightly greater reductions in the growth of sycamore than of silver maple. Analysis of biomass increment data suggests that both species have the capacity to recover physiologically and produce substantial amounts of aboveground biomass following all flooding treatments except an early flood of long duration. Silver maple and sycamore appear to be equally suitable for use in intensive biomass production on sites which are periodically flooded.

INTRODUCTION

The potential for increasing energy supplies in the United States by increased use of different types of plant biomass has been recognized for some time (Burwell, 1978). Fossil fuel consumption can be supplemented by the use of biomass fuels at power plants as well as at the level of the individual consumer. It has been demonstrated that the conversion of solar energy for biomass fuel production can be integrated with conventional agricultural and forestry operations (Lipinsky, 1978: Sirén, 1982).

It has been shown that various tree species can be used for biomass production in closely spaced plantations (Szego and Kemp, 1973; Wittwer, et. al., 1978). The most successful production of woody biomass has been achieved with fast-growing hardwood species which are native to floodplain environments (Baker and Blackmon, 1977; Harrington, et. al, 1979; Tuskan and De la Cruz, 1982).

Most experimental woody biomass plantations have been located on well-drained sites which are marginal for agricultural use. In the Mid-west, many poorly-drained sites in floodplains are also marginal for agriculture because of frequent flooding. These sites may be appropriate for biomass plantations which use fast-growing floodplain species, because these species are adapted to periodic flooding. Many floodplain soils are suitable for closely-spaced plantings because they have a high nutrient content (Peterson and Rolfe, 1982) and rarely have soil moisture low enough to induce physiological stress in woody plants.

The selection of appropriate species is critical if flooded sites are to be used for woody biomass production. There is a wide variety of native hardwood species which are potential candidates because of their fast growth rate and tolerance of flooding. There have been many studies of the relative growth of hardwood species under various flooding regimes (Hosner, 1960; Hosner and Boyce, 1962; Dickson, et. al., 1965; Hook and Brown, 1973; Baker, 1977). It is difficult to infer which species would be suitable for biomass plantings, however, because of the wide range of flooding treatments and tree age classes which were used. In addition, most of these studies focused on survival rates rather than measurements of biomass production.

Most of the studies cited above rate silver maple and American sycamore as highly tolerant to flooding. These species are native to Illinois floodplains and are both commercially available in large quantities as bare root stock suitable for mechanical tree planters. We investigated the flood tolerance of 1-year old planting stock of these species by simulating various flooding regimes which could occur in the field. The suitability of silver maple and sycamore for biomass production in flooded environments was assessed by analyzing a wide range of growth characteristics.

METHODS

One-year old bare root nursery stock of silver maple and American sycamore were obtained from a commercial nursery in northern Ohio. The seedlings were originally germinated from seed collected from a floodplain site near the nursery. All nursery stock was wrapped in sphagnum moss and stored at 4°C prior to planting.

Seedlings were planted on May 6, 1980, in plastic pots (20 cm diameter × 20 cm depth) containing potting soil composed of 3 parts silt loam field soil, 1 part sand, 1 part peat moss, and 1 part "Perlite". Seedlings were planted with each stem situated at its estimated original level with respect to the soil surface. All plants were placed in a shadehouse at 80% full sunlight and were protected from inputs of rainfall. Prior to establishment of treatments, plants were watered as necessary to keep the soil moist but not waterlogged.

Wet weight was measured for individuals of each species prior to planting. Dry weight/wet weight ratios were determined for each species by measuring the wet weight and dry weight (after drying at 80°C for 48 hr) of 20 individuals. Separate ratios were determined for aboveground and belowground biomass for each species.

All plants leafed out within 2 weeks after planting. Treatments were initiated on June 9, with eight individuals in each treatment and control group. Flooded plants were completely inundated in tanks with continuously circulating water. Control plants and nonflooded treatment plants were watered as necessary to keep the soil moist but not waterlogged. A control (nonflooded) group and 9 flooding treatments were established for each species. Treatments were various periods of early (E), late (L), and early and late (EL) periods of flooding. Duration of flooding within each of these groups was 10, 20, and 40 days as shown in Fig. 1. Treatments will be referred to hereafter as: C (control), E10, E20, E40, L10, L20, L40, EL10, EL20, EL40.

All plants were harvested 120 days after treatments were started. It was initially determined whether each plant was alive or dead. Height was measured to the nearest 0.5 cm above the soil surface. Aboveground biomass was separated into leaves and stems, and soil was removed from roots by gently rinsing with water. Plant tissue was dried at 80°C for 48 hr prior to determining leaf weight, stem weight, and root weight. Dry weight/wet weight and aboveground/belowground ratios were used to determine the initial (pre-treatment) biomass distribution of each individual.

Differences among treatments within a species were determined with analysis of variance and Duncan's multiple range test at the $P < .05$ level of significance. Differences between species within treatments were determined with a *t*-test at the $P < .05$ level of significance.

RESULTS AND DISCUSSION

Morphological Characteristics and Survival Patterns

Leaf necrosis was observed in most silver maple individuals after 10 days in treatments with early flooding. Leaf senescence was extensive after 20 days, and nearly all leaves had senesced after 40 days. Treatments with only late flooding had considerably less leaf necrosis and senescence. Most individuals had hypertrophied lenticels after 10 days of flooding.

American sycamore had less severe symptons of flooding damage. Extensive necrosis was observed only in treatments with 2-40 days of early flooding, and senescence was prominent only for treatments flooded for 40 days. Most individuals had hypertrophied lenticels after 20 days of flooding. Both silver maple and sycamore resumed leaf growth within a few days after 20 or less days of flooding.

Timing of flooding had a strong influence on the survival of the tree seedlings. Only treatments with early periods of flooding had any mortality. Only 2 out of 8 silver maple and 4 out of 8 sycamore survived the E40 treatment (Table 1). Silver maple had substantial mortality in both EL20 and EL40 treatments, while sycamore had mortality only in the EL40 treatment. These data suggest that the 1-year old sycamore seedlings had a greater capacity for survival than silver maple following long duration of flooding for the treatments used in this study. Late flooding had no effect on the survival of either species, probably because growth and assimilation processes were greatly reduced by the time the late treatments were initiated.

Growth Parameters

Treatments with early flooding were comparable to those with both early and late flooding for most growth measurements. Treatments with only late flooding generally has less growth reduction compared to the control group for both silver maple and sycamore.

Leaf biomass of silver maple was significantly less than the control group in all E and EL treatments (Fig. 2). Patterns of leaf production were similar between these groups, and there was only a minimal amount of leaf production in E40 and EL40. There was no significant reduction in leaf biomass in the L treatments however.

The actively growing seedlings probably suffered stomatal damage in the early flooding treatments. Stomatal closure is one of the first physiological responses of tree seedlings to flooding (Regehr, et. al., 1975; Sena Gomes and Kozlowski, 1980), and even flood-adapted species have a limited capacity for recovery of stomatal function after inundation. It has been shown that photosynthetic and transpiration rates of silver maple seedlings do not fully recover after 20 days of inundation (Peterson and Bazzaz, in press). The relatively high leaf biomass in the L treatments indicates that late flooding had little effect on leaf growth. This is because plant growth was relatively low when the late flooding period was initiated. Flooding during periods of negligible plant growth generally affects roots more than aboveground production (Teskey and Hinckley, 1977).

Sycamore leaf biomass was significantly reduced only in treatments E40 and EL40 (Fig. 3), which again indicates that early flooding treatments were more damaging. Sycamore leaf biomass was significantly greater than that of silver maple in all E and EL treatments, although control groups were not different. Sycamore appeared to be able to maintain leaf growth better than silver maple following long periods of inundation.

Silver maple stem weight was significantly reduced in all E and EL treatments, but was not reduced in any L treatments (Fig. 2). Sycamore stem biomass was significantly reduced only in treatments E40, L40, and EL40, and there was no difference among these treatments (Fig.3). Sycamore stem weight was greater than that of silver maple in all E and EL treatments, which suggests that sycamore stem growth was less affected by early flooding. Silver maple stem biomass was greater in treatments L20 and L40, however, which suggests that late flooding was detrimental to sycamore stem production. Stem growth of sycamore seedlings may continue later in the season than silver maple.

Silver maple root biomass was significantly reduced in treatments E20, E40, L40, and all EL treatments (Fig. 2). There was negligible root growth in treatments E40 and EL40. Sycamore root weight was significantly reduced in all treatments with 20 or more days of flooding, and there was no significant difference between and 20- and 40-day treatments. Silver maple root biomass was greater in all L treatments, while sycamore root biomass was greater in treatments E40 and EL40.

Early flooding was especially damaging to silver maple root growth, while late flooding was more damaging to sycamore. Flooding has been shown to cause root injury in seedlings of several species (Hosner and Leaf, 1968), and root death and inhibition of root elongation has been observed in previous studies of flooded sycamore seedlings (Tang and Kozlowski, 1982). Reduced root production slows the postflood recovery of seedlings because uptake and transpiration are greatly reduced.

The ratio "root biomass/aboveground biomass" varied considerably between the two species (Figs. 2 and 3). Since this ratio was higher in silver maple than sycamore for control plants, there was probably an inherent difference in biomass distribution for the seedlings. This may account for the higher root weight/aboveground weight ratio in silver maple in most of the treatments. This ratio was significantly reduced for both species in all treatments with 20 or more days of flooding. The root weight/aboveground weight ratio did not decrease beyond 20 days of flooding for either species.

Total biomass of silver maple was significantly reduced in all treatments with early flooding, with negligible growth in treatments E40 and EL40 (Fig. 2). Total weight of sycamore was significantly reduced in all treatments with 20 or more days of flooding (Fig. 3). Silver maple total weight was greater in treatments L20 and L40, while sycamore total weight was greater in all treatments with an early flood of 20 days or more. The susceptibility of silver maple to early flooding and of sycamore to late flooding is again apparent.

In addition to biomass production, height growth is critical for seedlings to compete with understory species for sunlight. This is especially true in energy plantation situations in which tillage practices can encourage annual weed production. Silver maple height growth was significantly reduced in treatments E20, E40, and all EL treatments (Fig. 2). Sycamore height growth was reduced only in treatments with 40 days of early flooding. Silver maple and sycamore had similar height growth across all treatments, so neither species would appear to have a competitive advantage for this growth parameter.

Biomass Increment

In addition to the growth parameters discussed above, the ratio "final weight/initial weight," or biomass increment, is critical in evaluating the relative performance of tree seedlings under different flooding treatments. This parameter provides additional information about the response of species to physiological stress, and indicates the capacity for seedlings to increase their biomass over the course of a growing season.

Silver maple had significant reductions in aboveground biomass increment only in early flooding treatments of 20 days or more (Fig. 4). Sycamore had exactly the same pattern (Fig. 5), and there was no significant differences between species for any of the treatments. Both species were able to substantially increase their aboveground biomass except when subjected to an early flood of 40 days.

Silver maple belowground biomass increment was significantly reduced in all treatments with 20 or more days of flooding (Fig. 4). Again sycamore had the same pattern (Fig. 5). The ratio was greater for silver maple in most cases, including the control, which suggests that greater relative root production was an inherent characteristic of this species.

The total biomass increment for both species was significantly reduced for early flood treatments of 20 days or more (Figs. 4 and 5). Large decrements of growth were observed as early flood duration increased. In contrast, late flood treatments had no significant effect on biomass increment. Although Figs. 4 and 5 suggest that silver maple total biomass increment was slightly larger than for sycamore, there are no significant differences between species due to large standard errors.

Most silver maple and sycamore seedlings were capable of increasing their aboveground biomass ⩾ 10 times if they were not subjected to early floods of 20 days or more. Late floods had little effect. Several silver maple treatments achieved nearly a tenfold increase in root production as well, while sycamore had a maximum belowground increment of about 5 times. Late floods did have a measurable effect on root production in both species.

CONCLUSIONS

In this study, we have attempted to differentiate between two species with respect to their suitability for biomass production in flooded environments. A variety of growth parmeters was measured, and conclusions about the relative growth of each species may vary depending upon which parameters are perceived to be most critical in the selection of species.

Aboveground biomass production is a critical factor in seedling growth because this is the portion of the trees which is normally harvested. Early periods of flooding were more damaging to leaf and stem growth in silver maple than in sycamore. However, the aboveground biomass increment for the two species was similar for most treatments, which suggests that they have approximately the same capacity for aboveground production with respect to initial weight. Only sycamore was affected somewhat by late flooding.

Although root biomass is not normally harvested, it plays a role in the physiological vigor of seedlings and indicates how production is allocated. Although seedling root production was inherently greater in silver maple, belowground weight was less than or equal to that of sycamore after 20 days of early flooding. Sycamore root production was affected considerably by late flooding as well as early flooding. The belowground biomass increment of silver maple was higher than that of sycamore in most cases, so although silver maple had lower biomass for some treatments, it had a greater capacity for increasing root production above its initial weight. Since biomass alone does not provide information on the physiological condition of roots, it is difficult to determine which species would have a competitive advantage.

There is no conclusive evidence for selecting either silver maple or American sycamore 1-year old nursery stock as superior for use in biomass plantations which are periodically flooded. Although silver maple may be more sensitive to early flooding, sycamore is more sensitive to late flooding. Overall physiological response, especially as indicated by biomass increment, is quite similar in most cases. Both species have the capacity to recover from moderate levels of flooding and produce substantial quantities of biomass in the first year following planting.

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Table 1. Number of living individuals (out of 8) in each treatment at the end of the 120-day treatment period.

	Treatment									
Species	C	E10	E20	E40	L10	L20	L40	EL10	EL20	EL40
Silver maple	8	8	8	2	8	8	8	8	5	1
American sycamore	8	8	8	4	8	8	8	8	8	6

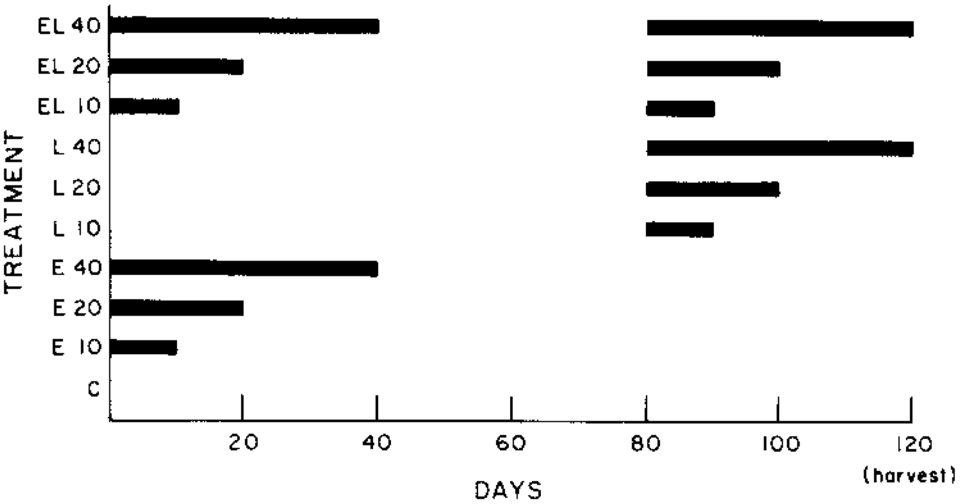

Fig. 1. Treatments used in the study, showing the timing and duration of periods of inundation. Treatments are abbreviated as: C (control), E (early), L (late), EL (early + late). Periods of flooding are 10, 20, and 40 days.

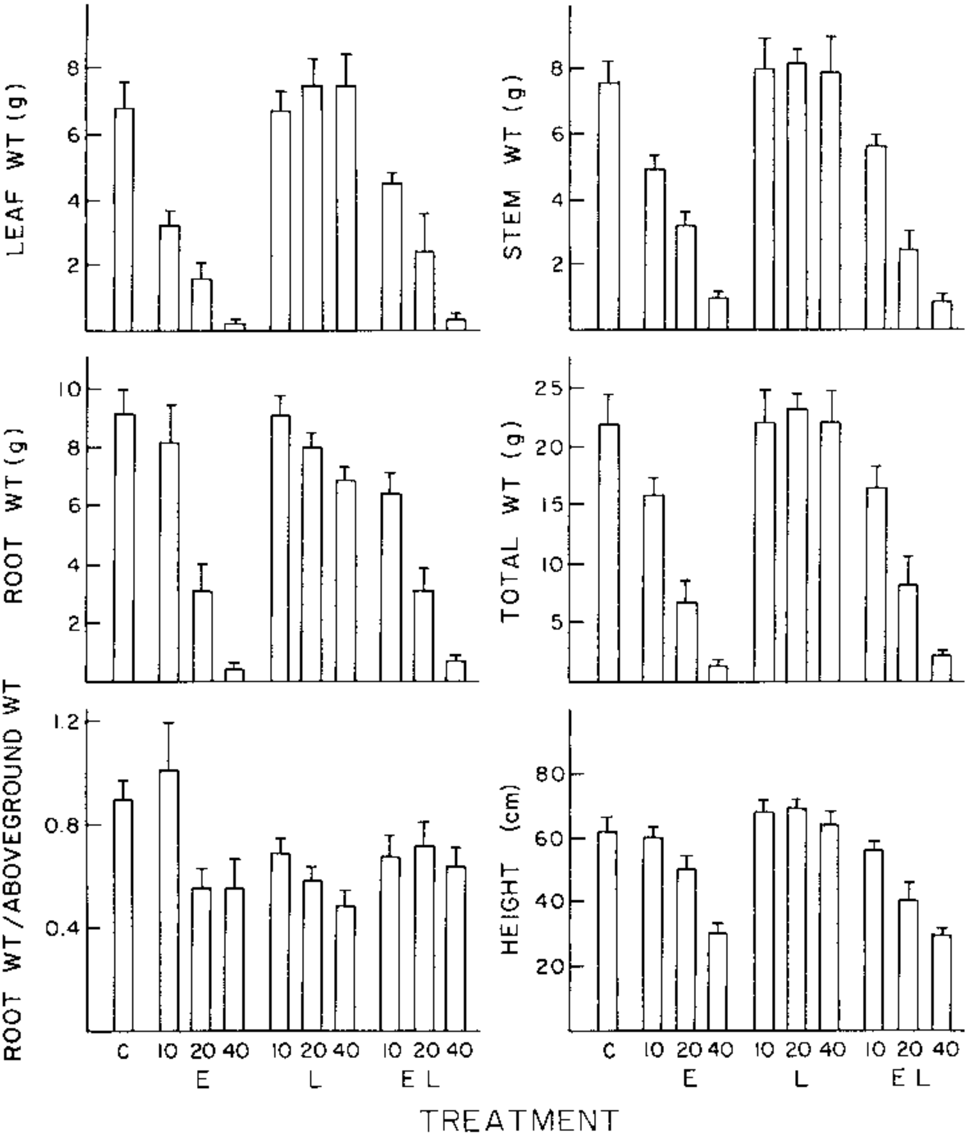

Fig. 2. Growth parameters for silver maple treatments. Aboveground weight is leaf weight plus stem weight. One standard error of the mean is indicated.

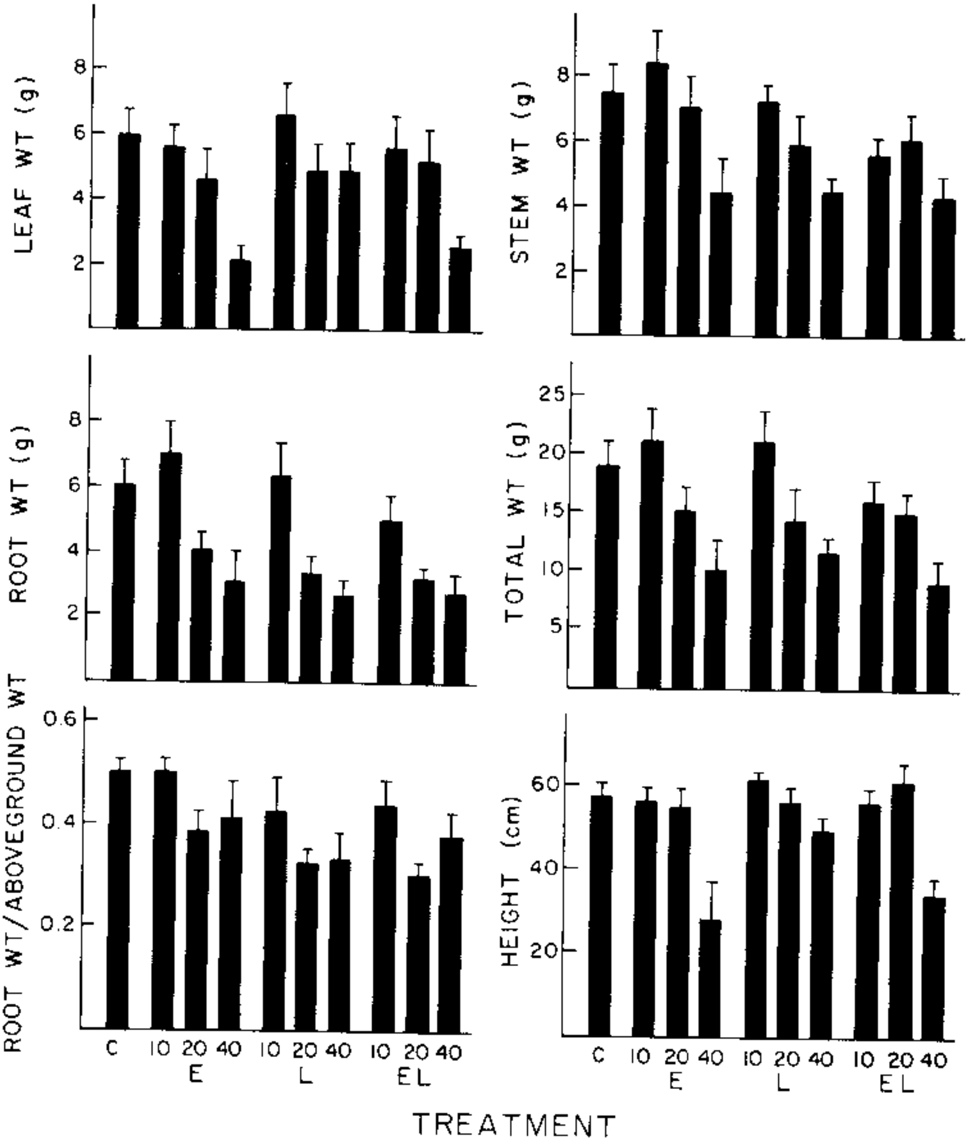

Fig. 3. Growth parameters for sycamore treatments. Aboveground weight is leaf weight plus stem weight. One standard error of the mean is indicated.

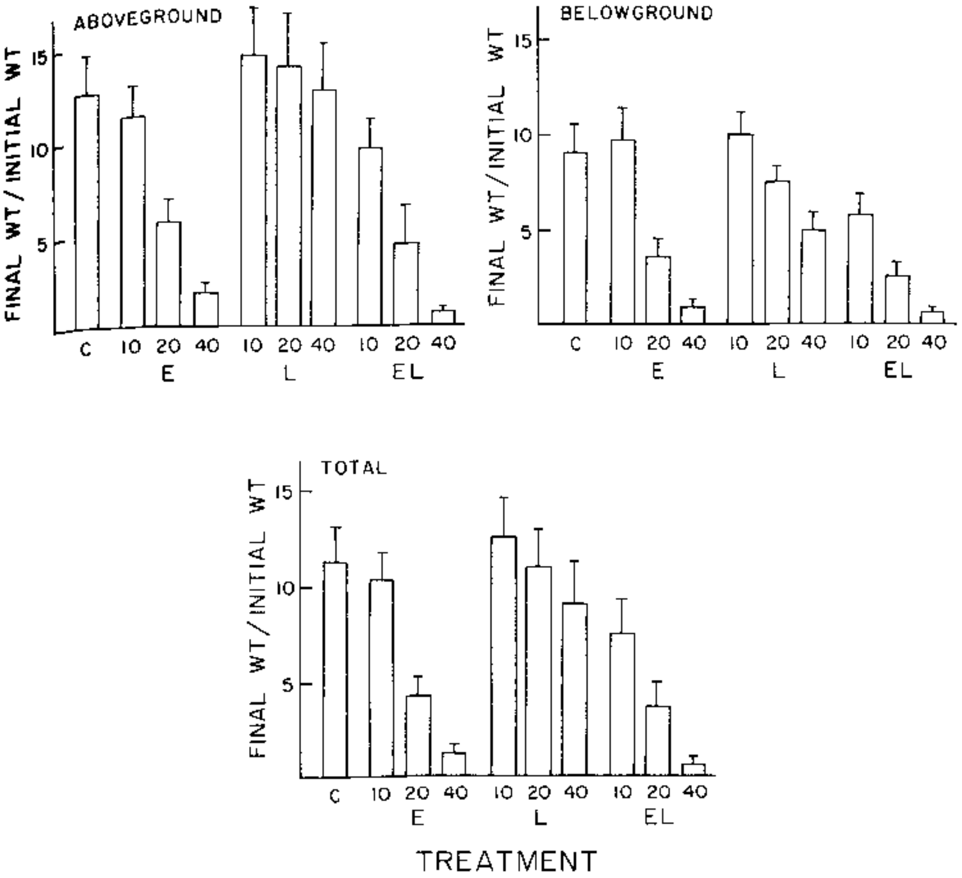

Fig. 4. Biomass increment for silver maple treatments. Aboveground weight is leaf weight plus stem weight. One standard error of the mean is indicated.

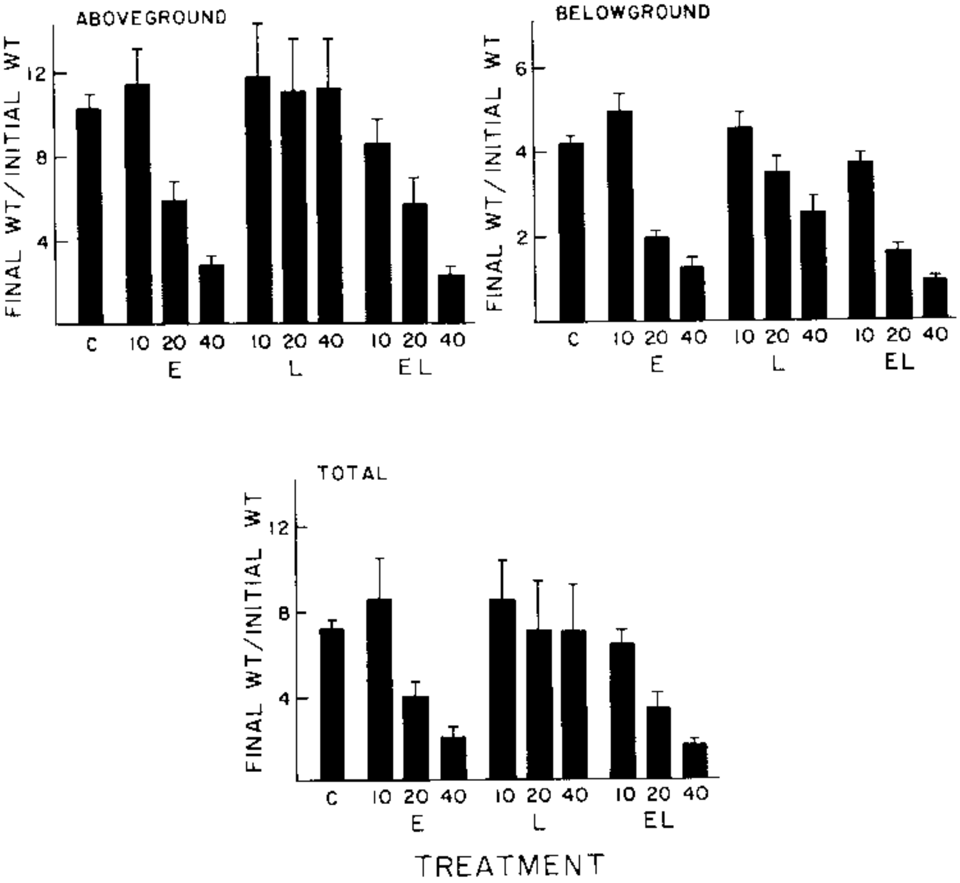

Fig. 5. Biomass increment for sycamore treatments. Aboveground weight is leaf weight plus stem weight. One standard error of the mean is indicated.