EFFECTS OF SHADE AND HERBACEOUS VEGETATION ON FIRST-YEAR GERMINATION AND GROWTH OF DIRECT-SEEDED NORTHERN RED OAK, WHITE ASH, WHITE PINE, AND YELLOW-POPLAR[1]

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Abstract. First-year seed germination and seedling growth of northern red oak, white ash, white pine, and yellow-poplar were evaluated in 12 environments consisting of four levels of herbaceous interference (fern, fern-free, grass, grass-free) crossed with three levels of light intensity (100%, 45%, 20% full sun) at three clearcuts in central Pennsylvania. Germination differed among species, ranging from 84% for northern red oak to 2% for yellow-poplar. Germination differed significantly among sites or levels of herbaceous interference for all species except yellow-poplar. Grass and fern interference significantly reduced height or stem diameter of all species. Decreased light intensity reduced fern biomass at one site, and grass biomass at two sites. Decreased light intensity in the absence of fern and grass interference significantly reduced height and stem diameter of all species except white pine, while light had no significant effect on growth of any species in the presence of fern and grass interference. Tolerance to both fern and grass interference and shading was greatest for white pine, intermediate for northern red oak, and lowest for yellow-poplar and white ash.

Additional keywords: *Fraxinus americana* L., *Liriodendron tulipifera* L., *Quercus rubra* L., *Pinus strobus* L., competitive ability, shade tolerance, weed-induced stress.

INTRODUCTION

Interference from herbaceous plants is widely recognized as being detrimental to establishment of forest trees in old-field plantings. Herbaceous interference also can be a problem in natural regeneration by clearcut or shelterwood methods. This is especially true in Pennsylvania, where many clearcut sites are rapidly invaded by persistent herbaceous vegetation. While the effects of competing vegetation can be reduced by herbicide treatments, effects of other environmental factors on interference-induced stresses are poorly understood. Site dominance by inherently slow-growing forest trees may depend on at least moderate levels of environmental stress that enhance their competitive ability by reducing the growth of inherently faster-growing plants, such as many herbaceous species (Grime 1979). For example, northern red oak (*Quercus rubra* L.) in the Ohio Valley and Allegheny Plateau often occurs more frequently on xeric, south-facing slopes in contrast to mesic, north-facing slopes (Carvell and Tryon 1959, Carvell and Tryon 1961, Hicks and Frank 1984, McCarthy et al. 1984, Whitney 1982). This pattern of occurrence suggests that some degree of environmental stress favors its ecological success.

This study compares the effects of herbaceous interference on first-year seed germination and growth of northern red oak, white ash (*Fraxinus americana* L.), white pine (*Pinus strobus* L.), and yellow-poplar (*Liriodendron tulipifera* L.) under different levels of light intensity. Herbaceous interference can reduce seedling growth of all these species (Farmer 1981, Bowersox and McCormick 1987, Von Althen 1972), but white pine and northern red oak are typically more tolerant to interference than white ash and yellow-poplar (Bowersox and

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McCormick 1987). They also differ in tolerance to shading. Seedlings of white ash are typically considered to be shade tolerant, northern red oak and white pine are intermediate in tolerance, and yellow-poplar is shade intolerant (Daniel et al. 1979, Fowells 1965). The primary hypothesis is that given the presence of herbaceous interference, stresses induced by shading will increase the growth of these species compared to that in full sun. Also, we expect that more shade tolerant species, such as northern red oak or white ash, will respond to shading in the presence of herbaceous interference more favorably than a less shade tolerant species, such as yellow-poplar.

METHODS AND MATERIALS

Seeds of northern red oak, white ash, white pine, and yellow-poplar were planted in spring 1987 into 12 environments consisting of four levels of herbaceous interference (grass, grass-free, fern, fern-free) crossed with three levels of light intensity (100%, 45%, 20% full sun). Each environment was replicated four times at each of three sites (four-hectares each) in the Ridge and Valley Province of central Pennsylvania (Harry's Valley, Laurel Run, Sandknob). All three sites were within 12km of each other on lower slopes in the same ridge system. All sites had similar topographic conditions except for aspect. Harry's Valley and Sandknob had a southeastern aspect and Laurel Run had a northwestern aspect. The sites received shelterwood cuts between 1970 and 1980 and were clearcut in 1984. Previous stands on all sites were dominated by oak species and the site index for northern red oak was about 70. All sites had unacceptably low numbers of advance regeneration of desirable tree species after harvest and were rapidly invaded by grass and fern communities. Numbers and composition of advanced regeneration and soil chemical properties for each site were described by Bowersox and McCormick (1987). Each site was enclosed by a five-strand electric fence to minimize deer browsing on seedlings.

In all environments, naturally occurring grass and fern communities covered from 80-100% of the soil surface at the onset of the study. Grass communities were primarily dominated by poverty oat grass (*Danthonia spicata* (L.) Beauv.), but also contained lesser proportions of *Rubus* L., goldenrod (*Solidago* L.), fireweed (*Erechtides hieracitolia* (L.) Rad.), whorled loosestrife (*Lysimachia quadrifolia* (L.) Ell.), hayscented fern (*Dennstaedtia punctilobula* L.), and sheep sorrell (*Rumex acetosella* L.). Fern communities were dominated by hayscented fern. Grass-free and fern-free environments were created by treating a $20m^2$ portion of each community with glyphosphate (1.7 kg/ha) in late-April and mid-June 1987. Grass-free and fern-free environments were both free of all herbaceous vegetation and differed only in herbaceous composition prior to the study. Grass and fern environments consisted of indigenous levels of herbaceous vegetation in each community. Woody stems were removed from all environments prior to the study.

At each level of herbaceous interference, treatments were applied using a split-plot design. Main plot levels of light intensity were randomly assigned to areas of 1m x 5m. Light levels of 45% and 20% full sun consisted of a canopy of black shade cloth which extended from the soil surface to a height of 1.2m. All sites were shaded from the first week of June to the end of October. Subplot levels of species were randomly assigned to planting spots at each light level. Seeds of all species were planted at Sandknob between April 15-16, Laurel Run between April 21-23, and Harry's Valley between May 1-5. Seed viability was evaluated by laboratory tests of germination over a 100-day period on samples of 300 seeds for each species.

Each species subplot consisted of a $1m^2$ area containing six planting spots for white ash, white pine, and yellow-poplar, and nine planting spots for northern red oak. Each planting spot contained one pre-stratified seed for northern red oak, six seeds for white ash, five seeds for white pine, and 30 seeds for yellow-poplar, planted to a depth of 2cm. A total of 1296 seeds of northern red oak, 5184 seeds of white ash, 4320 seeds of white pine, and 25,920 seeds of yellow-poplar were planted over all sites. At each planting spot, seeds were protected from animal predation by a 10cm length of PVC tubing (2.5cm diameter for northern red oak and yellow-poplar, 1.3cm diameter for white ash and white pine) inserted into the soil to a depth of 5cm. The top opening of each seed protector was covered by a metal rod to prevent small mammals from removing seeds. In grass and fern environments, seed protectors were in direct contact with herbaceous vegetation. All planting spots were watered one week after planting to insure initial adequate soil moisture.

After the last week of June, all planting spots with multiple germinants were thinned to two seedlings to minimize competition between trees. Seedlings grew in the presence of seed protectors over the entire season with no apparent detrimental effects. In mid-August, herbaceous growth was measured at each light level in grass and fern environments. At each level of light, all herbaceous biomass in a randomly selected $0.25m^2$ area was clipped, dried at 80°C for 24 hours, and weighed. Seedling height and stem diameter (1cm above the soil surface) were measured on the largest seedling in each planting spot in mid-October.

Cumulative germination percent, seedling height, stem diameter, and herbaceous biomass were analyzed by analysis of variance. Analyses of height, diameter, and germination were performed separately by species due to unequal error variances among species. All treatment effects were tested at the $p<0.05$ level. Mean

separations were performed using Fisher's protected least significant difference.

RESULTS

Germination

Germination percentages in laboratory tests were 70% for northern red oak, 85% for white pine, 6% for white ash, and 3% for yellow-poplar. In the field, end-of-season germination percentages averaged over all sites and environments were 84% for northern red oak, 48% for white pine, 20% for white ash, and 2% for yellow-poplar. Germination differed significantly among sites for all species except yellow-poplar. Average germination percentage for northern red oak and white ash was significantly greater at Laurel Run (90%, 31%, respectively) compared to Sandknob (82%, 13%, respectively) and Harry's Valley (81%, 15%, respectively). Average germination percentage for white pine was significantly greater at Sandknob (58%) and Laurel Run (52%) compared to Harry's Valley (32%). Germination differed significantly between levels of herbaceous interference at one site or more for northern red oak and white pine, but not white ash and yellow-poplar (Table 1). For northern red oak, germination percentages at all sites were significantly greater in the presence of grass and fern interference (mean of 88%) compared to interference-free environments (mean of 81%).

Table 1.--First-year percent germination[1] for northern red oak, white ash, white pine, and yellow-poplar with (Yes) and without (No) herbaceous interference at three sites, averaged over herbaceous communities and light levels. For each species, means in the same row followed by the same letter are not significantly different $p<0.05$.

	Northern red oak		White ash		White pine		Yellow-poplar	
Site	Yes	No	Yes	No	Yes	No	Yes	No
Laurel Run	91^a	88^b	32^a	31^a	53^a	51^a	2^a	2^a
Sandknob	86^a	79^b	14^a	11^a	59^a	57^a	2^a	2^a
Harry's Valley	88^a	75^b	13^a	16^a	46^a	19^b	2^a	2^a

[1]Each value is the average of 216 seeds of northern red oak, 864 seeds of white ash, 720 seeds of white pine, and 4320 seeds of yellow-poplar.

For white pine, germination percentage at Harry's Valley was significantly greater in the presence of grass and fern interference (mean of 46%) compared to interference-free environments (mean of 19%), while interference had no significant effect at Laurel Run or Sandknob. Light intensity had no significant effect on germination of any species.

Height growth

End-of-season seedling heights over all sites and environments averaged 18cm for northern red oak, 13cm for white ash, 8cm for yellow-poplar, and 7cm for white pine. Heights differed significantly among sites for all species, but differences were no more than 3cm for any species. At all sites, fern and grass interference at all levels of light intensity significantly reduced heights compared to interference-free environments for all species except white pine (Fig. 1). Effects of fern and grass interference were similar among sites for all species except yellow-poplar, where the average reduction in height at Sandknob (-54%) was greater than at Laurel Run (- 29%) or Harry's Valley (-26%). Averaged over all sites and light levels, herbaceous interference reduced the height of white ash by 65%, yellow-poplar by 60%, and northern red oak by 29% compared to interference-free environments. Northern red oak averaged 2.0 stem flushes in interference-free environments versus 1.2 flushes in grass and fern environments. Heights of all species did not differ significantly between fern and grass environments, or between grass-free and fern-free environments.

The effect of both fern and grass interference on northern red oak height was significantly greater in 100% sun than in shaded environments at both Harry's Valley and Sandknob, while effects of interference did not differ significantly among light levels at Laurel Run. Averaged over all sites, herbaceous interference reduced the height of northern red oak by 38% in 100% sun, 28% in 45% sun, and 20% in 20% sun. Effects of fern and grass interference did not differ significantly among light levels for other species.

Heights differed significantly among light levels in interference-free environments for all species except white pine, while light had no significant effect in grass and fern environments on any species (Fig. 1). In interference-free environments, average heights for northern red oak, white ash, and yellow-poplar were significantly greater in 100% sun compared to 45% and 20% sun. Decreasing light intensity from 100% to 20% sun in interference-free environments reduced the height of yellow-poplar by 40%, white ash by 31%, and northern red oak by 28%. Northern red oak in interference-free environments averaged 2.2 stem flushes in 100% sun, and 1.9 stem flushes in both 45% and 20% sun.

Diameter growth

End-of-season stem diameter differed significantly among sites for all species except white pine. Average differences among sites were no more than 0.7mm for all species. At all sites,

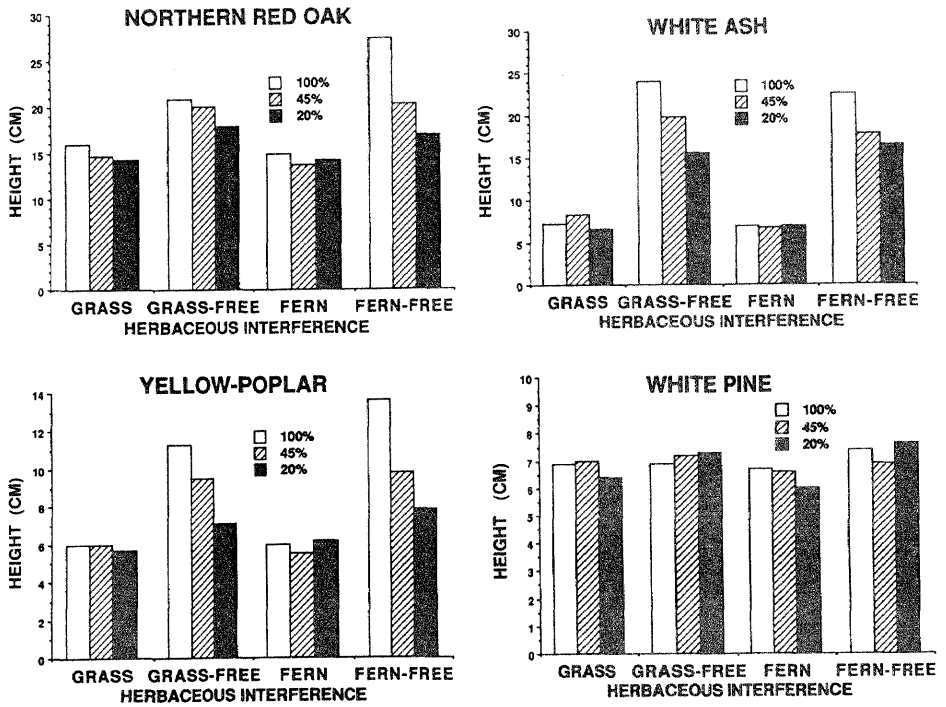

Figure 1.--First-year height of northern red oak, white pine, white ash, and yellow-poplar seedlings at four levels of herbaceous interference (grass, grass-free, fern, fern-free) and three levels of light intensity (100%, 45%, 20% sun). Each value is an average over three sites.

fern and grass interference at all light levels reduced stem diameter compared to interference-free environments for all species (Fig. 2).

For yellow-poplar, fern and grass interference reduced diameter more at Sandknob (mean of -64%) than at Harry's Valley (mean of -55%) or Laurel Run (mean of -54%). The effect of fern and grass interference did not differ significantly among sites for other species. Averaged over all sites and light levels, herbaceous interference reduced the diameter of white ash by 62%, yellow-poplar by 58%, northern red oak by 28%, and white pine by 23% compared to interference-free environments. Diameter did not differ significantly between grass and fern environments, or between grass-free and fern-free environments for any species except northern red oak, where average diameter in grass environments over all sites (3.1mm) was significantly greater than that in fern environments (2.8mm).

For northern red oak, the effect of fern and grass interference on diameter was significantly greater in 100% sun compared to shaded environments at Harry's Valley, while the effect of interference did not differ significantly among light levels at Laurel Run or Sandknob. Averaged over all sites, herbaceous interference reduced the diameter of northern red oak by 32% in 100% sun, 28% in 45% sun, and 24% in 20% sun compared to interference-free environments. Effects of fern and grass interference did not differ significantly among light levels for other species.

Diameter differed significantly among light levels for all species except white pine in interference-free environments, while light had no significant effect on any species in grass and fern environments (Fig. 2). In interference-free environments, average diameters for northern red oak and yellow-poplar were significantly greater in 100% and 45% sun compared to 20% sun, while average diameter for white ash was significantly greater in 100% sun compared to 20% sun. Decreasing light from 100% to 20% sun in interference-free environments reduced the diameter of yellow-poplar by 35%, white ash by 25%, and northern red oak by 20%.

Herbaceous growth

Oven dry herbaceous biomass in grass environments at Sandknob was significantly greater in 100% sun (230 g/m^2) compared to 45% (144 g/m^2) and 20% sun (125 g/m^2). Herbaceous biomass in grass environments at Harry's Valley was significantly greater in 100% (212 g/m^2) and 45% sun (198 g/m^2) compared to 20% sun (99 g/m^2). Light level had no significant effect on grass biomass at Laurel Run. Herbaceous biomass in

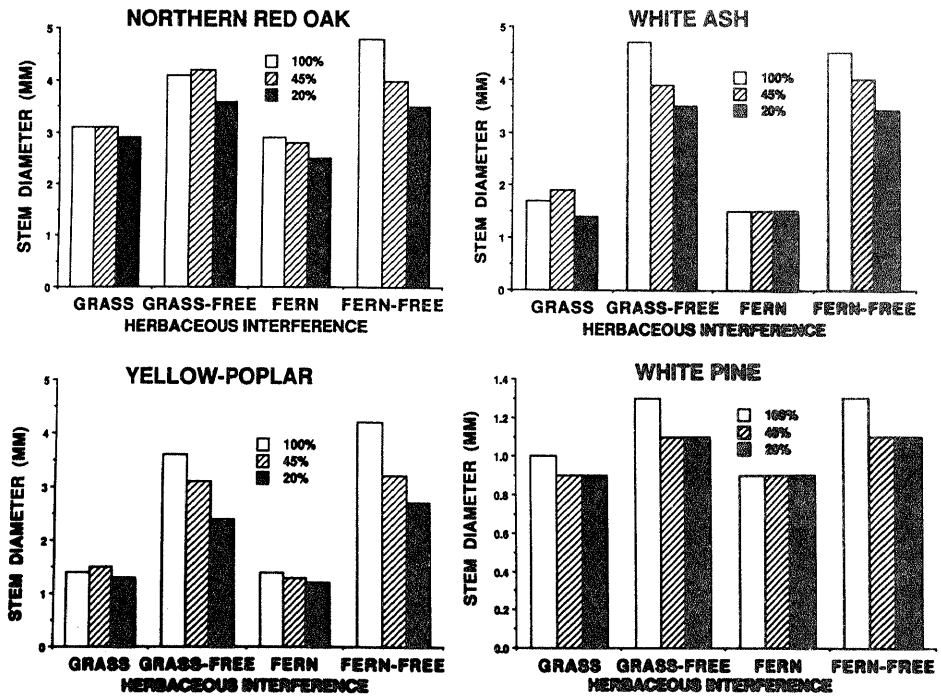

Figure 2.--First-year stem diameter (1 cm above ground level) of northern red oak, white pine, white ash, and yellow-poplar seedlings at four levels of herbaceous interference (grass, grass-free, fern, fern-free) and three levels of light intensity (100%, 45%, 20% sun). Each value is an average over three sites.

fern environments at Sandknob was significantly greater in 100% (270 g/m^2) and 45% sun (230 g/m^2) compared to 20% sun (140 g/m^2), while light intensity had no significant effect on fern biomass at Harry's Valley or Laurel Run.

DISCUSSION

Germination percentages in the field for northern red oak, white pine, and yellow-poplar were similar to or greater than those in laboratory tests, while field germination for white pine was considerably lower than that in the laboratory. This suggests that the seed protectors, planting methods, or environmental conditions at the study sites may have reduced germination of white pine, but not the other species. Average field germination after one year at any site was at best 90% for northern red oak, 58% for white pine, 31% for white ash, and 2% for yellow-poplar. Low first-year field germination of white ash and yellow-poplar is common - seeds normally remain viable in the soil and germinate over a period of years (Marquis 1975). Germination percentages for northern red oak and white ash were higher on a northwestern aspect (Laurel Run) than on the two southeastern aspects (Sandknob and Harry's Valley), while aspect had no consistent effect on germination of white pine and yellow-poplar.

Northern red oak's consistently greater germination in grass and fern environments compared to interference-free environments can be attributed to either a beneficial influence of herbaceous cover, or a detrimental effect of the glyphosphate herbicide used to control herbaceous growth. Glyphosphate has been reported to have no effect on northern red oak germination in forest soils (Shipman and Prunty 1988), suggesting that herbaceous cover aided germination, perhaps by moderating soil moisture.

Differences in first-year height growth among these species were directly related to initial seed size. Average height of northern red oak, the largest seeded species, was more than twice that of white pine and yellow-poplar, the two smallest seeded species. Species ranking in increasing susceptibility of first-year growth to herbaceous interference was: white pine, northern red oak, yellow-poplar, and white ash. This ranking of susceptibility to herbaceous interference is similar to that reported by Bowersox and McCormick (1987) for two-year growth of bareroot seedlings of these species planted on the same three sites. Species ranking in increasing susceptibility of first-year growth to shading (white pine, northern red oak, white ash, yellow-poplar) was similar to that for susceptibility to herbaceous interference. Thus, first-year tolerance to both herbaceous

interference and shading was greatest for white pine, intermediate for northern red oak, and lowest for yellow-poplar and white ash. Our ranking in shade tolerance for these species is fairly consistent with previous assessments (Daniel et al. 1979, Fowells 1965), except for placement of white ash. White ash is typically considered to be tolerant of shade as a seedling (Fowells 1965). For example, Logan (1973) reported greater growth of white ash seedlings in 45% compared to 100% sun. In contrast, growth of white ash seedlings in our study was greater in 100% compared to 45% sun.

Total above-ground growth of tree seedlings plus herbaceous plants was generally lower in shaded compared to full-sun environments. Shading reduced herbaceous growth at two sites, but had no effect on growth of any tree species in the presence of interference. This suggests a redistribution of total biomass from herbaceous plants to tree seedlings in response to shading. Despite the apparent more favorable competitive position of these tree seedlings in shade compared to full sun, seedlings of all species were still severely suppressed by herbaceous interference. Thus, the slight competitive advantage over herbaceous vegetation provided these tree seedlings by shading had little practical significance in the first growing season, although stronger differences may arise in later years.

CONCLUSIONS

1) Fern and grass interference had a slight beneficial influence on germination of northern red oak and, to a lesser extent, white pine, but not white ash and yellow-poplar.

2) Fern and grass interference reduced first-year growth of all species. Species' ranking in order of increasing susceptibility to interference was: white pine, northern red oak, yellow-poplar, white ash.

3) First-year growth of northern red oak, white ash, and yellow-poplar was reduced by levels of light intensity below one half full sun, while growth of white pine was unaffected by light levels as low as 20% full sun. Species' ranking in order of increasing susceptibility to shading was: white pine, northern red oak, white ash, and yellow-poplar.

4) Given the presence of fern and grass interference, levels of light intensity between 100% and 20% full sun had no effect on first-year growth of northern red oak, white ash, white pine, and yellow-poplar.

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