EFFECTS OF HAYSCENTED FERN DENSITY AND LIGHT ON WHITE ASH SEEDLING GROWTH

Tracy E. Hippensteel[1] and Todd W. Bowersox[2]

Abstract: Communities of hayscented ferns [*Dennstaedtia punctilobula* (Michx.) Moore] are present in many forested areas of Pennsylvania. These ferns can reduce the number and height growth of desirable tree seedlings. A study was conducted to determine the effects of fern frond density on the stem growth and leaf development of bare-root planted white ash (*Fraxinus americana* L.) seedlings. Treatments of 0, 25, 50, and 100% frond density created conditions of 0, 151, 271, and 448 g/m^2 of ovendry frond biomass in August. Amount and quality of sunlight passing through the fronds was measured. Shoot growth of the white ash seedlings was greatest in the 0% frond density (21 cm) and lowest in the 100% frond density (12 cm). A study using simulated fern fronds to alter sunlight conditions where root competition was not a factor was also conducted. White ash seedling stem growth was 23 to 45 cm for frond densities ranging from 80 to 0%. Reduced seedling shoot growth and changes in seedling leaf tissues associated with increased frond density were, in-part, due to changes in sunlight quality and quantity.

INTRODUCTION

In Pennsylvania and in other areas of the Northeast, the presence of hayscented fern [*Dennstaedtia punctilobula* (Michx.) Moore] often results in seedling establishment failure in hardwood stands. Hayscented fern can form a dense, nearly monospecific, ground cover beneath hardwood overstories following reproduction cuts. Dense ground covers of hayscented fern can reduce the number of desirable seedlings by 50-90% and inhibit seedling height growth by 40-60% (Horsley, 1983). When seedling growth is reduced, the seedlings are exposed to deer browsing for a longer period of time, seriously arrested advance regeneration development. Horsley (1993) recently has shown that reduced availability of light was the key factor preventing establishment and growth of black cherry (*Prunus serotina* Ehrh.) in Allegheny hardwood stands. We conducted two field studies to determine the effects of light altered by fern foliage on growth and development of planted white ash (*Fraxinus americana* L.) seedlings.

LITERATURE REVIEW

Competition for Light

Competition for light occurs when one species because of more rapid growth, taller stature, or established presence casts shade on another species, thereby limiting its growth. Competition for light differs in several ways from competition for other resources needed for plant growth. Basically, this difference arises from the nature of the supply of the resources. With water or nutrients there is a reservoir from which all competitors draw. It may be a virtually limitless supply or it may be a fluctuating or inadequate supply, such as occurs when soil moisture alternates between field capacity and wilting point. The situation for light is quite different; there is no reserve. Instead, light energy is instantaneously available and it must be instantaneously intercepted by leaves or it will be lost as a source of energy for photosynthesis. Light cannot accumulate in the environment for later use.

---

[1]Environmental Consultant, J.H. Carter III & Associates, P.O. Box 891, Southern Pines, NC 28387.

[2]Professor of Silviculture, School of Forest Resources, Pennsylvania State University, University Park, PA 16802.

A vital relationship in competition for light is one of physical position, the position of the foliage relative to the foliage of its competitors. Allocation of carbohydrate to new photosynthetic surface area will result in an exponential increase in growth. Increased growth may allow the development of a plant canopy that will shade a competitor, thereby reducing its growth and ability to exploit available resources. Allocation to below ground structures, although necessary for water and nutrient uptake, increases respiratory demand and decreases carbohydrates available for canopy development.

As one plant overtops another, not only is the quantity of light changed but also the quality. Plant canopies act not only to weaken but to filter sunlight. For plants growing under a vegetative canopy, there are three spectral changes which are of potential physiological significance. First, the quantity of photosynthetically active radiation is drastically reduced; second, a marked reduction in the quantity of radiation in the blue waveband; and third is the strong depletion of the red waveband and relatively weak reduction of the far-red waveband. These spectral changes occur as a result of the selective spectral absorption of leaves (Federer and Tanner, 1966). Light arriving at a green leaf is absorbed selectively, the remainder being scattered (reflected or transmitted). The blue and red (450-500 nm and 650-700 nm, respectively) wavebands are absorbed strongly, the green waveband is less strongly absorbed and the far-red is almost entirely reflected or transmitted (Holmes, 1981). The ratio of red to far-red radiation is expressed by R:FR which is the ratio of the photon fluence rate in 10 nm wide wavebands centered at 660 nm and 730 nm respectively (Holmes, 1981). Red:far-red during daylight, irrespective of time of year and weather conditions, remains remarkably constant, averaging 1.15 + 0.02 (Smith, 1982).

The first person to make accurate measurements of the radiation spectrum on a forest floor was Knuchel (1914) who used a spectrophotometer. Unfortunately his measurements did not extend beyond 650 nm.

Seybold (1936) and Engle (1937) made measurements with glass filters which extended to 720 nm, but the wave bands were not sharply defined. These measurements clearly showed that the light in a forest is relatively rich in far red and near infrared. Only recently have suitable interference filters become available which make satisfactory field measurements possible.

Dirmhirn (1964) made measurements (between 400 nm and 1100 nm) under a group of walnut trees using a monochromator with interference filters. Federer and Tanner (1966) made measurements with a similar instrument under different stands in a wavelength range of 400-740 nm. Goodfellow and Barkham (1974) used an ISCO Spectroradiometer to measure quantity of radiation in the range 380-1100 nm in a beech forest. More recently, the LI-COR Spectroradiometer has become available and is capable of a similar range of readings (300 nm-1100 nm).

As early as 1936, Meischke drew attention to the fact that germination of many seeds is inhibited by far-red light, the wavelength band which is very strongly transmitted by green leaves. He concluded that under natural conditions this inhibition might occur under dense vegetation and showed in an experiment that light filtered through a leaf could inhibit seed germination (Stoutjesdijk,1972).

Smith (1982) found that low R:FR light led to increased petiole length, reduced leaf area, increased stem dry weight, reduced branching, and changes in chlorophyll content. Thus there is strong evidence that plants are able to detect and react to both light quantity and R:FR levels associated with vegetation shade.

A typical spectral photon distribution for daylight between 400 nm and 800 nm at a station at 53°N latitude, under a clear midsummer sky and near midday, is shown in Figure 1 (Holmes and Smith, 1977a). There is some decrease in fluence rate at the blue end, but between 450 nm and 850 nm the photon fluence rate is remarkably uniform, being interrupted only by O_2 and H_2O absorption troughs.

Under a vegetative canopy, Figure 1 (Holmes and Smith, 1977b), highest transmission occurs beyond 700 nm which is maintained to 900 nm or 1100 nm. The transmission curve for the visable region shows a slight minimum being found between 425 nm and 475 nm and at 675 nm, with a maximum at 550 nm. This is explained by the absorption and reflection spectra for deciduous leaves. Within the visible spectrum a certain amount of radiation will be

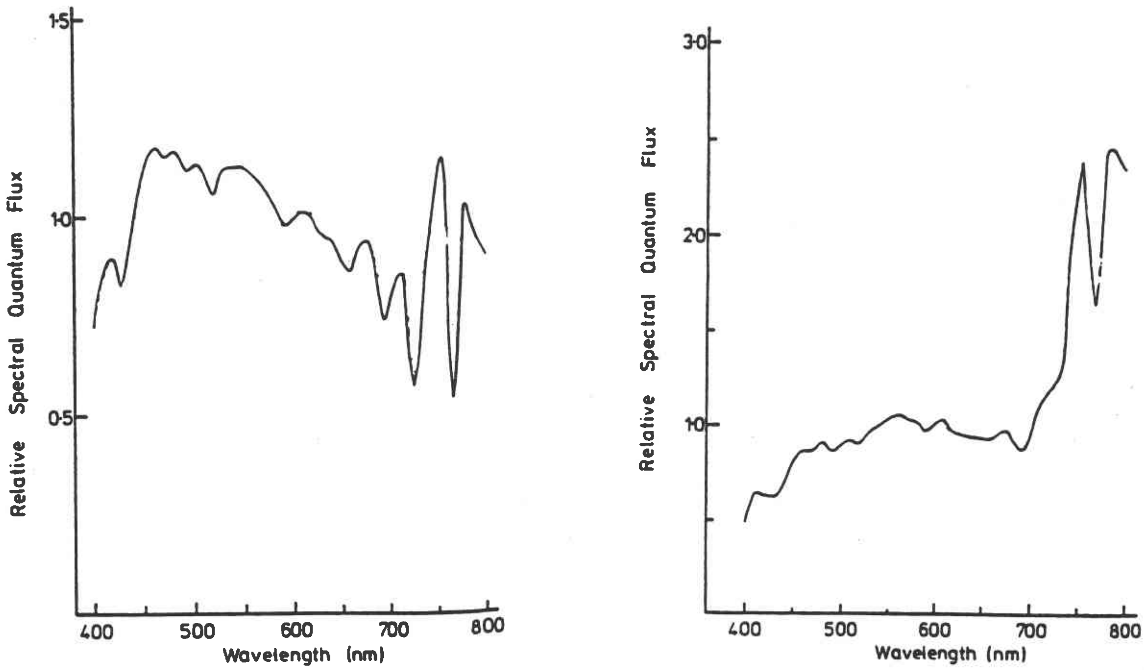

Figure 1. Light quality spectrum under clear skies, left (Holmes and Smith, 1977a); and light quality spectrum under a wheat canopy, right (Holmes and Smith, 1977b).

absorbed in all wavebands, but at 440 nm and 670 nm, the peaks of the photosynthetic action spectra, absorption is strongest. Other wavebands will be subjected to greater amount of transmission and reflection by the canopy. At 550 nm absorption is at a minimum, and the amount of radiation reflected and transmitted will be high. Similarly, beyond 700 nm in the far red and near infrared wavebands, absorption is low and these wavelengths therefore figure prominently under vegetative canopies.

Hayscented Fern

Hayscented fern [*Dennstaedtia punctilobula* (Michx.) Moore] is a native perennial fern of North America with its range centered in the Appalachian region and extending into adjacent parts of eastern Canada and eastern United States (Cody et al., 1977).

It reproduces both sexually and asexually. Sexually it produces spores which are released in late summer. Several million spores may be produced by a single well developed frond (Cody et al., 1977). These minute spores can travel through the air, depending on wind and other conditions, several hundred feet from the mother plant. These spores, given the correct conditions, generally bare, moist mineral soil, in a protected microsite will germinate and eventually produce a new fern plant (Groninger, 1991). Fern spores are known to be capable of germination under a very wide range of light intensities (Page, 1979). Light quality may also be of significance. In the wild, the vast majority of forest fern spores must be able to germinate successfully under low light conditions. The highest temperatures which permit germination are 30-35°C (Page, 1979). Most species of fern succeed between 10-20°C in high humidity and shade (Page, 1979). Once mature, spore production takes place regularly from year to year, showing very little fluctuation with annual variations in climate such as those that may produce good and bad seed years in Angiosperms (Page, 1979).

Asexually, ferns can reproduce by an extensive rhizome or root system which generally occurs in the mineral and organic soil layers generally 5-15 cm below the surface (Cody et al., 1977). The rhizome system produces frond buds which may remain dormant for one or two years and then develop into mature fern fronds. Two to five fronds is the common annual growth from each branch of the rhizome (Cody et al., 1977). The rhizome overwinters and produces new fronds in the spring and throughout the growing season. Where a single plant can spread its rhizomes and occupy and entire area, a frond density as high as 55,000 per hectare may occur (Page, 1979).

Horsley (1984), in a study comparing fern rhizome development in uncut and thinned Allegheny hardwood stands, found that rhizomes from thinned stands elongated more, and produced more nodes between forks than those from uncut stands. In the uncut stands 10-15% of the frond petioles bore rhizomes buds and these did not grow into new rhizomes unless the parent rhizome was injured. In the thinned stands, 55% of the frond petioles had rhizome buds and many of these grew into rhizomes the same year they were formed. This can possibly explain its rapid expansion in thinned or cleared areas.

There are three main stages in the annual development of the aerial part of the fern plant. The first stage is the fiddlehead stage which is characterized by a short straight rachis with a small curled top. This stage is visible from mid-April to mid-May. The second stage is the frond stage and is characterized by an increase in growth of the fiddlehead and the uncurling of the fern fronds to their full size. This stage occurs between mid-May and mid-September. The last stage is the dead frond stage. This stage is characterized by frond senescence, leaving the dried rachis which generally lies down on the soil and may persist for several years before degrading.

The only known method of totally eliminating hayscented fern is through the use of herbicides. The herbicides glyphosate (Roundup) and sulfometuron (Oust) are used in the northern hardwood forests of Pennsylvania to control hayscented fern (Groninger, 1991). Glyphosate must be applied to photosynthesizing foliage and has no soil residual activity. Sulfometuron, though, applied to exposed mineral soil may prevent the establishment of hayscented fern through spore germination (Groninger, 1991).

White Ash

Fraxinus americana (L.) grows most commonly on fertile soils with high nitrogen content and moderate to high calcium content. The absence of nitrogen reduces seedling dry weight by 38% (Schlesinger, 1990). Soil moisture is an important factor affecting local distribution. Natural regeneration from seeds will occur if the soil, humus, or leaf litter is wet in the spring. Best growth occurs in moderately well-drained soil. Tolerance to pH varies from 5.0 to 7.5 (Schlesinger, 1990). Seedlings are capable of withstanding protracted periods of soil drought and are intermediately tolerant to temporary flooding (Rink and Sambeek, 1987).

Young white ash exhibit strong apical dominance. Open-grown seedlings 2 m tall often have only two or three pairs of lateral branches. If the terminal bud is removed, apical dominance is altered and new branches develop from the uppermost pair of lateral buds. Generally one of these grows faster than the other and assumes dominance.

Seedlings develop best in 45% full sun or greater (Logan, 1973). Therefore, silvicultural systems that provide sunlight, such as shelterwood or clearcutting, have been recommended for white ash. When seedlings are young, they are shade tolerant but with age they become more intolerant. Seedlings are capable of survival under a canopy with less than 3% full sun, but they show very little growth at these light levels (Schlesinger, 1990). Under good conditions, they complete 90% of their height growth in 30 days and complete 100% in 60 days. Diameter growth continues until August (Schlesinger, 1990).

Despite its low shade tolerance, white ash is characteristic of intermediate as well as early stages of plant succession. Throughout its range it is a minor but constant component of both the understory and overstory of mature forests on suitable soils. It owes its position in the final overstory to its ability to persist for a few years in moderately dense shade and to respond quickly to openings in the canopy.

White ash was chosen for the studies based on its behavior in a study by Kolb et al. (1990). They studied the influence of light intensity on weed-induced stresses of tree seedlings (white ash, red oak, and white pine). They found that white ash produced the greatest height growth in interference-free environments but also showed the greatest reduction in growth in a fern environment. These results suggest that white ash has a lower tolerance to herbaceous interference than either red oak or white pine. For this reason white ash was chosen as the study species.

METHODS

The study site was located in the Rothrock State Forest, Huntingdon County, PA, in the Ridge and Valley Province of central Pennsylvania. The area chosen had a southeastern aspect with soils derived from sandstones. The soils were mapped as a Hazelton-DeKalb association having moderately rapid permeability, low to moderate water availability, severe erosion hazard, and medium runoff (Soil Survey of Huntingdon County, PA). Soil pH averaged 4.6 for the site. A shelterwood cut was made in the late 1960's prior to clearcutting during the 1984 growing season. The site index prior to any cutting activity was approximately 70 for oak. Oak species dominated the stand. The site now consists of 80-100% fern and grass communities.

Four areas measuring 8 m by 8 m were selected which contained a dense fern population. The 8 m by 8 m areas were divided into 4 m by 4 m sections with each section representing a fern treatment.

Four areas measuring 2 m by 8 m were selected adjacent to the fern treatment areas and were herbicided with glyphosate (Roundup) at a rate of 1.1 ai/ha one year prior to study initiation. The 2 m by 8 m areas were divided into four 2 m by 2 m sections with each section representing a shade treatment. All areas were cleared of brush and logging debris in the spring of 1991.

On April 19, 1991 one year old bare root, white ash (*Fraxinus americana* L.) seedlings obtained from the Pennsylvania Bureau of Forestry's Penn Nursery at Potters Mills, PA, were planted randomly in the designated areas. White ash was selected for this study because it had a substantial response to ferns in an earlier study (Kolb et al., 1990). The seedlings were top clipped to 10 cm and root clipped to 15 cm before planting. Each fern treatment received 24 seedlings with either one or two seedlings per meter square, a total of 384 seedlings for the fern treatment areas. Each shade treatment received 5 seedlings in each replication for a total of 80 seedlings for the shade treatment areas.

Each treatment in the fern plots was randomly assigned one of four density treatments; 100% fern, 50% fern, 25% fern, and 0% fern. The treatments assigned 100% fern were left untouched with the ferns being allowed to grow to their natural density. The 50% fern treatments were marked off with parallel lines every 0.25 m. The 25% fern treatments were marked off by a combination of parallel and perpendicular lines every 0.25 m.

Shade frames were built over the shade plots with each replication receiving four different shade treatments: 0%, 30%, 60%, and 80% shade. White PVC pipe was used as a frame to support black polypropylene shade cloth 1.2 m above the ground. The shade cloth also extended halfway down the side of the frame to eliminate large amounts of sidelighting but to allow for air circulation under the frames. A four-foot-high wire mesh fence was erected around each area to exclude deer.

Four gypsum moisture blocks and two copper-constantan thermocouples were installed at random locations at 7 cm depth in each fern treatment areas. Two gypsum blocks and one thermocouple were installed at random locations in each of the shade treatments. Soil moisture readings from the gypsum blocks and soil temperature readings from the thermocouples were taken once a week beginning in June and continuing throughout the study. The readings were taken between 11:00 AM and 1:00 PM.

Seedling heights from root collar to top of stem and stem diameters were measured after all treatment preparations had been made. Seedling growth (shoot growth from site of initiation on original stem) was measured every six weeks until mid-September. Any herbaceous vegetation which grew in the shade plots during the study was removed.

The fern treatments were clipped after the fern fronds had grown to about 50% of full size (May 25, 1991), but before bud break in the seedlings. In areas designated 0% fern, all of the fern fronds were cut off at the soil surface. In treatments designated 25% fern, every other 0.25 m wide strip was cut in both directions leaving 0.25 m^2 per 1.0 m^2 patch of fern. In areas designated 50% fern every other 0.25 m wide strip was cut leaving alternating strips of 0.5 m^2 fern and 0.5 m^2 of non-fern. In treatments designated as 100% fern, no ferns were cut. Since the seedlings were located randomly in the plots, some occurred in the fern strips whereas others occurred in the cut strips. Two 1.0 m^2 samples of fern fronds were collected from each treatment in each replication for a total of 8 samples for each treatment. The dry weight of the ferns per 1.0 m^2 were measured for each treatment and are shown in Table 1. Several days after the cutting treatments were completed the fern fronds leaned over and filled in the non-fern spaces in a somewhat uniform manner with the fronds facing in all directions. The areas were re-clipped once a month to maintain the cut strips.

Table 1. Average fern biomass per square meter ± SE as compared to 100% fern treatment. Ferns were collected from two 1.0 m^2 areas in each treatment of each replication for a total of 8 samples for each treatment. The ferns were then oven dried, weighed, and averaged among treatments.

Treatment	Dry Weight (g)	% Biomass
100% FERN	448 ± 28.1 g/m^2	100%
50% FERN	271 ± 18.2 g/m^2	60%
25% FERN	151 ± 21.9 g/m^2	30%
0% FERN	0 g/m^2	0%

Light quantity readings were taken under all treatments on July 10, 1991 with a LI-COR 191SA Line Quantum Sensor, Lincoln, NE. Two light quantity readings were taken in each treatment of each replication for a total of 8 readings per treatment. The line sensor is 1 m long and approximately 5 cm in height. The sensor was placed under the ferns in the fern treatments perpendicular to the cut strips so that fern/no fern strips were uniformly distributed across the sensor. The sensor was placed in the center of the shade treatments for the readings.

Light quality readings were taken randomly under each fern treatment with a LI-COR 1800 Spectroradiometer Lincoln, NE. Light quality readings were taken on two consecutive days (September 7th and 8th, 1991) with two readings per treatment per replication for a total of eight measurements for each fern treatment and one reading was taken in each treatment of each replication for a total of 4 readings for each shade treatment. The sensor was located approximately 18 cm off the ground and was approximately 4 cm in diameter. Readings were taken in both fern and cut areas of the fern treatments to try to get an average. All light readings were taken within two hours of midday in order to eliminate variations in light intensity and quality due to rapidly changing zenith angle of the sun. Readings were taken in reference to the horizontal surface under clear-sky, calm weather conditions.

The study was conducted for a single growing season and seedlings were harvested at the soil surface on September 17, 1991. Shoot growth was measured at this time and the leaves from each plant were removed and leaf area measured with a LI-COR Area Meter Lincoln, NE. The stem and leaves were then dried in a drying oven for 5 days and then weighed to obtain dry weights.

The data were treated as a randomized block experiment and analysis of variance (ANOVA) was run on the following parameters to test for significant treatment effects; shoot growth, dry weight of the stem, number of leaves, leaf area per plant, area per leaf, dry weight of the leaves, dry weight per leaf, and specific leaf area. Root length was not measured because the hardness of the soil due to lack of rain did not permit the extraction of the entire root system. Mean separations were performed on those parameters which showed significant treatment effects with Tukey's Method of Multiple Comparisons (0.05 was the level of alpha considered significant).

RESULTS AND DISCUSSION

Fern Treatments

Light Quantity. The range of light quantity readings, their averages and percentages are shown in Table 2. Light quantity readings taken in full sun were the basis for comparison. One would not expect this much variability in the ranges of light quantity as the Line Quantum Sensor is designed to reduce variability. The wide range in values for each treatment could be due to the variability of the fern populations and the nature of the treatments (fern/no fern strips). Another explanation is that in some areas the ferns were thicker (more fern fronds per unit area) than in other areas. Also the fern appeared more 'transparent' in some areas than in others, so more light may get through the more 'transparent' ferns.

Table 2. Light quantity ranges, averages, and percentages in the four fern treatments. The measurements were taken with a LI-COR Line Quantum Sensor under the ferns. Values are in μmol. The shade percentages were calculated relative to full sun (0% fern). The measurements were made within two hour of mid-day on July 10, 1991, with clear-sky conditions.

TREATMENT	RANGE (μmol)	AVERAGE	% SHADE	RANGE
0% FERN	1570-1985	1778	0%	-----
25% FERN	201-1413	545	70%	21-89%
50% FERN	136-781	277	84%	56-92%
100% FERN	5-162	53	97%	91-100%

Light Quality. Plants need light in the red and blue region (650-700 nm and 450-500 nm respectively) of the spectrum to carry out photosynthesis. The R:FR ratios (ratio of the photon fluence rate in 10 nm bands centered at 660 nm and 730 nm respectively) showed the reduction in red light as the fern densities increased. In the open the ratio was 1.13, under 25% fern the ratio was 0.84, under 50% fern was the ratio was 0.31, and under 100% fern the ratio was 0.20. The averaged light quality measurements are shown in Figure 2. The graph shows not only a reduction in light quantity but a large change in light quality in the wavelength range from 300-700 nm for the 100% fern and 50% fern treatments. This graph is similar to Figure 1 shown previously. So light penetrating a fern canopy is almost entirely far-red in quality, unusable by plants.

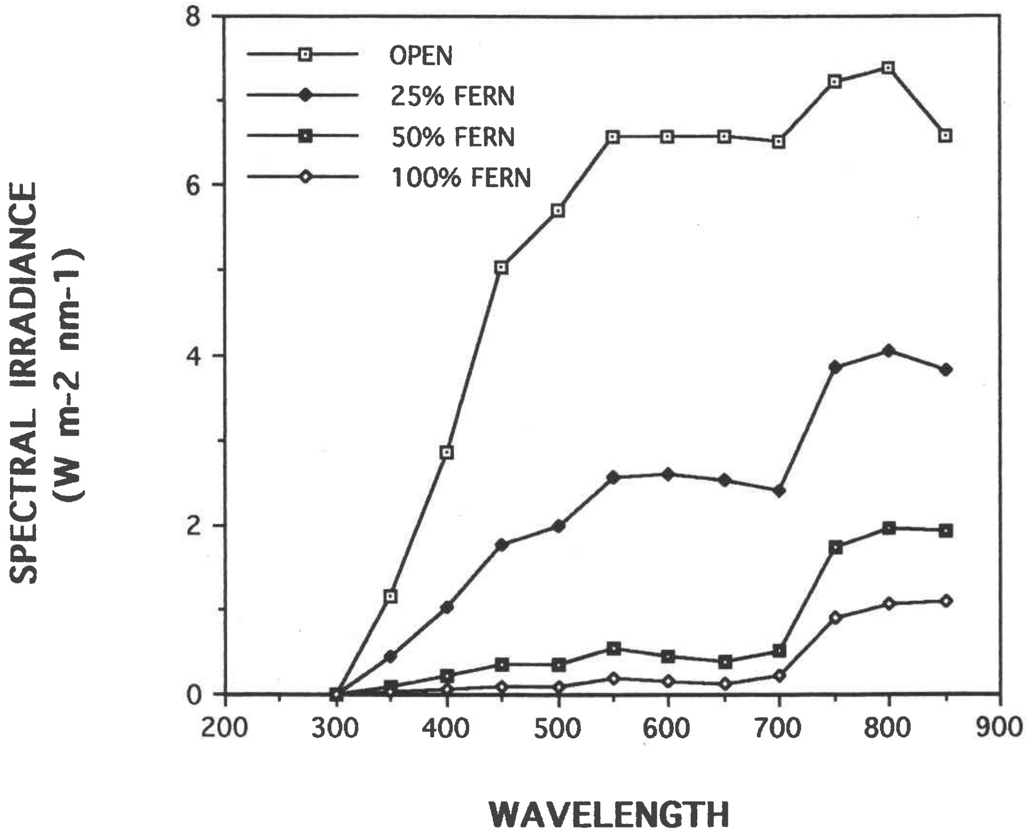

Figure 2. Average spectral irradiance values for the four fern treatments by wavelength. The measurements were made with a LI-COR Spectroradiometer. Each point is an average of 8 measurements.

Soil Moisture. Measurements taken with the gypsum blocks in all four treatments showed no significant difference between the treatments. Soil moisture fluctuated by month with rainfall events as recorded by The Agricultural Research Center at Rock Springs located approximately 12 km northwest of the study site. In general percent soil moisture increased after rainfall events as would be expected. Overall the soil moisture percentages seem much higher than would be expected in the field. The reason for this is unknown. Lower readings would be expected because of the low amounts of rainfall received in the 1991 growing season.

Soil Temperature. Soil temperature measurements showed that 0% fern treatments had significantly higher average soil temperatures at 7 cm depth than the 100% fern treatments. This difference averaged 2.5°C. The other treatments did not differ significantly. Kolb et al. (1989) found soil temperatures to be 4°C greater in fern free environments. In general, the 0% fern treatments had higher soil temperatures than the average air temperature for that particular day and 100% fern had lower average soil temperatures than the average air temperature for that day. The soil temperature difference between the 0% fern and 100% fern would be expected because there is less radiation reaching the soil surface beneath the ferns and so less soil heating.

Shoot Responses to the Treatments. Seedlings growing in the 0% fern treatment were significantly taller than all the other treatments averaging 20.6 cm of shoot growth (tallest stem measured from site of growth on initial stem) Table 3. Shoot growth of the seedlings growing in 25% fern, 50% fern, and 100% fern were not significantly different from each other. The average shoot growth was 12 cm in these treatments. So shoot growth was reduced

Table 3. Growth responses of white ash seedlings to different levels of hayscented fern cover. Means ± SE followed by the same letter are not significantly different at the P<0.05 level (n=96).

	TREATMENT			
RESPONSE	0% FERN	25% FERN	50% FERN	100%FERN
Shoot growth (cm)	20.6a ± 1.2	13.0b ± 0.60	11.3b ± 0.50	11.8b ± 0.60
Dry weight stem (g)	2.0a ± 0.27	0.65b ± 0.05	0.40b ± 0.03	0.33b ± 0.03
# Leaves/plant	16a ± 0.68	11b ± 1.08	8c ± 0.30	8c ± 0.33
Leaf area (cm^2)	503a ± 48.5	213b ± 13.3	156b ± 8.6	144b ± 9.3
Area/leaf (cm^2/leaf)	28.5a ± 1.5	19.9b ± 0.95	19.6b ± 0.89	18.8b ± 0.93
Dry weight leaves (g)	3.1a ± 0.30	1.0b ± 0.07	0.7b ± 0.04	0.5b ± 0.03
Dry weight/leaf (g/leaf)	0.18a ± 0.01	0.1b ± 0.005	0.08c ± 0.004	0.07c ± 0.003
Specific leaf area (cm^2/g)	167d ± 2.7	213c ± 3.9	241b ± 4.2	284a ± 6.1

40% in the presence of any amount of fern. Others have studied seedling height growth under fern and have also found that height growth is severely inhibited by the presence of ferns (Drew, 1988; Horsley and Marquis, 1983; Kolb et al., 1990).

Reasons for the reduced growth of seedlings under fern canopies have been proposed and studied by some authors. Allelopathic studies have been done on hayscented fern by Horsley (1977). He demonstrated that black cherry seedlings watered with nutrient solutions containing foliage extracts from hayscented fern reduced their growth. In future studies though, he dismisses the allelopathic effects of hayscented fern (Horsley, 1986).

Drew (1988) in his paper on the interference of seedling growth by hayscented fern and whorled aster suggests competition for soil nitrogen and forest microsite as the possible cause of reduced growth under the ferns and also suggests the reduced light environment under the ferns as a cause.

Stem (new growth taken from site of initiation on initial stem) dry weights showed results similar to shoot growth with the 0% fern treatment producing the most stem biomass; averaging 2.0 g (Table 3). The three fern treatments did not differ significantly; averaging 0.5 g per stem.

Leaf Responses to the Treatments. The seedlings growing free from above ground competition (0% fern) had larger leaves than the trees with above ground competition (Table 3). The 0% fern treatment averaged 28.5 cm^2/leaf and the 25% fern, 50% fern, and 100% fern did not differ and averaged 19.4 cm^2/leaf.

The largest dry weight per leaf averaged 0.18 g/leaf and was measured in the 0% fern treatment. This was significantly greater than all other treatments. The 25% fern treatment (0.10 g/leaf) differed significantly from 100% fern treatment (0.07 g/leaf), but did not differ from the 50% fern treatment (0.08 g/leaf). The 50% fern treatment dry weight per leaf did not differ from that of the 100% fern treatment.

Specific leaf area (SLA) is a measurement of area per unit weight and gives an indication of leaf expansion. Generally SLA increases in low light as a result of the formation of thinner leaves with a higher water content (Corre, 1983; Morgan and Smith, 1981; Nygren and Kellomaki, 1983). The results of this study produced similar results with all treatments being significantly different. The seedlings in the 0% fern treatment with the lowest SLA averaging 167 cm^2/g and seedlings in the 100% fern treatment with the highest SLA averaging 284 cm^2/g.

One reason for the general reduced shoot growth under the ferns was both a reduction in the amount and a change in quality of light passing through the ferns. The amount of light was reduced to 3-30% of full sun in the presence of 25-100% ferns. From Figure 2, it is clear that the R/FR ratio has changed significantly. Studies show that white ash is capable of survival but not growth under a canopy with less than 3% full sun, but they show very little growth under these circumstances (Schlesinger, 1990). In this study light varied from 100% sun to almost 0% sun and the seedlings survived, but showed very little growth. Only the above ground portion of the fern plant was manipulated, leaving the entire rhizome system intact. Perhaps the rhizomes have more of an influence on seedling growth than the fronds, since the rhizome system remained constant in all the treatments.

Shade Frame Treatments

Light Quantity. The light quantity readings taken under the shade treatments were consistent with the shade ratings of the nylon shade cloth used (30%, 60%, 80%), varying only 2-3% from the rating.

Light Quality. Light quality readings under the shade treatments (Figure 3) show the reduction in quantity but also show that the general shape of the spectra remained constant. Wavelength quantities were proportionately reduced, but all wavelengths remained in the spectrum. There was no reduction in the proportion of red light to far red light. The R:FR ratios under the shade treatments remained constant averaging 1.10 which is very similar to readings taken by Smith (1982) whose R:FR ratio in daylight averaged 1.15.

Soil Moisture. Measurements taken with the gypsum blocks in all four treatments showed no significant difference among them. Overall soil moisture remained fairly high throughout the study despite the low amounts of rainfall. Again soil moisture percentages seem very high for unknown reasons.

Soil Temperature. Soil temperature measurements showed that 0% shade treatments had significantly higher soil temperatures than all the other treatments. The 30%, 60%, and 80% shade treatments did not differ significantly. There was an average of 3°C difference between 0% shade and 30% shade, and average of 3.5° C between 0% shade and 60% shade, and and average of 4.5° C between 0% shade and 80% shade. In general, 0% shade treatment produced the highest soil temperatures which averaged above the average air temperature. Generally, the 30%, 60%, and 80% shade treatments averaged below the average air temperature.

Since the shade cloth produces an artificial environment some of its affects on the environment beneath it needs to be discussed. First there is reduced air circulation and so less evaporation of soil moisture. Second, there is less radiation reaching the soil surface and so cooler temperatures both beneath the cloth and in the soil. Rainfall amounts reaching beneath the shade cloth were probably different for all treatments since the shade cloth trends to intercept rainfall (different rainfall amounts were intercepted depending on the density of the shadecloth) and direct it off of the plots, running down the sides of the frames. Despite this redirection of rainfall, it seemed definitely damper under the shade cloth than in the open. This is probably due to the lack of air circulation and radiation under the cloth which would increase evaporation.

The shade cloth environments would compare to the different levels of shade cover in the following ways; first, under the ferns there would also be reduced air circulation, especially in the 100% fern. Second, the ferns also intercept radiation and rainfall much in the same manner as the shade cloths, with different levels of fern intercepting different amounts of each. So although different in composition and appearance, the shade cloth and the fern cover do produce similar results in the way of reducing air circulation, reducing radiation, and intercepting rainfall. The main difference being the selective spectral absorbance of the ferns.

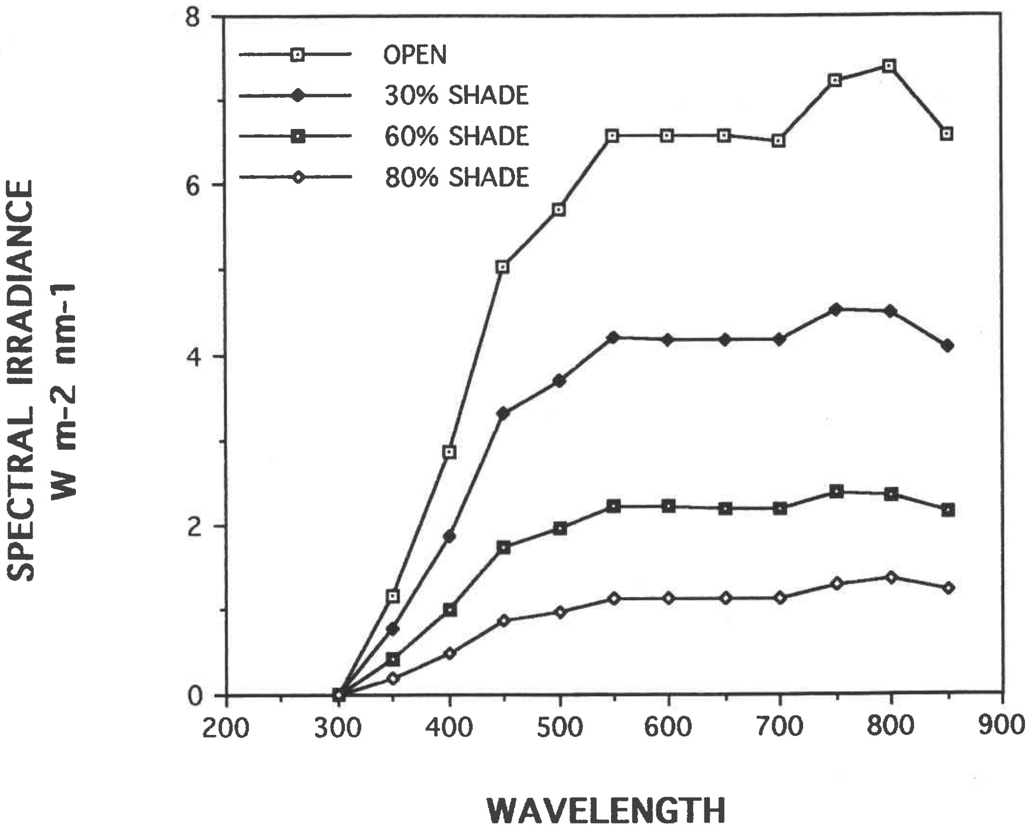

Figure 3. Average spectral irradiance values for the four shade treatments by wavelength. The measurements were made with a LI-COR Spectroradiometer. Each point is an average of 4 measurements.

<u>Shoot Responses to the Treatments</u>. Analysis of shoot growth (Table 4) shows that seedlings in the 30% shade treatment produced the best height growth averaging 44.7 cm in height (tallest stem). The 30% and 0% shade treatments did not differ significantly though and average growth between the two was 42.2 cm. The 0% shade treatment did not differ from the 60% shade treatment which averaged 34.4 cm in height. The 60% shade treatment did not differ from the 80% shade treatment averaging 26.0 cm. Schlesinger (1990) found that white ash seedlings grow best in 45% full sun.

The dry weight of the stems show that 0% shade, 30% shade, and 60% shade were not significantly different averaging 6.8 g. The 60% shade treatment did not differ from the 80% shade treatment and averaged 3.1 g.

<u>Leaf Responses to the Treatments</u>. The number of leaves produced did not differ significantly between 0% shade, 30% shade, and 60% shade and averaged 23 leaves per plant. The 60% shade treatment and the 80% shade treatment did not differ and averaged 19 leaves per plant (Table 4).

Total leaf area per plant exhibited a similar trend as the number of leaves per plant. Generally the more leaves a plant has, the greater the total leaf area. The 0%, 30%, and 60% shade treatments did not differ significantly and averaged 1331 cm^2. The 60% shade treatment and the 80% shade treatment did not differ and averaged 875 cm^2 (Table 4).

Table 4. Growth responses of white ash seedlings to varying shade treatments. Means ± SE followed by the same letter are not significantly different at the P<0.05 level (n=20).

	TREATMENT			
RESPONSE	0% SHADE	30% SHADE	60% SHADE	80%SHADE
Shoot growth (cm)	39.7 ab ± 3.8	44.7a ± 3.3	29.2cb ± 3.2	22.9c ± 3.4
Dry weight stem(g)	7.9a ± 1.5	8.5a ± 2.1	4.0ab ± 0.78	2.3b ± 0.44
# Leaves/plant	24ab ± 1.9	26a ± 2.1	21ab ± 1.7	18b ± 1.4
Leaf area (cm^2)	1468a ± 252	1498a ± 227	1037ab ± 142	713b ± 112
Area/leaf (cm^2/leaf)	55.4ab ± 6.0	59.4a ± 6.7	51.1ab ± 6.3	37.0b ± 3.9
Dry weight leaves (g)	8.9a ± 1.5	8.3a ± 1.7	5.2ab ± 0.83	2.9b ± 0.45
Dry weight/leaf (g/leaf)	0.34a ± 0.04	0.33a ± 0.05	0.23ab ± 0.02	0.15b ± 0.02
Specific leaf area (cm^2/g)	165a ± 11.0	215a ± 28.0	284a ± 89.0	252a ± 8.5

Area per leaf measurements show the seedlings in the 30% shade treatment to have the largest leaves with 59.4 cm^2/leaf average. The 30% shade treatment though did not differ from the 0% shade treatment or the 60% shade treatments. The 0% shade, 30% shade, and 60% shade treatments averaged 55.3 cm^2/leaf. The 80% shade treatment though did not differ significantly from 0% shade or 60% shade either averaging 47.8 cm^2/leaf overall.

Dry weight per leaf shows that 0% shade, 30% shade, and 60% shade did not differ averaging 0.30 g/leaf. Again, 60% shade does not differ from 80% shade averaging 0.19 g/leaf.

Specific leaf area (SLA) surprisingly did not differ significantly between treatments but the expected trend is shown in the results (Table 4). Plants growing in low light intensity have a higher SLA than plants growing in a higher light intensity (Corre, 1983; Nygren and Kellomaki, 1983). In this study 60% shade had the highest SLA averaging 252 cm^2/g and 0% shade had the lowest average of 165 cm^2/g. Why 80% shade treatment did not produce the highest SLA is unknown. One possible explanation is that 80% shade is past the threshold for shade tolerance of white ash and so shading decreased leaf area instead of increasing it. Huxley (1967) and Wassink and Stolwijk (1956) found similar results where leaf area increased with increased shading up to a certain point and then decreased.

Comparison of the two field studies results shows some interesting points that warrant further research. Overall, all of the shade treatments showed better growth than any of the fern treatments. The 0% fern treatments showed 100% lower growth than the 0% shade treatments despite the fact that they received equal amounts of sunlight. The only difference between the two treatments was the presence of active fern rhizomes in the 0% fern treatments. So obviously light is not the only factor reducing the growth of the seedlings, there is also some sort of soil effect (Drew, 1988). Comparison of soil moisture in both treatments, indicate a difference in percent soil moisture between 0% fern and 0% shade, with 0% shade having greater soil moisture than 0% fern. Perhaps the fern rhizomes are still utilizing soil resources without the fern fronds being present. Perhaps this difference in soil moisture is one explanation for the difference in growth between these two treatments.

It is also possible that the fern litter produced by herbiciding the shade plots enhanced the nutrient supply in the shade treatments, thereby influencing growth. Soil nutrient levels were not intensively studied here so no definite conclusion can be drawn.

CONCLUSIONS

It is obvious from the results of these studies that hayscented fern [*Dennstaedtia puntilobula* (Michx.) Moore] definitely influences the growth of tree seedlings. These studies indicate that hayscented fern produces not only an above-ground influence through changes in light quantity and quality, but a below-ground influence where the causal factors are unknown.

The fern cover study showed that a range of levels of fern cover; 25%, 50%, or 100% did not produce significantly different growth of white ash. Again only the above ground portion of the fern plant was manipulated leaving the entire rhizome system intact. Removing all of the fern fronds produced a significant increase in growth, probably due to increased light.

The shade frame study brought out some interesting points. First, all of the shade frame treatments showed better growth than all of the fern treatments. The seedlings growing in the 80% shade treatments showed better growth than the seedlings growing in the 0% fern treatments, despite the fact that the seedlings in the 80% shade treatments are receiving 80% less light than the 0% fern treatments. Light cannot be the only limiting factor. Second, the seedlings in the 0% shade treatment grew 100% taller than the 0% fern treatment although both were receiving the same amount of sunlight. There must be a below ground influence, whether it be soil moisture differences, nutrient differences, or another means. Although this study focused on light, it was shown that light has perhaps only a very small influence. Further studies are needed to determine what influence the rhizomes have on the seedlings and the soil environment in general. At this point it can be concluded that fern- free conditions are necessary to attain the maximum height growth of seedlings.

REFERENCES

Cody, W.J., Hall, I.V., and Crompton, C.W. 1977. The biology of Canadian weeds 26. *Dennstaedtia punctilobula* (Michx.) Moore. Can. J. Plant Sci. 57: 1159-1168.

Corre, W.J. 1983. Growth and morphogenesis of sun and shade plants I. The influence of light intensity. Acta. Bot. Neerl. 32(1/2): 49-62.

Dirmhirn, I. 1964. Das Strahlungsfeld im Lebensraum. Akademische Verlagsgesellschaft, Frankfurt am Main.

Drew, A.P. 1988. Interference of black cherry by ground flora of the Allegheny uplands. Can. J. For. Res. 18: 652-656.

Engle, K. 1937. Zur Kenntnis des Lichtfeldes der Pflanzen und der Blattfarbstoffe. Planta. 47: 546-583.

Federer, C.A. and Tanner, C.B. 1966. Spectral distribution of light in the forest. Ecol. 47(4): 555-560.

Goodfellow, S. and Barkham, J.P. 1974. Spectral transmission curves for a beech (*Fagus sylvatica* L.) canopy. Acta Bot. Neerl. 23(3): 225-230.

Groninger, J.W. 1991. Occurrence and control of sexually reproduced hayscented fern. M.S. thesis, Penn State, University Park, PA. 75 p.

Holmes, M.G. 1981. Spectral distribution of radiation within plant canopies. In: H. Smith (Editor) Plants and the Daylight Spectrum. Academic Press, New York. pp.147-158.

Holmes, M.G. and Smith, H. 1977a. The function of phytochrome in the natural environment I. Characterization of daylight for studies in photomorphogenesis and photoperiodism. Photochemistry and Photobiology. 25: 533-538.

Holmes, M.G. and Smith, H. 1977b. The function of phytochrome in the natural environment II. The influence of vegetation canopies on the spectral energy distribution of natural daylight. Photochemistry and Photobiology. 25: 539-545.

Horsley, S.B. 1993. Mechanisms of interference between hayscented fern and black cherry. Can. J. For. Res. 23: 2059-2069.

Horsley, S.B. 1986. Evaluation of Hayscented fern interference with black cherry. Am. J. Bot. 73: 668-669.

Horsley, S.B. 1984. Hayscented fern rhizome development in uncut and thinned Allegheny hardwood stands. Am. J. Bot. 71(5): Part 2 80-81.

Horsley, S.B. 1983. Interference with desirable northern hardwood regeneration by herbaceous and woody plants. p. 81-93. In: Proceedings of regenerating hardwood stands, Penn State Forestry Issues Conference. March 15-16, University Park, PA.

Horsley, S.B. 1977. Allelopathic inhibition of black cherry. II. Inhibition by woodland grass, ferns, and club moss. Can. J. For. Res. 7: 515-519.

Horsley, S.B. and Marquis, D.A. 1983. Interference by weeds and deer with Allegheny hardwood reproduction. Can. J. For. Res. 13: 61-69.

Huxley, P. 1967. The effects of artificial shading on some growth characteristic of *Arabica* and *Robusta* coffee seedlings. I. The effects of shading on dry weight, leaf area, and derived growth data. J. Appl. Ecol. 4: 291-308.

Knuchel, H. 1914. Spektrophotometrische Untersuchungen im Walde. Mitt. Schweiz. Zentralanst. Forst. Versuchsw. 11: 1-94.

Kolb, T.E., Bowersox, T.W., and McCormick, L.H. 1990. Influences of light intensity on weed-induced stresses of tree seedlings. Can. J. For. Res. 20: 503-507.

Kolb, T.E., Bowersox, T.W., McCormick, L.H. and Steiner, K.C. 1989. 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. In: G. Rink and C.A. Budelsky (Editors), Proc. 7th Central Hardwood Forest Conference, 5-8 March 1989, Carbondale, IL. USDA Forest Service, North Central Forest Experiment Station, pp. 156-161.

Logan, K.T. 1973. Growth of tree seedlings as affected by light intensity. V. White ash, beech, eastern hemlock, and general conclusions. Canadian Forestry Service, Publication 1323. Ottawa, ON. 12 p.

Morgan, D.C. and Smith, H. 1981. Non-photosynthetic responses to light quality. In: P.S. Nobel, C.B. Osmond, and H. Ziegler (Editors), Physiological Plant Ecology I. Springer-Verlag, New York, pp. 109-134.

Nygren, M. and Kellomaki, S. 1983. Effect of shading on leaf structure and photosynthesis in young birches, *Betula pendula* Roth. and *Betula pubescens* Ehrh. For. Ecol. Manage. 7: 119-132.

Page, C.N. 1979. Experimental aspects of fern ecology. In: A.F. Dyer (Editor) The Experimental Biology of Ferns. New York, pp. 552-581.

Rink, G. and Van Sambeek, J.W. 1987. Variation among four white ash families in response to competition and allelopathy. For. Ecol. Manage. 18:127-134.

Schlesinger, R.C. 1990. *Fraxinus americana* L. In: R.M. Burns and B.H. Honkala (Technical Coordinators) Silvics of North America: 2. Hardwoods. Agricultural Handbook 654. U.S. Department of Agriculture, Forest Service, Washington, D.C. pp. 333-338.

Seybold, A. 1936. Ueber den Lichtfaktor photophysiologischer Prozesse. Jb. Wiss. Bot. 82: 741-795.

Smith, H. 1982. Light quality, photoperception, and plant strategy. Ann. Rev. Plant Physiol. 33: 481-518.

Stevenson, R.E. and S.P. Pennypacker. 1991. Meteorological summary for the Russell E. Larson agricultural research center at Rock Springs. The Pennsylvania State University, Department of Plant Pathology. Cont. No. 1888, 60 p.

Stoutjesdijk, P.H. 1972. Spectral transmission curves of some types of leaf canopies with a note on seed germination. Acta Bot. Neerl. 21(3): 185-191.

USDA. 1978. Soil survey of Huntingdon County, Pennsylvania. USDA Soil Conservation Service. 122 p.

Wassink, E.C. and Stolwijk, J.A. 1956. Effects of light quality on plant growth. Ann. Rev. Plant Physiol. 7: 373-400.