FERNS AS A FOREST FARMING CROP: EFFECTS OF LIGHT LEVELS ON GROWTH AND FROND QUALITY OF SELECTED SPECIES WITH POTENTIAL IN MISSOURI

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CHAPTER I
INTRODUCTION

Agroforestry in the United States is defined as “intensive land use management that optimizes the benefits (physical, biological, ecological, economic, and social) from biophysical interactions created when trees and/or shrubs are deliberately combined with crops and/or livestock” (Gold et al. 2000). One of the five widely recognized agroforestry practices is forest farming. Forest farmers manage various layers of the forest structure to maximize sustainable harvests of forest products (Becker and Workman 2004). This is accomplished by thinning existing stands of timber and uses the canopy as shade for a harvestable understory crop. This type of forest utilization may prove especially profitable in Missouri where 11.3 million acres of commercial forests are privately owned (Secretary of State – Matt Blunt 2003).

PURPOSE

The purpose of this research is to quantify the effects of various levels of light intensity on selected fern species believed to have potential use in the floral green and landscape industries and, to determine the feasibility of commercially grown ferns in Missouri.
OBJECTIVE

The primary objective of this research is to evaluate the growth response of selected fern species when grown in full sun, 50 percent shade, and 80 percent shade. Secondarily, the study is designed, through the assessment of quantitative and qualitative parameters, to identify species that might have value in the floral green and landscape industries in Missouri.

HYPOTHESES

Several hypotheses are presented and will be tested:

Hypothesis 1 - There is no difference in the amount of biomass measured in fresh weight for ferns grown under 80 percent shade, 50 percent shade, and full sun;

Hypothesis 2 - There is no difference in frond lengths of ferns grown under 80 percent shade, 50 percent shade, and full sun;

Hypothesis 3 - There is no difference in frond widths of ferns grown under 80 percent shade, 50 percent shade, and full sun;

Hypothesis 4 - There is no difference in surface area of ferns grown under 80 percent shade, 50 percent shade, and full sun;

Hypothesis 5 - There is no difference in the number of necrotic spots of ferns that are potentially useful in the floral green and landscaping industries when grown under 80 percent shade, 50 percent shade, and full sun;
Hypothesis 6 - There is no difference in the color of ferns that lend themselves to use in the floral green or landscaping industries when grown under 80 percent shade, 50 percent shade, and full sun.
FOREST FARMING

Agroforestry is divided into five practices; silvopasture, alley cropping, windbreaks, riparian buffer strips, and forest farming. In forest farming, high-value specialty crops that require some degree of shade are grown under the protection of the surrounding forest’s canopy. The canopy, or overstory, is judiciously modified and managed to provide the proper amount of shade necessary for the specialty crop (Hill and Buck 2000). Overstory trees are managed for high-value timber or veneer logs. In the event that the overstory canopy is not adequate to provide the necessary shade for the high-value understory crop, a rapidly growing mid-level canopy may be added that contributes to the shade needs of the understory crop. This mid-level planting should be a tree species that, when thinned, can make an economic contribution to the farming operation. The idea driving this thesis is that ferns may be an option to forest farmers as a high-value understory crop.

MARKET DEMANDS FOR FERNS

Based on information from other regions of the country, it would seem that a floral green industry has great potential to make an economic contribution to the
State of Missouri. From a 1989 survey in western Washington, western Oregon and British Columbia, the average floral green and Christmas ornamental processor employed 12 full time, permanent employees with an additional 71 part time, seasonal employees (Schlosser et al. 1995). Processors bought materials from an average of approximately 50 full time and 50 part time harvesters. These purchases resulted in approximately $397,000 being paid out in wages and benefits and approximately $795,000 in the purchase of materials. The approximate contribution to the economy was $1.53 million (Schlosser et al. 1995). The overall contribution of the special forest products industry was employment of over 10,000 people in the region (Schlosser et al. 1991). Furthermore, it generated an estimated $128.5 million in sales (Schlosser et al. 1991). While it may take many years for Missouri to create a floral trade the size of that in the Pacific Northwest, Missouri has the climate and overall potential to be successful in the floral green industry.

Missouri lacks a sufficient supply of native ferns to support a “gather and sell” industry similar to that in the Pacific Northwest (Schlosser and Blatner 1997). However, Missouri’s climate is suitable for growing ferns (Mater Engineering, Ltd. 1993). Furthermore, Missouri could support a fern industry (Mater Engineering, Ltd. 1993). A landowner could plant and market certain high value ferns in the floral green industry or landscaping industry if they were sufficiently knowledgeable about species selection and culture. Missouri is already the home to 465 acres of floriculture crops (i.e., bedding/garden plants, cut flowers and cut florist greens, foliage plants, and potted flowering plants) grown in open conditions (USDA National Agriculture Statistics Service 2002). The 2002 figures are down from the
687 acres reported in 1997. Of the 465 acres reported in 2002, only 76 acres were
sowed for cut flowers and cut florist greens (USDA National Agriculture Statistics
Service 2002) suggesting that there is room for expansion. The leatherleaf fern
represents popular greenery in the cut flower industry and provides a basis for
looking at the potential for ferns as a floral green. A 1991 USDA survey showed that
leatherleaf fern sales increased from $59 million to $70 million between the years of
1986 and 1990 (Mater Engineering, Ltd. 1993). During that time, they accounted for
40 percent of all cut flower foliage. This is to be expected since each time a florist
sells a rose, a background of leatherleaf fern fronds are included.

The leatherleaf fern fronds are sold in bunches of approximately 20 fronds.
Florists typically purchase a case of 25 bunches from floral distributing companies at
a cost of $1.55 per bunch or $38.75 per case. On occasion, wholesale companies will
sell fronds on an individual bunch basis for as much as $2.45 (Kelly, J. 2003.
Personal communication. Florist Distributing, Inc., Columbia, Missouri.). If an
appropriate fern adaptable to Missouri conditions could be identified, there would be
a reasonable probability that a thriving industry could be created that would compete
favorably with the leatherleaf industry.

MARKET STANDARDS FOR FERNS

Floral greens

In general, plants that are deep green with long lasting evergreen properties
are commonly used by the floral industry as accents in floral arrangements (Schlosser
and Blatner 1997). In the Pacific Northwest, wholesale suppliers purchase sword fern (*Polystichum munitum*) fronds using established quality parameters. The fronds of the sword fern should be green and healthy, 26 to 27 inches in length, have a minimum of seeds or buds on the back, with 51 to 52 blades to a single stem (Thomas and Schumann 1993). The leatherleaf fern (*Rumohra adiantiformis*), an accent fern often grown in Florida, must be free from defects including discoloration, blemishes, and missing tips to be marketable. The frond should be 24 inches in length, of which, nine inches should be stem (Kelly, J. 2003. Personal Communication. Florist Distributing, Inc. Columbia, Missouri). Stamps and McColley (1997) suggested that the floral greens industry prefers leatherleaf fern fronds that are large, dark green, and blemish-free.

Schlosser and Blatner (1997) emphasize that diverse growing conditions are necessary to produce the characteristics demanded by various markets for special forest products. And, market prices for forest products reflect the differences in product quality or grade. A slightly different view is that professionals in the cut flower industry expect perfection in their flowers and greenery (Trinklein, D.H. 2003. Personal communication. Department of Horticulture, University of Missouri, Columbia, Missouri). Uniqueness of a fern is important to the floral green and landscape markets. Secondary markets exist in the floral green industry for products that are slightly less than perfect; however, the primary market must be in place for a secondary market to exist (Trinklein, D.H. 2003. Personal communication. Department of Horticulture, University of Missouri, Columbia, Missouri).
Therefore, any new green foliage that enters the floral green market must enter as relatively flawless material.

Fern color varies with species. Both the cut floral green and landscape markets require consistency within a species. Color consistency is more important than shade of color (Trinklein, D.H. 2003. Personal communication. Department of Horticulture, University of Missouri, Columbia, Missouri). However, plants with a deep green color and long-lasting evergreen characteristics are often preferred in the floral industry to balance floral arrangements (Schlosser and Blatner 1997).

An example of the market requirements for ferns can be found in the Pacific Northwest. Fresh western sword fern fronds are marketed around the world as a product for use in floral arrangements. The world market requires long fronds with deep green color. Fronds in excess of 30 inches with no discoloration or breaks in the frond are required (Schlosser and Blatner 1997). Mature annual growth free of reproductive spores is harvested from the base of the plant (Schlosser and Blatner 1997).

Another significant example is found in Florida where leatherleaf fern production has 60 years of experience backing the industry. Most producers grow leatherleaf fern under 73 percent shade cloth. However, 35 percent of production takes place under the canopy of oak forests in hammocks – fertile, elevated beds rich in organic matter (Vasquez and Nesheim 2000).

Landscape use in shade gardens

Ferns used in shade gardens have an entirely different set of standards from those used in the floral greens industry. The location within the garden that the fern
will be used will dictate what qualities a fern must possess. The gardener can consider the use of both deciduous and evergreen ferns (Hoshizaki and Moran 2001). Even in the warmer climates of the southern United States, deciduous ferns will undergo a dormant period. Evergreen ferns will stay green throughout the cooler months, even in cold climates. However, colder temperatures will likely restrict new growth until warmer temperatures occur in the spring.

Some ferns can be used as accents in gardens to form distinctive lines, shapes, textures, or patterns. Upright species such as *Dryopteris marginalis* and *Osmunda cinnamomea* are suitable for accents in shade gardens (Hoshizaki and Moran 2001). Using ferns as borders and foundations in shade gardens can also be effective. Ferns that have short creeping or clumping rootstock are appropriate. Ferns with short creeping or clumping roots will stay where they are placed and not invade other areas of the garden. Suitable selections include *Athyrium filix-femina*, *Athyrium niponicum* ‘Pictum’, and *Dryopteris erythrosora* (Hoshizaki and Moran 2001). Ferns with long creeping rhizomes become unsuitable for borders and foundations very quickly as they outgrow their boundaries too quickly.

Ferns in shade gardens can be used as ground cover. As ground cover, a fern’s ability to spread over an area is its strength. An example of an appropriate ground cover fern is *Matteuccia struthiopteris* (Hoshizaki and Moran 2001). These ferns eventually carpet an area using widely creeping rhizomes or stolons to spread.
EFFECTS OF CLIMATE ON FROND QUALITY

Missouri’s seasonal climate

Geographically, Missouri is located in the center of the United States. This location often results in extreme temperatures. Mean temperatures and precipitations have been recorded since 1885. The winter months (December through February) receive 6.5 inches of rain on average; far less rain than any other season. The mean temperature during these months is 32°F Fahrenheit. January is the coldest month at 29.8°F but extremely cold temperatures can occur at any time during the winter. Spring (March through May) has a mean temperature of 54°F accompanied by 12 inches of precipitation. Spring rains often continue through June, which receives 4.65 inches on average. Summer (June through August) is the hottest time of the year with mean temperatures of 75°F. Summers in Missouri receive 12 inches of rain on average with the greatest rainfall occurring in June. The highest temperatures occur in July or August. Fall (September through November) has decreasing precipitation throughout the season. September averages 4 inches of rain while October and November average 3 inches. The mean temperature during the fall is 56.5°F (Atmospheric Science Department at the University of Missouri College of Agriculture Food and Natural Resources, 2003). Missouri’s weather is unique because of the variability from year to year and the occurrence of extreme highs and lows. Temperature extremes and drought may cause quality decline during the summer months. Because Missouri has a seasonal climate, most ferns will produce marketable fronds only during the summer and early fall of the year.
Quality Issues/Assessment

Necrotic spots on fern fronds may result from a number of causes. Spots can occur due to physical damage and improper moisture or shade. Necrotic spots can also be caused by fungi, bacteria, and foliar nematodes. Pathogens that have been identified on ferns include fungal *Cercospora, Cladosporium, Colletotrichum, Cylindrocladium, Fusarium, Myrothecium, Peyronellae, Phoma*, and bacterial diseases *Pseudomonas*, and *Xanthamonas* (Hoshizaki and Moran 2001).

Foliar nematodes are parasites that feed on the fern fronds. It is often difficult to diagnose nematode damage because the damage they cause is seldom distinctive (Dunn and Crow 2001). Nematode damage is commonly mistaken for water soaked spots that rapidly turn brown to black (Poole *et al.* 2005). Actual diagnosis of a nematode infestation must be carried out through a laboratory assay of soil and plant samples (Dunn and Crow 2001). Nematodes spread in contaminated soil, therefore, sanitary tools and workspace are important. Control methods that are effective for annual crops such as crop rotation and root destruction after harvest may not be practical for a perennial fern. Nematicides are available that control the parasites in the soil. However, nematicides are very costly and control is often limited to species-specific population reduction (Dunn and Crow 2001). Plant removal and destruction are sometimes the only effective means of controlling a nematode problem (Poole *et al.* 2005).

*Colletotrichum* has caused an extensive amount of economic damage to the leatherleaf crop in Florida (Stamps 1996). The damage is most noticeable in the fern fronds but results in damage to yield, growth and development rates. The spread of
the fungus throughout a fernery can occur on workers’ tools and clothing, on the fur of rodents, and in splashing water. *Colletotrichum* travels from one geographical location to another on people’s clothing, tools and vehicles. Practicing good sanitation can exclude the fungus from an operation, however, decontamination may be justified.

**EFFECTS OF LIGHT ON FROND COLOR**

**Light in the understory**

Understory light is the light that reaches the plants in the understory of a timber stand. It is composed of unfiltered daylight, which passes through the holes in the canopy, and filtered daylight, which has been altered by the uppermost canopy as a result of absorption, reflection, and transmission (Fournier *et al.* 2004, Morgan and Smith 1981, Woolley 1971, Vézina and Boulter 1966, Coombe 1957, and Federer and Tanner 1966). Federer and Tanner (1966) emphasize from their findings that the effects of light that penetrates a canopy on understory plants cannot be predicted until both the plant’s response to light of different wave lengths and the spectral characteristics of the understory light are quantified.

Thompson and Harper (1988) and Allard *et al.* (1991) conducted studies that compared the photosynthetically active radiation (PAR) transmitted through a forest canopy to that transmitted through a black polyethylene shade cloth. Both studies found that the red to far-red ratio was reduced under the forest canopy; however, the ratio was not significantly different from that in ambient light under the black
polyethylene shade cloth. The leaves of the canopy act as a filter of light, reducing the red to far-red ratio.

Fournier *et al.* (2004) conducted a study which evaluated the relationship between understory light and the growth of American ginseng, a species with light requirements similar to those of fern species, in Quebec, Canada. The broadleaf forest was composed primarily of *Fagus grandifolia*, *Acer saccharum*, and *Betula alleghaniensis*. The understory light quality (300 to 1100 nm) was measured to determine ultraviolet (300 to 380 nm), red (655 to 665), far-red (725 to 735 nm), and the red:far-red ratio. The measurements taken on the ginseng included fresh weight and dry weight of the roots, the leaf surface area, and the area of the fibrous (less than or equal to 1 mm diameter) and tap (greater than 1 mm diameter) root. Fournier *et al.* (2004) found that the heterogeneous nature of the forest canopy creates a mosaic of light in the understory that significantly affects growth and morphology of one and two year old American ginseng plants. The multiple regression analysis showed that the shoot and root dry weights and taproot area of one year old American ginseng plants were best modeled by daily sunfleck durations, accounting for up to 56 percent of the variation. However, this relationship reached a plateau at approximately two hours per day of sunfleck exposure. Fournier *et al.* (2004) reported that this was likely due to the photon flux density at a point of light saturation. Photon flux density is the amount of electromagnetic radiation per unit of surface area at a given time. In July, at the end of canopy development, shoot and root growth and leaf area were positively related to cumulative diffuse photon flux density. At the same time, a higher red:far-red ratio stunted leaflet area and root
growth of American ginseng. The data supports the practice of exposing American
ginseng to higher diffuse photon flux density and higher sunfleck durations to
maximize root growth.

Sims and Pearcy (1993) suggested that photon flux density could be more
uniformly distributed by growing tall canopies composed of small leaves. A more
uniform distribution of sunflect would allow photons to be better utilized by the
understory plant.

Light in relation to photosynthesis of shade plants

Böhning and Burnside (1956) studied the effects of light intensity on the rate
of photosynthesis of sun and shade plants. Their purpose was to obtain knowledge
of compensation points, light saturation and maximum photosynthetic rates of
several plant species. The light compensation point is defined as the point where the
plant’s net CO₂ assimilation (photosynthesis and root absorption) is zero (i.e., the
point at which assimilation is equal to respiration) (Levitt 1980). Shade plants have
lower light compensation points than sun plants. Therefore, shade plants can
accumulate photosynthetic products at lower light levels than sun plants. Shade
plants experience light saturation at much lower levels of light intensity than sun
plants as well (Levitt 1980). In the sun species tested, Böhning and Burnside (1956)
found that apparent photosynthesis began at 100 to 150 foot candles while light
saturation occurred at 2000 to 2500 foot candles. In the shade species tested, they
discovered that photosynthesis began at a light intensity of only 50 foot candles and
that light saturation occurred at 400 to 1000 foot candles. Two of the genera studied
in this experiment were *Dryopteris*, the Japanese painted fern, and *Nephrolepis*, the
sword fern. *Dryopteris* experienced light saturation at 400 foot candles and *Nephrolepis* underwent light saturation at 800 foot candles.

Ludlow (1967) compared photosynthesis in shade- and sun-adapted ferns then investigated the relationship between photosynthesis and morphological and physiological aspects of these plants. In this study, Ludlow conducted an experiment comparing sun and shade ferns in which he found light saturation curves to be very similar to those observed by Böhning and Burnside (1956).

In a 1963 experiment by Björkman and Holmgren, their purpose was to determine the role light intensity played in the reactions of the photosynthetic apparatus in *Solidago virgaurea* plants secured from differing habitats. The shaded habitats included beech forests on northeast-facing slopes in Denmark and oak forests from a small island off the southern coast of Sweden. Exposed habitats consisted of a dry meadow in a sparsely wooded region of southern Sweden and an alpine heath on a waste plateau in northern Norway. They compared the capability of sun and shade ecotypes to growth rate and photosynthesis capability at both low and high photon flux area density (PFD). The ecotypes commonly found in full sun habitats grew well at the higher PFD and grew slowly at the low PFD. The ecotypes commonly found in shaded areas grew satisfactorily in low PFD but inadequately in the higher PFD. Their findings clearly suggest genetic differences within a species relative to light needs.

Gauhl (1975) was interested in the differential adaptability of shade tolerant plants of *Solanum dulcamara* to high light intensities. The plants used in the study were vegetatively propagated cuttings collected from deep shade areas in Germany.
Gauhl found that these plants fix their maximum amount of CO$_2$ under low light intensities. Furthermore, primary photosynthetic processes were inhibited by higher light intensities than those found where the plant grew normally.

Powles and Thorne (1981) followed up on a study by Björkman (1968) suggesting that Björkman’s (1968) study lacked a “systematic investigation of the various contributing factors leading to the expression of the photoinhibition phenomenon” in leaves of *Phaseolus vulgaris*, bean bush, and *Lastreopsis microsora*, the tindale fern. Powles and Thorne (1981) considered the effects of invivo CO$_2$ uptake capacity when leaves of “low light adapted” plants were exposed to high light intensities. They concluded that photoinhibition of photosynthesis occurred when both *Phaseolus vulgaris* and *Lastreopsis microsora* plants that were adapted to grow in four percent of full sunlight were exposed to high light intensity. Furthermore, the photoinhibition occurred when a CO$_2$ partial pressure was applied and when the leaf temperature was kept at a level that allow maximum rates of CO$_2$ uptake.

Shropshire *et al.* (2001) evaluated conifer plantation’s susceptibility to stress during establishment due to competing vegetation. They realized that trees in new stands are small and slow growing; therefore early successional plants have an advantage with faster regrowth and reproduction rates. Shropshire *et al.* (2001) devised a study to compare the characteristics of light penetrating through the canopies of different plant species during the early stages of forest plantations. This was accomplished by developing a model to predict PAR based on planting density, actual density, projected leaf area index, and crown cover. One objective of the study was to examine the vertical profile of PAR movement through the plant
canopies. The PAR was measured as photosynthetic photon flux density at the time of maximum canopy development for each of the species studied: *Pteridium aquilinum*, bracken fern, *Aster macrophyllus*, large-leaved aster, *Epilobium angustifolium*, fireweed, *Rubus idaeus*, wild red raspberry, *Alnus crispa*, green alder, *Salix humilis*, upland willow, and *Betula papyrifera*, white birch. The analytical approach of the study evaluated the vertical PAR profiles. The maximum canopy height for the bracken fern was 60 centimeters. The vertical profiles of PAR transmissions at ground level for the bracken fern and large-leaved aster averaged 40 to 50 percent then increased rapidly with height to a value of 90 percent transmission at the top of the jack pine. PAR transmissions of less than 10 percent were measured at ground level under red raspberry, green alder, and upland willow. When compared to the other species in this study, the bracken fern and large-leaved aster intercepted the least amount of PAR per unit increase of cover.

Color

Describing color involves the evaluation and description of the color by one individual and the visualization of the description by another. Color charts, such as the Munsell Color Charts for Plant Material, have been used in the past to communicate colors between individuals. Using the Munsell Color Charts involves matching the color of the object (i.e., fronds) to the color in the chart. This method is flawed however due to differences in the perception of color between individuals. A more objective method of evaluating and communicating color is possible by using a portable spectrophotometer (Barrett 2002, Voss 1992).
Spectrophotometers output Cartesian coordinates from a three dimensional color space \((Y, x, y)\) or \((L^*, a^*, b^*)\). \(L^*\) (luminosity) represents the lightness or darkness of a color ranging from black = 0 to white = 100. This number is roughly analogous to the Munsell value scale times 10 (McGuire 1992). \(L^*\) is correctly reported without further manipulation however, \(a^*\) and \(b^*\) are simply coordinates which require further computation to become meaningful (Francis 1980).

Hunter (1942) and Little (1975) discussed color saturation or intensity. The color saturation or intensity is similar to its chroma and hue (McGuire 1992). Chroma is the purity of a color or its freedom from white. Chroma is measured as the degree of departure from gray toward pure chromatic color (McGuire 1992). The coordinates \(a^*\) and \(b^*\) are used to calculate \(C^*\) or chroma as \((a^{*2} + b^{*2})^{1/2}\). \(C^*\) represents the hypotenuse of a right triangle created by adjoining points \((0, 0)\), \((a^*, b^*)\), and \((a^*, 0)\).

Hue is the gradation of color. The hue angle \((h^\circ)\) is the angle between the hypotenuse and 0° on the \(a^*\) (bluish-green/red-purple) axis. Hue angle is calculated as the arctangent of \(b^*/a^*\). A red-purple hue is represented at 0° (also 360°), 90° represents yellow, 180° represents bluish-green, and 270° represents blue. The use of arctangent assumes the first and third quadrants are positive while the second and forth quadrants are negative. However, \(h^\circ\) must remain positive between zero° and 360° of the color wheel. The SAS program used to analyze this data keeps \(h^\circ\) positive and was published by McGuire (1992).

McGuire (1992) gives the example of the effect that three fruit fly treatments have on the color of grapefruit peels (Table 2-1). Treatment 3 made the fruit peels
significantly darker (L*) than those of treatments 1 and 2. The grapefruit peels in treatments 1 and 2 are more vivid (C*) than the peels in treatment 3. The h° of treatment 1 indicates peeling that is leaning toward green while treatments 2 and 3 are leaning toward red.

Table 2-1 - Analysis of grapefruit peel color after three heat treatments for quarantine control of Caribbean fruit flies.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>L*</th>
<th>C*</th>
<th>h°</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>76.5 a&lt;sup&gt;1&lt;/sup&gt;</td>
<td>56.0 a</td>
<td>92.0 a</td>
</tr>
<tr>
<td>2</td>
<td>74.4 a</td>
<td>56.0 a</td>
<td>88.0 b</td>
</tr>
<tr>
<td>3</td>
<td>63.2 b</td>
<td>34.0 b</td>
<td>88.0 b</td>
</tr>
</tbody>
</table>

<sup>1</sup>McGuire 1992.
<sup>2</sup>Means of 90 fruit per treatment using a Minolta chroma meter CR-200 measuring in CIELAB. L* = lightness, C* [(a*<sup>2</sup> + b*<sup>2</sup>)<sup>½</sup>] = chroma, h° (from arctangent b*/a*) = hue angle (0° = red-purple, 90° = yellow, 180° = bluish-green, 270° = blue).
<sup>3</sup>Mean separation at P = 0.05 according to the Ryan-Einot-Gabriel-Welsh multiple F test.

**BIOLOGICAL AND SOCIALLY LIMITING FACTORS**

The thesis assumed in this project is that landowners of forested land will consider using the understory of their timber as a production area for marketable ferns if marketable ferns are identified. Most entrepreneurs would like to have some established knowledge of an enterprise prior to investing their money. This thesis is the first step toward establishing the knowledge base necessary for a viable fern industry in Missouri.
Some potentially limiting factors to the development of a fern industry are: Missouri’s seasonal climate along with other possible limiting biological factors; also social barriers may play a preventative role.

Biologically limiting factors

Growing ferns for a profit and creating a fern industry in the Midwest may be difficult at best due to biophysical problems. Ferns that are suitable for the floral green and landscape industries may not grow adequately outside a highly controlled setting. The lack of adaptability of fern species that are suitable for the floral green and landscape industries could limit new interest in growing ferns for profit. The cost of growing and marketing ferns may be prohibitive on a small, manageable scale. Further research is needed to determine the appropriate scale of operation for profitable production of growing and marketing ferns. The proper canopy cover for fern production may be different than the proper canopy cover for timber production. Timber may require a more closed or open canopy for maximum growth depending on timber species present while the selected fern species may require more or less filtered light. Moreover, keeping the proper canopy cover for ideal fern production may limit the interest in growing ferns for profit.

In all businesses, product quality determines the price and contributes to the demand of the product. For individuals involved in growing ferns for resale, the quality of both incoming and outgoing product is of great importance. If the incoming ferns are diseased then they could ruin the entire crop. While if the outgoing product is of poor quality it could damage the grower’s reputation. Quality
control efforts can reduce costs by limiting waste and marketing time associated with one's reputation (Mater Engineering, Ltd. 1993).

Socially limiting factors

Much of the marketing legwork typically needs to be done by the business owner. A marketing network for a fern industry in the Midwest is not firmly established at the present time. For this reason, operators must stay abreast of the market structure of the floral green and landscape industries (Becker and Workman 2004). Any new enterprise should have an individual with a solid background in market research dedicated to recognizing and securing market opportunities (Mater Engineering, Ltd. 1993) - - it is no different when trying to establish a new industry such as with ferns.
STUDY AREA

This study was conducted at the University of Missouri’s Horticulture and Agroforestry Research Center (HARC) in New Franklin, Missouri (longitude 92°46’W; latitude 39°1’N). New Franklin is located three and one half miles north of Boonville, Missouri on State Highway 5. The shade study area used in this project is located near the main entrance of the Center.

FERN SPECIES AND CULTIVARS

Fern selection

Twelve fern species or cultivars were chosen for use in this study based upon their presumed suitability for the floral green and/or landscaping industries (Table 3-1). Three basic criteria were established for ferns selected for testing for the floral green industry; a minimum frond length of one and a half feet was established, a deep green color was required, and for non-natives, the species could not have an aggressive habit of spreading. It would be undesirable to recommend a variety to landowners that could become invasive in our forests. To qualify as a fern selected for use by the landscaping industry, it had to be capable of serving as an accent,
Table 3-1 - Suggested moisture and shade requirements for the fern species used in this study.

<table>
<thead>
<tr>
<th>Common Name</th>
<th>Moist/dry</th>
<th>Moist</th>
<th>Moist/wet</th>
<th>Light</th>
<th>Partial</th>
<th>Full</th>
</tr>
</thead>
<tbody>
<tr>
<td>Articulate lady fern</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Autumn fern</td>
<td>x</td>
<td></td>
<td>x</td>
<td></td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Christmas fern</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Eastern wood fern</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Lady fern</td>
<td></td>
<td>x</td>
<td></td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Log fern</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Japanese painted fern</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Ostrich fern</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Recurved broad buckler fern</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>‘Silver Falls’</td>
<td></td>
<td>x</td>
<td></td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Tatting fern</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>‘Wildwood Twist’</td>
<td>x</td>
<td>x</td>
<td></td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
</tbody>
</table>

1 Hoshizaki and Moran 2001, Missouri Botanical Garden 2001a through 2001i.
a border or foundation plant, or a ground cover. One other selection criteria used for all ferns was plant hardiness. The State of Missouri is primarily located in USDA Hardiness Zones 5 and 6. All cultivars chosen were hardy to at least Zone 5. To ensure uniformity in plant quality, all plants were purchased from Casa Flora, Dallas, Texas or Terra Nova Nurseries Inc., Tigard, Oregon.

Species tested in this study

The eight fern species initially tested for shade tolerance during the 2002 growing season were:

1) *Athyrium filix-femina* (Linnaeus) – lady fern
2) *Athyrium niponicum Pictum* (Mettenius) – Japanese painted fern
3) *Athyrium niponicum Pictum* (Mettenius) – ‘Silver Falls’ fern
4) *Athyrium otophorum* (Miquel) – articulate lady
5) *Dryopteris celsa* (W. Palmer) – log fern
6) *Dryopteris dilatata Recurvata* (Hoffman) – recurved broad buckler fern
7) *Dryopteris erythrosora* (D.C. Eaton) – autumn fern and
8) *Polystichum acrostichoid* (Michaux) – Christmas fern

Species and cultivars tested in 2003 consisted of:

1) *Athyrium filix-femina* (Linnaeus) – lady fern
2) *Athyrium filix-femina ‘Frizelliae’* (Linnaeus) – tatting fern
3) *Athyrium niponicum Pictum* (Mettenius) – Japanese painted fern
4) *Athyrium niponicum Pictum* (Mettenius) – ‘Wildwood Twist’ fern
5) *Dryopteris celsa* (W. Palmer) – log fern
6) *Dryopteris erythrosora* (D.C. Eaton) – autumn fern
7) *Dryopteris marginalis* (Linnaeus) – eastern wood fern

8) *Matteuccia struthiopteris* (Linnaeus) – ostrich fern and

9) *Polystichum acrostichoid* (Michaux) – Christmas fern

Description of ferns studied

*Athyrium filix-femina*

The lady fern is a deciduous Missouri native found in wooded valleys near streams, on rich wooded slopes, and ravine floors. This light green fern has finely divided fronds that grow up to three feet in length. The lady fern becomes ragged during mid- to late-summer (Missouri Botanical Garden (MBG) 2001a). Its fronds are brittle and break easily (Hoshizaki and Moran 2001) which may make this species undesirable for the floral green market.

The lady fern is easy to grow in rich, medium wet, well-drained soil or potting medium; yet, it tolerates drier soils (MBG 2001a). Hoshizaki and Moran (2001) report that this species grows under conditions of little to full shade. The Missouri Botanical Garden (2001a) reports that *A. filix-femina* prefers partial to full shade but can tolerate full sun in areas that are consistently moist.

*Athyrium filix-femina ‘Frizelliae’*

The tatting fern is a deciduous, dwarfed, narrow leafed mutation of the lady fern. Its fronds have fan shaped pinna along the rachis. As it grows older, it may produce fronds shaped more similarly to those of the lady fern (MBG 2001b).
Possible uses of this fern would include woodland gardens, shaded border fronts, and along streams and pond banks (MBG 2001b).

*A. filix-femina ‘Frizelliae’* prefers organically rich, humus soil that is medium wet and well-drained (MBG 2001b). The Missouri Botanical Gardens (2001b) reports that *A. filix-femina ‘Frizelliae’* does best in partial to full shade.

*Athyrium niponicum Pictum*

The Japanese painted ferns are a very popular, deciduous fern with various shades of maroon midribs. *A. niponicum Pictum* is one of the most popular cultivated ferns. It has one and one-half foot variegated fronds that grow in a slowly spreading clump (MBG 2001c).

This fern prefers a potting medium or soil that is moist to wet (Hoshizaki and Moran 2001). The Japanese painted ferns are easily grown as a shade garden plant in organically rich, medium wet to wet, well-drained soil (MBG 2001c). The Missouri Botanical Garden (2001c) reports that this fern produces its best color in light shade, however, it grows best in partial to full shade.

This ferns popularity has encouraged many variations to be propagated and marketed. Two other varieties that were researched in this program were:

1. ‘Silver Falls’ which has a silver hue along the middle section of the frond with green on the outer edge of the frond, and

2. ‘Wildwood Twist’ that resembles the typical Japanese painted fern with maroon midribs, but whose fronds often twist 180 degrees.
The growing conditions for the *A. niponicum* ‘Silver Falls’ and *A. niponicum* ‘Wildwood Twist’ are identical to those of the common Japanese painted fern. *A. niponicum* ‘Silver Falls’ is patented under U.S. Plant Patent PP12,803 issued July 23, 2002.

*Athyrium otophorum*

The articulate lady fern is a deciduous, medium-sized fern with short, creeping, clump-forming rhizomes. The color of the fronds is dusty green with a dark burgundy stem. The articulate lady fern can appear two toned due to young, pale green fronds that emerge throughout the growing season (MBG 2001d). This fern is commonly used in shade or woodland gardens.

The articulate lady fern does best in moist soils and potting medium (Hoshizaki and Moran 2001). Leaf scorch or general foliage decline can be a problem if the soil is allowed to dry. The articulate lady fern grows best under partial to full shade conditions.

*Dryopteris celsa*

The log fern is a hardy native of woodlands and swamps in the eastern United States ranging from New York to Missouri and extends deep into the southeastern United States. This fern is a natural hybrid of *D. goldiana* and *D. ludoviciana*. It is commonly found growing on decomposing logs; consequently, its common name is log fern (MBG 2001e). The log fern is also used in temperate gardens as background foliage and is a semi evergreen (MBG 2001e).
The Missouri Botanical Garden (2001e) identifies the shade requirements for log fern as being partial to full with the best results from bright shade (MBG 2001e). The log fern prefers a potting medium or soil that is moist/wet (Hoshizaki and Moran 2001).

*Dryopteris erythrosora*

The autumn fern has erect, evergreen fronds. New fronds are produced throughout the growing season in a coppery green color that matures to deep green in the summer and russet in the fall (MBG 2001f). The autumn fern is commonly grown in shaded woodland gardens and contrasts well with hostas and purple-leafed heucheras. The autumn fern is easily grown in moist, humus soil but needs protection from the wind and drought (MBG 2001f). This fern prefers partial to full shade (MBG 2001f).

*Dryopteris marginalis*

The eastern wood fern or marginal shield fern is a Missouri native that can be found naturally in the shaded crevices of rocky bluffs. The fronds of the eastern wood fern are grayish green, deeply cut, and slightly leathery. This fern’s rhizomes form an erect crown. This evergreen can provide an interesting winter landscape and mixes well with spring flowers (MBG 2001g).

The eastern wood fern does best in moist soils and potting medium (Hoshizaki and Moran 2001). Hoshizaki and Moran (2001) report that this fern
prefers partial shade while the Missouri Botanical Garden (2001g) suggests partial to full shade.

*Matteuccia struthiopteris*

The ostrich fern is a somewhat aggressively spreading fern that sends out stolons to form new plants. The results are dense stands in moist areas (Hoshizaki and Moran 2001). The dense stands can become a nuisance to shade gardeners who want to contain their plants in strategic locations.

The ostrich fern is a deciduous plant that requires constant moisture (MBG 2001h). The ostrich fern grows best in a moist/wet to moist soil or potting medium (Hoshizaki and Moran 2001). It will grow up to three feet in cultivation and can reach six feet in the wild (MBG 2001h). The Missouri Botanical Garden (2001h) suggests partial to full shade while Hoshizaki and Moran (2001) indicate that this fern does best under medium shade.

*Polystichum acrostichoid*

The Christmas fern has dark green, glossy, evergreen foliage. For this reason, ferns of this species are common in temperate gardens (Hoshizaki and Moran 2001). The Christmas fern is a Missouri native. As an evergreen, it holds its color until the end of December. This fern is subject to crown rot in poorly drained soils; therefore, it should be planted at a 45° angle to help combat this problem (MBG 2001i). The fronds of this fern provide a good winter landscape (Hoshizaki and Moran 2001). Several wholesalers and distributors replying to a Mater Engineering, Ltd. survey
indicated that the Christmas fern could be a viable competitor to the sword fern that is grown and marketed in the Pacific Northwest (Mater Engineering, Ltd. 1993).


TECHNIQUES AND PROCEDURES

Pre-study treatment – 2002

The 2002 plants were received in early May as plugs in 72 count trays. To ensure uniformity, all plants were purchased from Casa Flora, Dallas, Texas or Terra Nova Nurseries Inc., Tigard, Oregon. All ferns were repotted on May 8, 9, and 10 into DURA-POT 550 S pots (Gage Industries, Lake Oswego, Oregon) measuring 5¼” x 5¼” x 5¾” in a pine bark based growing medium. All ferns were grown in an 80 percent shaded greenhouse for 30 days to develop healthy root systems. They were then moved to an 80 percent shaded outdoor area for seven days to enable the foliage to acclimate to outdoor growing conditions. The ferns remained in the outdoor shaded area until they were repotted and moved to the shade study area.

Pre-study treatment – 2003

The 2003 plants arrived in late January and early February as plugs in 72 count trays (Casa Flora, Dallas, Texas or Terra Nova Nurseries Inc., Tigard, Oregon). All ferns were repotted between the dates of January 29 and February 7
into DURA-POT 311 S pots (Gage Industries, Lake Oswego, Oregon) measuring 3½” x 3½” x 3¼”. The ferns were grown in an 80 percent shaded greenhouse until April 24 when they were moved to a shaded area outside. The plants remained in the outdoor shaded area until they were repotted and placed in the shade study area. (Final re-potting is described later in this chapter.)

Potting medium

One growing medium was used throughout this study (i.e., in all repottings and trials). The growing medium consisted of a 90:19:40:12:12 ratio of pine bark, peat moss, perlite, vermiculite, and sand. This ratio was accomplished by mixing 9 cubic feet of pine bark, 1.9 cubic feet of compressed sphagnum peat moss, 4 cubic feet of perlite, 1.2 cubic feet of vermiculite, and 1.2 cubic feet of sand. The macronutrient fertilizer consisted of 29.7 percent nitrogen, 7.4 percent phosphorus, and 7.4 percent potassium obtained from 3 cups of 38-0-0 four month slow release Nitroform Blue Chip (AgrEvo, Wilmington, Delaware) and 4 cups of 13-13-13, eight to nine month, slow release Osmocote (Scotts-Sierra Horticulture Product Co., Marysville, Ohio). The micronutrient fertilizer consisted of 12 percent sulfur, 0.1 percent boron, 0.5 percent copper, 12 percent iron, 2.5 percent manganese, 0.05 percent molybdenum, and 1 percent zinc obtained from 2 cups of Micromax (Scotts Company, Columbus, Ohio). Additionally, 3 ounces of Soax liquid concentrate wetting agent (Smithers-Oasis, Kent, Ohio) were diluted in 5 gallons of water and added to the 17.3 cubic feet of potting medium. A one cubic yard mixer (Boulden and Lawson Inc., McMinnville, Tennessee) was used to simultaneously mix all of the above ingredients. Mixing continued for three minutes after all the ingredients
were added to ensure an even and consistent distribution. All fertilizer was added to the growth medium at the time of soil mixing. Supplemental fertilization was not employed.

Final potting

Just prior to placement in the shade laboratory, 72 high quality plants of each taxon were selected and repotted into two gallon white pots (The Classic 1000 measuring 10” top diameter x 9” height x 8½” bottom diameter; Gage Industries, Lake Oswego, Oregon) using the previously described potting mix.

Experimental design for research conducted during 2002 and 2003

Three treatments were applied consisting of three light levels; full sun, 50 percent shade, and 80 percent shade. “Full sun” consisted of open plots. The 50 percent and 80 percent shade treatments were created by using a woven, reinforced, high-density polyethylene fabric, coated with low density polyethylene called Mai-Weave (Hummert International, Earth City, Missouri) placed over a wood and wire greenhouse frame (Figure 3-1). Each light treatment plot was 20 feet wide, 40 feet long and 10 feet high. The light spectrum that reached the ferns under the black polyethylene shade cloth was not measured. However, it is believed to be similar to the light spectrum that reached ferns in studies conducted by Thomson and Harper (1988) and Allard et al. (1991). The University of Florida Extension Service published a guide that outlines the foot candles of light in full sun and shaded conditions using polyethylene fabric (Chen et al. 2003). Full sun is 10,000 foot
candles, 50 percent shade is about 6,250 foot candles, and 80 percent shade is about 2,500 foot candles.

Figure 3-1 - - The three shade treatments (from left to right; full sun, 80 percent shade, and 50 percent shade) at the University of Missouri’s Horticulture and Agroforestry Research Center in New Franklin, Missouri.

This study was conducted over a two-year period. After the first growing season in 2002, the ferns were over-wintered so they could be reused in 2003 and an analysis could be made on both the first and second year of data.

The ferns that were started in 2002 were over-wintered using the following procedure. All ferns were thoroughly watered then stacked next to each other, two pots high, four pots wide, and eight pots long. Wheat straw bales were stacked on their sides surrounding the fern pots. A cattle panel was placed on top of the straw bales above the pots. A four-foot by eight-foot by 1/8\textsuperscript{th} inch sheet of Styrofoam
insulation was placed over the panel. A sheet of white plastic was placed over the entire structure. The white plastic sheet was then anchored to the ground with concrete blocks and wooden poles.

Eight fern cultivars were studied in the 2002 growing season including; *Athyrium filix-femina*, *Athyrium niponicum Pictum*, *Athyrium niponicum Pictum* ‘Silver Falls’, *Athyrium otophorum*, *Dryopteris celsa*, *Dryopteris dilatata Recurvata*, *Dryopteris erythrosora* and, *Polystichum acrostichoid*.

Nine different fern cultivars were used in the 2003 study including; *Athyrium* ‘Filix Femina’, *A. filix-femina ‘Frizelliae’*, *A. niponicum* Pictum, *A. niponicum* ‘Wildwood Twist’, *Dryopteris celsa*, *D. erythrosora*, *D. marginalis*, *Matteuccia struthiopteris*, and *Polystichum acrostichoid*.

The ferns that entered the shade laboratory in 2003, year two, were studied for only one growing season. Five of the species used in 2003 were duplicates of species studied in 2002: *Athyrium* ‘Filix Femina’, *A. niponicum* Pictum, *Dryopteris celsa*, *D. erythrosora*, and *Polystichum acrostichoid*. These five species were actually started as young plants in January, 2003 in the greenhouse at HARC. *A. filix-femina ‘Frizelliae’* and *Matteuccia struthiopteris* entered the 2003 shade laboratory as one year old plants started in January, 2003. Two other species entered the shade laboratory for the first time in 2003; *Athyrium niponicum* Wildwood Twist and *Dryopteris marginalis*. *Athyrium niponicum* ‘Wildwood Twist’ was started as a plug-sized plant in February, 2003 in the greenhouse at HARC. *Dryopteris marginalis* tissue cultivars were received in July, 2002, after the shade study had already started. These tissue
cultivars were held through the 2002 summer, over-wintered, and included in the 2003 shade trial.

A Latin Square Experimental Design was used to randomize eight plants from each cultivar within each of the three light treatments and in each of three replications. The design provided 576 plants in the 2002 study and an additional 648 new plants in the 2003 study (Figure 3-2). On June 17 to 19, 2002, and May 22 and 23 and June 5, 2003, 72 high quality plants of each variety were selected and repotted into two gallon white pots (as previously described). One replication per day was repotted and placed in the shade study.
Within each shade structure, each fern was provided a continuously moist growth medium environment by daily watering using an automatic drip irrigation system. The automatic drip irrigation system was operated by an automatic timer (RainDial RD-600, James Hardie Irrigation, El Paso, Texas). Each of the three light treatment plots (i.e., full sun, 50 percent, and 80 percent shade) were wired to
separate stations on the timer. Solenoid valves (RBDVX75, MPR Supply Co., St. Louis, Missouri) controlled the release of water into each of the nine study plots (i.e., three light treatments x three replications). High density, flexible, polyethylene pipe (Hummert International, Earth City, Missouri) was connected to the solenoid valve. The pipe was placed above ground extending throughout each plot. Micro tubing (0.125 x 0.197 inch polyethylene, MPR Supply Co., St. Louis, Missouri) was connected between the polyethylene pipe and the fern pot. The micro tubing was held in place one to two inches above the potting medium by running the tubing through the upright handles of a small binder clip. The binder clip was then attached to the side of the pot (Figure 3-3).
Each shade regime was watered differently so that a continuously moist growth medium environment was maintained in all pots, (i.e., the pots in the full sun treatment needed more water than those in the 80 percent shade treatment due to greater water evaporation and transpiration from exposure to the sun). The full sun treatment received 15 minutes of water twice a day at 8:00 a.m. and 2:00 p.m. The 50 percent shade treatment pots were watered for ten minutes twice a day beginning at 8:15 a.m. and 2:15 p.m. The 80 percent shade treatment received four minutes of water twice a day beginning at 8:25 a.m. and 2:25 p.m. This watering scheme was selected after monitoring the moisture of the pots by touch in the various shade regimes for a period of two weeks. During the two-week period, adjustments were made until the growth medium of each pot was observed to stay in a moist state with minimal drainage from the bottom of pots.
Figure 3-3 - - Diagram of the automatic drip irrigation system at HARC. The treatments were replicated three times. Each shade regime was placed on a single circuit. Components of the irrigation system; (a) three station, automatic timer (RainDial RD-600, James Hardie Irrigation, El Paso, Texas), (b) solenoid valve (RBDVX75, MPR Supply Co., St. Louis, Missouri), (c) $\frac{1}{2}$ inch diameter, high density, flexible, polyethylene pipe (Hummert International, Earth City, Missouri), (d) micro tubing (0.125 x 0.197 inch polyethylene, MPR Supply Co., St. Louis, Missouri).
Harvesting procedures

Harvesting of the ferns for data collection was conducted on September 10, 14, and 23, 2002, and August 21-29, 2003. To evaluate frond quantity, only fronds from the northeast quadrant of each pot were harvested. The northeast quadrant was chosen simply as a consistent location. The number of fronds harvested from each fern ranged from 1 to 40. Each sample was taken at one-inch above the potting medium, with exception of the ostrich fern. The ostrich fern was sampled one inch above the scale cluster. Scales of the fern are similar to buds on a tree. The scale is the point from which the frond grows. In the ostrich fern the scales are grouped together to form a mass at the base of the fronds. The mass on the ferns in this study was approximately one to one and one-half inches thick. Since the ostrich fronds grew out of the scale cluster, it became necessary to harvest the fronds from further up the stipe (stem). Harvested material was placed in separately labeled Ziploc bags and stored in a refrigerator to preserve freshness and weight until measurements were completed. All measurements were completed within 72 hours of harvesting.

At the end of the 2002 growing season, each replication was harvested and measurements taken from each frond harvested included, frond length and width, fresh weight, number of necrotic lesions per frond, number of dead fronds, surface area of each frond, and frond color. The first replication was sampled on September 10th and measurements were recorded from the 10th to the 13th. The second replication was sampled on September 14th and data collection was completed by September 17th. The third and final replication was harvested on September 23rd and measurements were made from the 23rd to the 26th of September.
The format and timing of the 2003 data collection were similar to that of the 2002 data collection. On August 21, the first replication of ferns carried over from 2002 was harvested and measurements were made and recorded. On August 22, the second replication of ferns carried over from the 2002 trial was harvested and measurements recorded. On August 23, samples were taken and all data was collected from the third and last replication. On August 25, the first replication from ferns started in 2003 (i.e., one year old plants) was harvested. Measurements were completed on August 25th and 26th. On August 27, the second replication was harvested with measurements taken on August 27 and 28th. The third replication of 2003 ferns was harvested on August 29th and measurements were made on August 29th and 30th.

Analytical procedures

The assessment of fern response to light regimes was based on both quantitative and qualitative measurements. Quantitative measurements included frond length and width, fresh weight of the plant top, the number of necrotic spots, and the surface area of the fronds. The literature indicates that it is a widely accepted practice to express photosynthesis in terms of either surface area or fresh weight. The writer has chosen to report this data in terms of surface area and fresh weight. Sample weights were made using a digital scale and weights were recorded to the nearest hundredth of a gram. The scale used was a DeltaRange digital scale (Mettler PC 4400, Mettler Instrument Corporation, Hightstown, New Jersey). Frond area was measured using a LI-3000 portable area meter (LI-COR Inc., Lincoln, Nebraska). Length and width measurements were made at the longest axis in each
direction of the frond using a standard ruler. The necrotic spots were simply counted per frond.

Within each fern harvested, a representative frond was selected to evaluate color. This frond was then matched to the appropriate color tile in the Munsell Color Notation for Plant Material (Gretag MacBeth LLC, New Windsor, New York). Following the establishment of a match, a Miniscan XE Plus spectrophotometer (Hunter Associates Laboratory Inc., Reston, Virginia) was used to transform the color data from a qualitative to a quantitative form. The spectrophotometer was calibrated first with a black tile followed by a white tile to create the color scale. Next, the spectrophotometer was used to assign a quantitative value (number) to the color tile from the Munsell Color Notation for Plant Material (Gretag MacBeth LLC, New Windsor, New York) that had been identified as matching the color of the representative frond from each of the ferns harvested.

STATISTICAL ANALYSES

The SAS System (Copyright 1999-2001 by SAS Institute Inc., Cary, NC) was used to analyze the data collected in this research. The SAS System software is licensed to the University of Missouri at Columbia on a campus wide contract.

The mean values ($p \leq 0.05$) were compared for all the quantitative and qualitative comparisons. F values were compared at ($p \leq 0.01$), ($p \leq 0.05$), and ($p \leq 0.10$).
Analytical parameters

Both qualitative and quantitative parameters were used to analyze the data in this study. The quantitative parameters in this study include frond surface area, the total fresh weight of the fern top, and the frond length and width per fern species. The variance among the treatments of all quantitative data were heterogeneous thus, a log transformation was performed prior to Analysis of Variance (ANOVA). Actual values are presented in tables; however, all differences between treatments were determined using log transformations. Means followed by the same letter do not differ significantly \( (p \leq 0.05) \) using the least significant difference (LSD) comparison.

Fern color was the single qualitative parameter evaluated. The number of necrotic spots per frond was a quantitative parameter. However, these results were used as an indication of quality. The variance among treatments was homogeneous for both necrotic spots and color, therefore; no transformations were needed on the data involving necrotic spots and color.

The results of the growth indicators (length, width, and surface area) and the results of the necrotic spots and color data are organized according to the growing season the material was evaluated (i.e., one-year old nursery stock tested in 2002, two-year old nursery stock tested in 2003, and one-year old nursery stock tested in 2003).
SIGNIFICANCE OF F VALUES

The condition of ferns grown in full sun in this study was so meager that meaningful data could not be collected from the treatment. In year-one (2002), 50 percent of all ferns in full sun died (Appendix Table A-1). Of the one-year old nursery stock ferns grown in 2003, 29 percent died (Appendix Table A-2). As a result of the high mortality and lack of meaningful data, the full sun treatment was omitted from the Results chapter. In Tables 4-1 to 4-6, there is only one degree of freedom (i.e., $n - 1 = DF$) under the category of shade due to the elimination of the full sun treatment.

For the categories of species and shade, all one-year old nursery stock tested in 2002 showed a significant $F$ ($p \leq 0.01$) for total fresh weight, frond length, frond width, and total surface area (Table 4-1). The shade within species category (interaction) also had a significant $F$ ($p \leq 0.01$) for total fresh weight, frond length, frond width, and total surface area.

The significance of $F$ values across all two-year old nursery stock tested in 2003 are shown in Table 4-2. Treatment (50 percent shade versus 80 percent shade) had a highly significant ($p \leq 0.01$) effect on frond total surface area and width. Total fresh weight and frond length were found to be significant at $p \leq 0.10$. No significant
differences were found in number of dead fronds per fern between shade treatments. Species/shade interactions were highly significant ($p \leq 0.01$) for total fresh weight, frond length and frond width. Total surface area was significant ($p \leq 0.05$).

The significance levels across all one-year old nursery stock tested in 2003 are shown in Table 4-3. Within the shade treatments, significance ($p \leq 0.01$) was found for total surface area, total fresh weight, frond length, and frond width. F values across all species started and tested in 2003 (i.e., one-year old stock) within the two shade treatments were significant ($p \leq 0.01$) for total surface area, total fresh weight, frond length, and frond width.

Table 4-1 - - F value significance for measurements across all one-year old nursery stock tested in 2002 using a log transformation of ferns grown under treatments of 50 and 80 percent shade.

<table>
<thead>
<tr>
<th>Treatments</th>
<th>DF</th>
<th>Total Fresh Weight</th>
<th>Frond Length</th>
<th>Frond Width</th>
<th>Total Surface Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Species</td>
<td>6</td>
<td>**</td>
<td>**</td>
<td>**</td>
<td>**</td>
</tr>
<tr>
<td>Shade</td>
<td>1</td>
<td>**</td>
<td>**</td>
<td>**</td>
<td>**</td>
</tr>
<tr>
<td>Shade x Species</td>
<td>6</td>
<td>**</td>
<td>**</td>
<td>**</td>
<td>**</td>
</tr>
</tbody>
</table>

** = $p \leq 0.01$
Table 4-2 - F value significance for measurements across all two-year old nursery stock tested in 2003 using a log transformation of ferns grown under treatments of 50 and 80 percent shade.

<table>
<thead>
<tr>
<th>Treatments</th>
<th>DF</th>
<th>Total Fresh Weight</th>
<th>Frond Length</th>
<th>Frond Width</th>
<th>Total Surface Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Species</td>
<td>6</td>
<td>**</td>
<td>**</td>
<td>**</td>
<td>**</td>
</tr>
<tr>
<td>Shade</td>
<td>1</td>
<td>†</td>
<td>†</td>
<td>**</td>
<td>**</td>
</tr>
<tr>
<td>Shade x Species</td>
<td>6</td>
<td>**</td>
<td>**</td>
<td>**</td>
<td>*</td>
</tr>
</tbody>
</table>

** = p ≤ 0.01  
* = p ≤ 0.05  
† = p ≤ 0.10

Table 4-3 - F value significance for measurements across all one-year old nursery stock tested in 2003 using a log transformation of ferns grown under treatments of 50 and 80 percent shade.

<table>
<thead>
<tr>
<th>Treatments</th>
<th>DF</th>
<th>Total Fresh Weight</th>
<th>Frond Length</th>
<th>Frond Width</th>
<th>Total Surface Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Species</td>
<td>10</td>
<td>**</td>
<td>**</td>
<td>**</td>
<td>**</td>
</tr>
<tr>
<td>Shade</td>
<td>1</td>
<td>**</td>
<td>**</td>
<td>**</td>
<td>**</td>
</tr>
<tr>
<td>Shade x Species</td>
<td>10</td>
<td>**</td>
<td>**</td>
<td>**</td>
<td>**</td>
</tr>
</tbody>
</table>

** = p ≤ 0.01
The significances of F values as they relate to fern color across all one-year old nursery stock tested in 2002 are presented in Table 4-4. Between the 50 percent and 80 percent shade treatments, F (p ≤ 0.01) was significant for luminosity, chroma, and hue angle. The F values between shade treatments, within each species (the interaction term) show a significant difference (p ≤ 0.05) only for luminosity.

A significant F (p ≤ 0.01) was found for fern color across all two-year old nursery stock tested in 2003 for each of the color components; luminosity, chroma, and hue angle (Table 4-5). However, differences in fern color for the species within shade category for two-year old nursery stock tested in 2003 were significant (p ≤ 0.05) for luminosity and highly significant (p ≤ 0.01) for hue angle. Once again, as was found to be the case for one-year old stock tested in 2002, differences in chroma were not significant.

For all one-year old nursery stock tested in 2003, a significant F (p ≤ 0.01) was found for luminosity, chroma, and hue angle between the shade regimens. In addition, a significant F (p ≤ 0.01) was found for species within treatment for all color factors luminosity, chroma, and hue angle (Table 4-6).
Table 4-4 - F value significance for frond color across all one-year old nursery stock tested in 2002 (no transformation) for ferns grown under treatments of 50 and 80 percent shade.

<table>
<thead>
<tr>
<th>Treatments</th>
<th>DF</th>
<th>Luminosity</th>
<th>Chroma</th>
<th>Hue angle</th>
</tr>
</thead>
<tbody>
<tr>
<td>Species</td>
<td>6</td>
<td>**</td>
<td>**</td>
<td>**</td>
</tr>
<tr>
<td>Shade</td>
<td>1</td>
<td>**</td>
<td>**</td>
<td>**</td>
</tr>
<tr>
<td>Shade x Species</td>
<td>6</td>
<td>*</td>
<td>NS</td>
<td>NS</td>
</tr>
</tbody>
</table>

1Luminosity represents the lightness or darkness of a color ranging from black = 0 to white = 100. Chroma is measured as the degree of departure from gray toward pure chromatic color. The hue angle is the angle between the hypotenuse and 0° on the a* (bluish-green/red-purple) axis.

** = p ≤ 0.01
* = p ≤ 0.05
NS = no significance
Table 4-5 - F value significance for frond color across all two-year old nursery stock tested in 2003 (no transformation) for ferns grown under treatments of 50 and 80 percent shade

<table>
<thead>
<tr>
<th>Treatments</th>
<th>DF</th>
<th>Luminosity</th>
<th>Chroma</th>
<th>Hue angle</th>
</tr>
</thead>
<tbody>
<tr>
<td>Species</td>
<td>6</td>
<td>**</td>
<td>**</td>
<td>**</td>
</tr>
<tr>
<td>Shade</td>
<td>1</td>
<td>**</td>
<td>**</td>
<td>**</td>
</tr>
<tr>
<td>Shade x Species</td>
<td>6</td>
<td>*</td>
<td>NS</td>
<td>**</td>
</tr>
</tbody>
</table>

1Luminosity represents the lightness or darkness of a color ranging from black = 0 to white = 100. Chroma is measured as the degree of departure from gray toward pure chromatic color. The hue angle is the angle between the hypotenuse and 0° on the a* (bluish-green/red-purple) axis.

** = p ≤ 0.01
* = p ≤ 0.05
NS = no significance

Table 4-6 - F value significance for frond color across all one-year old nursery stock tested in 2003 (no transformation) for ferns grown under treatments of 50 and 80 percent shade

<table>
<thead>
<tr>
<th>Treatments</th>
<th>DF</th>
<th>Luminosity</th>
<th>Chroma</th>
<th>Hue angle</th>
</tr>
</thead>
<tbody>
<tr>
<td>Species</td>
<td>10</td>
<td>**</td>
<td>**</td>
<td>**</td>
</tr>
<tr>
<td>Shade</td>
<td>1</td>
<td>**</td>
<td>**</td>
<td>**</td>
</tr>
<tr>
<td>Shade x Species</td>
<td>10</td>
<td>**</td>
<td>**</td>
<td>**</td>
</tr>
</tbody>
</table>

1Luminosity represents the lightness or darkness of a color ranging from black = 0 to white = 100. Chroma is measured as the degree of departure from gray toward pure chromatic color. The hue angle is the angle between the hypotenuse and 0° on the a* (bluish-green/red-purple) axis.

** = p ≤ 0.01
GROWTH INDICATOR RESPONSES

Fresh weight

Means for the total fresh weight of fern tops for all one-year old nursery stock tested in 2002 are presented in Table 4-7. Significantly heavier fronds were produced by the autumn, Christmas, and ‘Silver Falls’ ferns in the 80 percent shade than in the 50 percent shade. Significant differences were not detected in the articulate lady, Japanese painted, lady, and log fern species even though; the articulate lady, Japanese painted, and lady produced the heaviest fronds in the 80 percent shade treatment. In general, when the mean weights of the two shade treatments were compared (50 percent = 4.07a and 80 percent = 6.92a), the 80 percent shade treatment yielded the heavier fronds although the difference was not significant.

The articulate lady was the only species within the two-year old nursery stock tested in 2003 to show a significant difference between the 50 and 80 percent shade regimens for total fresh weight of tops (Table 4-8). The autumn fern had too much missing data (because of mortality) to show results. All other 2002 species re-tested in 2003, including the Christmas, log, Japanese lady, and ‘Silver Falls’, had no significant differences in fresh weights of tops.

Table 4-9 shows the means for the total fresh weight of fern tops across all one-year old nursery stock tested in 2003. A significant difference in the shade regimens of the autumn, Christmas, lady, log, ostrich, and tatting ferns clearly indicate better growth under conditions of the 80 percent shade. Significant differences were not found between the shade treatments for the eastern wood, Japanese painted, and ‘Wildwood Twist’ ferns. A test of the means across all 2003
species grown in 2003 indicates that plants grown in 50 percent (8.13a) were significantly smaller than plants grown in 80 percent (16.22b) shade (Table 4-9).
Table 4-7 - Means of total fresh weight (grams) for all one-year old nursery stock tested by species in 2002 in the 50 and 80 percent shade treatments.

<table>
<thead>
<tr>
<th>Shade</th>
<th>Articulate Lady</th>
<th>Autumn</th>
<th>Christmas</th>
<th>Lady</th>
<th>Log</th>
<th>Japanese Painted</th>
<th>‘Silver Falls’</th>
<th>Means of one-year old nursery stock tested in 2002</th>
</tr>
</thead>
<tbody>
<tr>
<td>50%</td>
<td>1.38 a&lt;sup&gt;1&lt;/sup&gt;</td>
<td>3.39 a</td>
<td>2.24 a</td>
<td>18.20 a</td>
<td>0.95 a</td>
<td>17.38 a</td>
<td>5.75 a</td>
<td>4.07 a</td>
</tr>
<tr>
<td>80%</td>
<td>1.54 a</td>
<td>8.51 b</td>
<td>6.92 b</td>
<td>33.88 a</td>
<td>0.78 a</td>
<td>27.54 a</td>
<td>12.59 b</td>
<td>6.92 a</td>
</tr>
</tbody>
</table>

<sup>1</sup>The variance among treatments was heterogeneous thus, a log transformation was performed prior to ANOVA. Actual values are presented. However, all differences between treatments were determined on log transformations.

<sup>2</sup>Means between shade treatments within a fern species with different letters are significantly different ($p \leq 0.05$) using the least significant difference comparison.
Table 4-8 - Means of total fresh weight (grams) for all two-year old nursery stock tested by species in 2003 in the 50 and 80 percent shade treatments.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>50%</td>
<td>6.03 a&lt;sup&gt;1&lt;/sup&gt;</td>
<td>Non-est</td>
<td>5.89 a</td>
<td>40.74 a</td>
<td>2.82 a</td>
<td>35.48 a</td>
<td>20.89 a</td>
</tr>
<tr>
<td>80%</td>
<td>12.88 b</td>
<td>4.27</td>
<td>4.47 a</td>
<td>48.98 a</td>
<td>2.88 a</td>
<td>46.77 a</td>
<td>18.62 a</td>
</tr>
</tbody>
</table>

<sup>1</sup>The variance among treatments was heterogeneous thus, a log transformation was performed prior to ANOVA. Actual values are presented. However, all differences between treatments were determined on log transformations.

<sup>2</sup>Means between shade treatments within a fern species with different letters are significantly different (<i>p</i> ≤ 0.05) using the least significant difference comparison.

<sup>3</sup>Non-est = There was insufficient data due to mortality for a statistically valid comparison to be executed.
Table 4-9 - Means of total fresh weight (grams) for all one-year old nursery stock tested by species in 2003 in the 50 and 80 percent shade treatments.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>50%</td>
<td>6.03 a¹</td>
<td>4.90 a</td>
<td>3.09 a</td>
<td>9.33 a</td>
<td>10.47 a</td>
<td>16.98 a</td>
<td>12.30 a</td>
<td>2.75 a</td>
<td>38.02 a</td>
<td>8.31 a</td>
</tr>
<tr>
<td>80%</td>
<td>7.59 a</td>
<td>10.72 b</td>
<td>5.50 b</td>
<td>20.42 b</td>
<td>19.05 b</td>
<td>23.99 a</td>
<td>26.92 b</td>
<td>9.33 b</td>
<td>40.74 a</td>
<td>16.22 b</td>
</tr>
</tbody>
</table>

¹The variance among treatments was heterogeneous thus, a log transformation was performed prior to ANOVA. Actual values are presented. However, all differences between treatments were determined on log transformations.

²Means between shade treatments within a fern species with different letters are significantly different ($p \leq 0.05$) using the least significant difference comparison.
Length, width, and surface area

Surface area, length, and width are presumed to be closely correlated and the data are presented in a single table. Measurements taken under 50 and 80 percent shade conditions are shown in Tables 4-10, 4-11, and 4-12.

The lady fern was the only one-year old species tested in 2002 that showed a significantly greater growth response at 80 than 50 percent shade in all three categories – surface area, length and width (Table 4-10). The autumn fern produced significantly longer fronds with greater surface area, while the Christmas fern produced a significantly wider frond with greater surface area in 80 percent shade (Table 4-10). The remaining one-year old nursery stock tested in 2002 showed no significant differences for surface area, length, and width when grown under the two shade percentages. The means for all the one-year old nursery stock (i.e., across all species) tested in 2002 showed a significant difference between shade percentages for length only (Table 4-10).

For the two-year old nursery stock tested in 2003, the articulate lady fern was the only species to yield significantly greater leaf surface area under conditions of the 80 percent shade than 50 percent shade (Table 4-11). During the 2003 study, the lady fern produced the longer and wider fronds in 80 percent shade but no significant difference was found in surface area (Table 4-11). The Japanese painted fern produced greater length and the Christmas fern yielded greater width in 80 percent shade than in 50 percent shade (Table 4-11). Two-year old autumn fern performed inadequately in the 2003 trial yielding insufficient data for analysis.
One-year old ostrich, tatting, and lady ferns tested in 2003 produced significantly larger fronds (longer and wider) in 80 percent shade than in 50 percent shade (Table 4-12). The ostrich and autumn ferns had greater surface area and were significantly wider in the 80 percent shade treatment than in 50 percent shade. The Japanese painted fern was significantly longer and wider when grown in 80 percent shade than in 50 percent shade however; surface area was not found to be significantly greater (Table 4-12). The log fern was found to have significantly greater surface area in 80 percent shade than in 50 percent shade. Means across all species within surface area, length, and width were found to be significantly different for plants grown under conditions of 50 and 80 percent shade with the 80 percent shade plants being consistently larger (Table 4-12).
Table 4-10 - Means for frond surface area, length, and width for all one-year old nursery stock tested in 2002 under 50 percent and 80 percent shade conditions.

<table>
<thead>
<tr>
<th>Species of fern</th>
<th>Treatment</th>
<th>Surface Area (cm²)</th>
<th>Length (cm)</th>
<th>Width (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Articulate lady</td>
<td>50 percent shade</td>
<td>24.55 a¹</td>
<td>6.03 a</td>
<td>3.31 a</td>
</tr>
<tr>
<td></td>
<td>80 percent shade</td>
<td>31.62 a</td>
<td>7.08 a</td>
<td>4.17 a</td>
</tr>
<tr>
<td>Autumn</td>
<td>50 percent shade</td>
<td>38.02 a</td>
<td>3.31 a</td>
<td>2.34 a</td>
</tr>
<tr>
<td></td>
<td>80 percent shade</td>
<td>85.11 b</td>
<td>4.68 b</td>
<td>3.09 a</td>
</tr>
<tr>
<td>Christmas</td>
<td>50 percent shade</td>
<td>26.30 a</td>
<td>3.89 a</td>
<td>2.29 a</td>
</tr>
<tr>
<td></td>
<td>80 percent shade</td>
<td>61.66 b</td>
<td>4.90 a</td>
<td>2.63 b</td>
</tr>
<tr>
<td>Japanese painted</td>
<td>50 percent shade</td>
<td>173.78 a</td>
<td>7.59 a</td>
<td>2.51 a</td>
</tr>
<tr>
<td></td>
<td>80 percent shade</td>
<td>177.83 a</td>
<td>6.46 a</td>
<td>2.34 a</td>
</tr>
<tr>
<td>Lady</td>
<td>50 percent shade</td>
<td>213.80 a</td>
<td>9.12 a</td>
<td>3.16 a</td>
</tr>
<tr>
<td></td>
<td>80 percent shade</td>
<td>426.58 b</td>
<td>14.13 b</td>
<td>6.03 b</td>
</tr>
<tr>
<td>Log</td>
<td>50 percent shade</td>
<td>14.79 a</td>
<td>3.55 a</td>
<td>2.19 a</td>
</tr>
<tr>
<td></td>
<td>80 percent shade</td>
<td>11.75 a</td>
<td>4.27 a</td>
<td>2.45 a</td>
</tr>
<tr>
<td>‘Silver Falls’</td>
<td>50 percent shade</td>
<td>57.54 a</td>
<td>6.76 a</td>
<td>2.82 a</td>
</tr>
<tr>
<td></td>
<td>80 percent shade</td>
<td>93.33 a</td>
<td>6.76 a</td>
<td>2.69 a</td>
</tr>
<tr>
<td>Means of one-year old nursery stock tested in 2002</td>
<td>50 percent shade</td>
<td>50.12 a</td>
<td>5.37 a</td>
<td>2.63 a</td>
</tr>
<tr>
<td></td>
<td>80 percent shade</td>
<td>75.86 b</td>
<td>6.46 b</td>
<td>3.02 a</td>
</tr>
</tbody>
</table>

¹The variance among treatments was heterogeneous thus, a log transformation was performed prior to ANOVA. Actual values are presented in the table. However, all differences between treatments were determined on log transformations. Means within species and measured parameters followed by the same letter are not significantly different ($p \leq 0.05$) using the least significant difference comparison.
Table 4-11 - - Means for frond surface area, length, and width for all two-year old nursery stock tested in 2003 under 50 percent and 80 percent shade conditions.

<table>
<thead>
<tr>
<th>Species of fern</th>
<th>Treatment</th>
<th>Surface Area (cm²)</th>
<th>Length (cm)</th>
<th>Width (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Articulate lady</td>
<td>50 percent shade</td>
<td>38.02 a¹</td>
<td>14.45 a</td>
<td>4.90 a</td>
</tr>
<tr>
<td></td>
<td>80 percent shade</td>
<td>104.71 b</td>
<td>19.05 a</td>
<td>7.24 a</td>
</tr>
<tr>
<td>Autumn</td>
<td>50 percent shade</td>
<td>Non-est²</td>
<td>Non-est</td>
<td>Non-est</td>
</tr>
<tr>
<td></td>
<td>80 percent shade</td>
<td>25.12</td>
<td>5.75</td>
<td>4.68</td>
</tr>
<tr>
<td>Christmas</td>
<td>50 percent shade</td>
<td>38.90 a</td>
<td>6.31 a</td>
<td>3.02 a</td>
</tr>
<tr>
<td></td>
<td>80 percent shade</td>
<td>31.26 a</td>
<td>6.76 a</td>
<td>3.47 b</td>
</tr>
<tr>
<td>Japanese painted</td>
<td>50 percent shade</td>
<td>229.09 a</td>
<td>12.30 a</td>
<td>3.72 a</td>
</tr>
<tr>
<td></td>
<td>80 percent shade</td>
<td>338.84 a</td>
<td>14.79 b</td>
<td>4.57 a</td>
</tr>
<tr>
<td>Lady</td>
<td>50 percent shade</td>
<td>407.38 a</td>
<td>14.79 a</td>
<td>4.68 a</td>
</tr>
<tr>
<td></td>
<td>80 percent shade</td>
<td>426.58 a</td>
<td>18.20 b</td>
<td>6.03 b</td>
</tr>
<tr>
<td>Log</td>
<td>50 percent shade</td>
<td>13.49 a</td>
<td>Non-est</td>
<td>Non-est</td>
</tr>
<tr>
<td></td>
<td>80 percent shade</td>
<td>32.36 a</td>
<td>8.51</td>
<td>4.47</td>
</tr>
<tr>
<td>‘Silver Falls’</td>
<td>50 percent shade</td>
<td>204.17 a</td>
<td>12.30 a</td>
<td>3.31 a</td>
</tr>
<tr>
<td></td>
<td>80 percent shade</td>
<td>169.82 a</td>
<td>11.22 a</td>
<td>3.31 a</td>
</tr>
</tbody>
</table>

Means of two-year old nursery stock tested in 2002

<table>
<thead>
<tr>
<th></th>
<th>Treatment</th>
<th>Surface Area (cm²)</th>
<th>Length (cm)</th>
<th>Width (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>50 percent shade</td>
<td>Non-est</td>
<td>Non-est</td>
<td>Non-est</td>
<td>93.33 4.68</td>
</tr>
<tr>
<td>80 percent shade</td>
<td>Non-est</td>
<td>Non-est</td>
<td>Non-est</td>
<td>10.96 4.68</td>
</tr>
</tbody>
</table>

¹The variance among treatments was heterogeneous thus, a log transformation was performed prior to ANOVA. Actual values are presented in the table. However, all differences between treatments were determined on log transformations. Means within species and measured parameters followed by the same letter are not significantly different (p ≤ 0.05) using the least significant difference comparison.

²Non-est = There was insufficient data due to mortality for a statistically valid comparison to be executed.
Table 4-12 - Means for frond surface area, length, and width for all one-year old nursery stock tested in 2003 in the 50 percent and 80 percent shade conditions.

<table>
<thead>
<tr>
<th>Species of fern</th>
<th>Treatment</th>
<th>Surface Area (cm$^2$)</th>
<th>Length (cm)</th>
<th>Width (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eastern wood</td>
<td>50 percent shade</td>
<td>53.70 a$^1$</td>
<td>7.94 a</td>
<td>4.57 a</td>
</tr>
<tr>
<td></td>
<td>80 percent shade</td>
<td>56.23 a</td>
<td>8.13 a</td>
<td>5.01 a</td>
</tr>
<tr>
<td>Autumn</td>
<td>50 percent shade</td>
<td>40.74 a</td>
<td>5.75 a</td>
<td>4.17 a</td>
</tr>
<tr>
<td></td>
<td>80 percent shade</td>
<td>97.72 b</td>
<td>7.24 b</td>
<td>5.50 b</td>
</tr>
<tr>
<td>Christmas</td>
<td>50 percent shade</td>
<td>23.99 a</td>
<td>4.57 a</td>
<td>2.57 a</td>
</tr>
<tr>
<td></td>
<td>80 percent shade</td>
<td>38.02 a</td>
<td>4.90 a</td>
<td>2.75 a</td>
</tr>
<tr>
<td>Japanese painted</td>
<td>50 percent shade</td>
<td>112.20 a</td>
<td>9.55 a</td>
<td>3.16 a</td>
</tr>
<tr>
<td></td>
<td>80 percent shade</td>
<td>158.49 a</td>
<td>12.59 b</td>
<td>3.80 b</td>
</tr>
<tr>
<td>Lady</td>
<td>50 percent shade</td>
<td>95.50 a</td>
<td>7.24 a</td>
<td>3.47 a</td>
</tr>
<tr>
<td></td>
<td>80 percent shade</td>
<td>263.03 b</td>
<td>11.48 b</td>
<td>4.47 b</td>
</tr>
<tr>
<td>Log</td>
<td>50 percent shade</td>
<td>100.00 a</td>
<td>15.49 a</td>
<td>6.17 a</td>
</tr>
<tr>
<td></td>
<td>80 percent shade</td>
<td>173.78 b</td>
<td>20.89 a</td>
<td>8.13 a</td>
</tr>
<tr>
<td>Ostrich</td>
<td>50 percent shade</td>
<td>104.71 a</td>
<td>14.45 a</td>
<td>6.03 a</td>
</tr>
<tr>
<td></td>
<td>80 percent shade</td>
<td>239.88 b</td>
<td>18.20 a</td>
<td>7.76 b</td>
</tr>
<tr>
<td>Tatting</td>
<td>50 percent shade</td>
<td>15.14 a</td>
<td>6.31 a</td>
<td>0.76 a</td>
</tr>
<tr>
<td></td>
<td>80 percent shade</td>
<td>52.48 b</td>
<td>11.22 b</td>
<td>1.02 b</td>
</tr>
<tr>
<td>Wildwood Twist</td>
<td>50 percent shade</td>
<td>223.87 a</td>
<td>17.78 a</td>
<td>5.62 a</td>
</tr>
<tr>
<td></td>
<td>80 percent shade</td>
<td>316.23 a</td>
<td>18.20 a</td>
<td>5.89 a</td>
</tr>
<tr>
<td>Means of one-year old nursery stock tested in 2003</td>
<td>50 percent shade</td>
<td>63.10 a</td>
<td>9.33 a</td>
<td>3.24 a</td>
</tr>
<tr>
<td></td>
<td>80 percent shade</td>
<td>123.03 b</td>
<td>12.30 b</td>
<td>4.07 b</td>
</tr>
</tbody>
</table>

$^1$The variance among treatments was heterogeneous thus, a log transformation was performed prior to ANOVA. Actual values are presented in the table. However, all differences between treatments were determined on log transformations. Means within species and measured parameters followed by the same letter are not significantly different ($p \leq 0.05$) using the least significant difference comparison.
NECROTIC SPOTS

Means of necrotic spot measurements for all one-year old nursery stock tested in 2002 are shown in Figure 4-1. Three out of seven species; autumn, Christmas, and ‘Silver Falls’ ferns, showed significantly cleaner fronds (with zero to two necrotic spots) in the 80 percent shade treatment than the 50 percent shade treatment. The trend for the one-year old stock tested in 2002 suggested that approximately 50 percent of the fronds in the study (overall average) were high quality fronds. Forty-seven percent were high quality in the 50 percent shade treatment while 54 percent were high quality in the 80 percent shade treatment.

The percent of fronds with zero to two necrotic spots for two-year old ferns tested in 2003 is illustrated in Figure 4-2. The autumn, lady, and log ferns showed significant differences. The autumn and log ferns illustrated a higher percentage of clean fronds in the 80 percent shade treatment than in the 50 percent shade. The lady fern, however, had significantly more clean fronds (with zero to two necrotic spots) in the 50 percent shade than in the 80 percent shade. Overall, the 50 percent shade produced 35 percent of the fronds with zero to two necrotic spots while the 80 percent shade produced 43 percent.

Mean values for fern fronds with zero to two necrotic spots for one-year old nursery stock tested in 2003 are shown in Figure 4-3. The autumn fern is the sole species to show a significant difference. It had significantly cleaner fronds (zero to two necrotic spots) in the 80 percent shade treatment. Across all species, the 50 percent shade resulted in 35 percent of the fronds being clean – the 80 percent shade treatment resulted in 37 percent clean fronds.
Figure 4-1 - Mean percentages ($p \leq 0.05$) for one-year old nursery stock tested in 2002 of high quality fern fronds that have zero to two necrotic spots per frond in the 50 and 80 percent shade treatments.
Figure 4-2 - Mean percentages ($p \leq 0.05$) for two-year old nursery stock tested in 2003 of high quality fern fronds that have zero to two necrotic spots per frond in the 50 and 80 percent shade treatments.
Figure 4-3 - Mean percentages ($p \leq 0.05$) for one-year old nursery stock tested in 2003 of high quality fern fronds that have zero to two necrotic spots per frond in the 50 and 80 percent shade treatments.
COLOR RESULTS

The means for luminosity, chroma, and hue angle (measurements of fern color) for all one-year old nursery stock tested in 2002 are shown in Table 4-13. The average across all one-year old nursery stock tested in 2002 suggests greater potential for producing significantly darker ferns (luminosity) with lower chroma and greener color (hue angle) in the 80 percent shade than in 50 percent shade. All species tested showed similar trends. Of the seven species, five had significantly darker fronds (luminosity) with lower chroma and greener color (hue angle) under 80 percent shade conditions than under 50 percent shade. The five species were articulate lady, autumn, Christmas, lady, and Silver Falls (Table 4-13).

The means of fern color across two-year old nursery stock tested in 2003 were less consistent than found for the one-year old nursery stock tested in 2002. Autumn ferns were not included in the statistical analysis due to high mortality in the 50 percent shade treatment. All the remaining two-year old nursery stock grown in 2003 showed a relationship of darker ferns (luminosity) that had lower chroma and greener color (hue angle) in the 80 percent shade than in the 50 percent shade. However, the only significant difference was found in the articulate lady fern (Table 4-14).

The means for color across all one-year old nursery stock tested in 2003 showed significant differences between treatments with darker ferns (luminosity) having lower chroma and greener color (hue angle) under 80 percent shade than
under 50 percent shade (Table 4-15). Similarly, individual ferns including the autumn, Christmas, tatting, and eastern wood ferns were darker (luminosity), had a lower chroma, and greener color (hue angle) in the deeper shade treatment. The Wildwood Twist and lady fern species were likewise darker (luminosity) with lower chroma in the 80 percent shade but the hue (hue angle) was not significantly different from that of plants grown in 50 percent shade.
Table 4-13 - Means of luminosity, chroma, and hue angle (measurements of fern color) for all one-year old nursery stock tested in 2002 in the 50 and 80 percent shade treatments.

<table>
<thead>
<tr>
<th>Species of fern</th>
<th>Treatment</th>
<th>Luminosity$^1$</th>
<th>Chroma$^2$</th>
<th>Hue angle$^3$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Articulate lady</td>
<td>50 percent shade</td>
<td>62.54 a$^4$</td>
<td>51.20 a</td>
<td>103.29° a</td>
</tr>
<tr>
<td></td>
<td>80 percent shade</td>
<td>52.79 b</td>
<td>37.99 b</td>
<td>107.50° b</td>
</tr>
<tr>
<td>Autumn</td>
<td>50 percent shade</td>
<td>61.56 a</td>
<td>49.97 a</td>
<td>102.27° a</td>
</tr>
<tr>
<td></td>
<td>80 percent shade</td>
<td>49.50 b</td>
<td>35.78 b</td>
<td>107.09° b</td>
</tr>
<tr>
<td>Christmas</td>
<td>50 percent shade</td>
<td>60.73 a</td>
<td>49.16 a</td>
<td>102.84° a</td>
</tr>
<tr>
<td></td>
<td>80 percent shade</td>
<td>50.20 b</td>
<td>36.37 b</td>
<td>108.28° b</td>
</tr>
<tr>
<td>Japanese painted</td>
<td>50 percent shade</td>
<td>46.53 a</td>
<td>28.97 a</td>
<td>110.04° a</td>
</tr>
<tr>
<td></td>
<td>80 percent shade</td>
<td>43.04 a</td>
<td>23.51 a</td>
<td>113.41° b</td>
</tr>
<tr>
<td>Lady</td>
<td>50 percent shade</td>
<td>57.93 a</td>
<td>45.85 a</td>
<td>104.24° a</td>
</tr>
<tr>
<td></td>
<td>80 percent shade</td>
<td>49.54 b</td>
<td>35.83 b</td>
<td>108.39° b</td>
</tr>
<tr>
<td>Log</td>
<td>50 percent shade</td>
<td>67.08 a</td>
<td>57.64 a</td>
<td>100.75° a</td>
</tr>
<tr>
<td></td>
<td>80 percent shade</td>
<td>62.76 a</td>
<td>51.62 a</td>
<td>103.73° a</td>
</tr>
<tr>
<td>‘Silver Falls’</td>
<td>50 percent shade</td>
<td>51.65 a</td>
<td>35.03 a</td>
<td>108.95° a</td>
</tr>
<tr>
<td></td>
<td>80 percent shade</td>
<td>44.99 b</td>
<td>26.48 b</td>
<td>112.47° b</td>
</tr>
<tr>
<td>Means of one-year old nursery stock tested in 2002</td>
<td>50 percent shade</td>
<td>58.29 a</td>
<td>45.40 a</td>
<td>104.63° a</td>
</tr>
<tr>
<td></td>
<td>80 percent shade</td>
<td>50.40 b</td>
<td>35.37 b</td>
<td>108.70° a</td>
</tr>
</tbody>
</table>

$^1$Luminosity = lightness or darkness, black = 0 to white = 100.

$^2$Chroma = degree of departure from gray toward pure chromatic color.

$^3$Hue angle: 90° = yellow, 180° = blue-green.

$^4$Means between shade treatments within a fern species and parameter followed by the same letter are not significantly different ($p \leq 0.05$) using the least significant difference comparison.
<table>
<thead>
<tr>
<th>Species of fern</th>
<th>Treatment</th>
<th>Luminosity(^1)</th>
<th>Chroma(^2)</th>
<th>Hue angle(^3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Articulate lady</td>
<td>50 percent shade</td>
<td>65.39 a(^4)</td>
<td>50.40 a</td>
<td>104.33° a</td>
</tr>
<tr>
<td></td>
<td>80 percent shade</td>
<td>54.99 b</td>
<td>42.16 b</td>
<td>107.93° b</td>
</tr>
<tr>
<td>Autumn</td>
<td>50 percent shade</td>
<td>Non-est(^5)</td>
<td>Non-est</td>
<td>Non-est</td>
</tr>
<tr>
<td></td>
<td>80 percent shade</td>
<td>51.16</td>
<td>39.66</td>
<td>108.77°</td>
</tr>
<tr>
<td>Christmas</td>
<td>50 percent shade</td>
<td>51.84 a</td>
<td>38.51 a</td>
<td>107.85° a</td>
</tr>
<tr>
<td></td>
<td>80 percent shade</td>
<td>48.34 a</td>
<td>32.78 a</td>
<td>110.19° a</td>
</tr>
<tr>
<td>Japanese painted</td>
<td>50 percent shade</td>
<td>46.53 a</td>
<td>33.81 a</td>
<td>109.40° a</td>
</tr>
<tr>
<td></td>
<td>80 percent shade</td>
<td>43.04 a</td>
<td>29.45 a</td>
<td>110.73° a</td>
</tr>
<tr>
<td>Lady</td>
<td>50 percent shade</td>
<td>58.92 a</td>
<td>44.57 a</td>
<td>106.61° a</td>
</tr>
<tr>
<td></td>
<td>80 percent shade</td>
<td>52.37 b</td>
<td>41.00 a</td>
<td>107.81° a</td>
</tr>
<tr>
<td>Log</td>
<td>50 percent shade</td>
<td>60.55 a</td>
<td>42.51 a</td>
<td>108.99° a</td>
</tr>
<tr>
<td></td>
<td>80 percent shade</td>
<td>53.66 a</td>
<td>43.52 a</td>
<td>107.57° a</td>
</tr>
<tr>
<td>‘Silver Falls’</td>
<td>50 percent shade</td>
<td>52.24 a</td>
<td>38.33 a</td>
<td>107.92° a</td>
</tr>
<tr>
<td></td>
<td>80 percent shade</td>
<td>51.89 a</td>
<td>35.21 a</td>
<td>109.56° a</td>
</tr>
<tr>
<td>Means of two-year old nursery stock tested in 2003</td>
<td>50 percent shade</td>
<td>Non-est</td>
<td>Non-est</td>
<td>Non-est</td>
</tr>
<tr>
<td></td>
<td>80 percent shade</td>
<td>51.29</td>
<td>37.68</td>
<td>108.93°</td>
</tr>
</tbody>
</table>

\(^1\) Luminosity = lightness or darkness, black = 0 to white = 100.

\(^2\) Chroma = degree of departure from gray toward pure chromatic color.

\(^3\) Hue angle: 90° = yellow, 180° = blue-green.

\(^4\) Means between shade treatments within a fern species and parameter followed by the same letter are not significantly different (\(p \leq 0.05\)) using the least significant difference comparison.

\(^5\) Non-est = There was insufficient data due to mortality for a statistically valid comparison to be executed.
Table 4-15 - Means of luminosity, chroma, and hue angle (measurements of fern color) for all one-year old nursery stock tested in 2003 under 50 and 80 percent shade treatments.

<table>
<thead>
<tr>
<th>Species of fern</th>
<th>Treatment</th>
<th>Luminosity$^1$</th>
<th>Chroma$^2$</th>
<th>Hue angle$^3$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eastern wood</td>
<td>50 percent shade</td>
<td>51.19 a</td>
<td>37.54 a</td>
<td>101.73° a</td>
</tr>
<tr>
<td></td>
<td>80 percent shade</td>
<td>46.05 b</td>
<td>29.18 b</td>
<td>110.51° b</td>
</tr>
<tr>
<td>Autumn</td>
<td>50 percent shade</td>
<td>57.31 a$^4$</td>
<td>46.98 a</td>
<td>101.74° a</td>
</tr>
<tr>
<td></td>
<td>80 percent shade</td>
<td>48.35 b</td>
<td>35.04 b</td>
<td>109.38° b</td>
</tr>
<tr>
<td>Christmas</td>
<td>50 percent shade</td>
<td>53.65 a</td>
<td>41.34 a</td>
<td>104.51° a</td>
</tr>
<tr>
<td></td>
<td>80 percent shade</td>
<td>46.44 b</td>
<td>31.00 b</td>
<td>110.47° b</td>
</tr>
<tr>
<td>Japanese painted</td>
<td>50 percent shade</td>
<td>47.62 a</td>
<td>30.88 a</td>
<td>110.36° a</td>
</tr>
<tr>
<td></td>
<td>80 percent shade</td>
<td>45.37 a</td>
<td>27.10 a</td>
<td>111.37° a</td>
</tr>
<tr>
<td>Lady</td>
<td>50 percent shade</td>
<td>56.68 a</td>
<td>44.62 a</td>
<td>106.88° a</td>
</tr>
<tr>
<td></td>
<td>80 percent shade</td>
<td>49.54 b</td>
<td>36.85 b</td>
<td>108.92° a</td>
</tr>
<tr>
<td>Log</td>
<td>50 percent shade</td>
<td>50.60 a</td>
<td>35.62 a</td>
<td>108.60° a</td>
</tr>
<tr>
<td></td>
<td>80 percent shade</td>
<td>49.41 a</td>
<td>35.99 a</td>
<td>109.00° a</td>
</tr>
<tr>
<td>Ostrich</td>
<td>50 percent shade</td>
<td>52.00 a</td>
<td>40.44 a</td>
<td>108.12° a</td>
</tr>
<tr>
<td></td>
<td>80 percent shade</td>
<td>49.49 a</td>
<td>36.96 a</td>
<td>109.01° a</td>
</tr>
<tr>
<td>Tatting</td>
<td>50 percent shade</td>
<td>60.67 a</td>
<td>50.44 a</td>
<td>104.48° a</td>
</tr>
<tr>
<td></td>
<td>80 percent shade</td>
<td>50.67 b</td>
<td>37.81 b</td>
<td>108.70° b</td>
</tr>
<tr>
<td>Wildwood Twist</td>
<td>50 percent shade</td>
<td>46.11 a</td>
<td>27.81 a</td>
<td>111.23° a</td>
</tr>
<tr>
<td></td>
<td>80 percent shade</td>
<td>42.37 b</td>
<td>23.15 b</td>
<td>112.19° a</td>
</tr>
<tr>
<td>Means of one-year old nursery stock tested in 2003</td>
<td>50 percent shade</td>
<td>53.35 a</td>
<td>40.34 a</td>
<td>106.49° a</td>
</tr>
<tr>
<td></td>
<td>80 percent shade</td>
<td>48.04 b</td>
<td>33.63 b</td>
<td>109.68° b</td>
</tr>
</tbody>
</table>

$^1$Luminosity = lightness or darkness, black = 0 to white = 100.

$^2$Chroma = degree of departure from gray toward pure chromatic color.

$^3$Hue angle: 90° = yellow, 180° = blue-green.

$^4$Means between shade treatments within a fern species and parameter followed by the same letter are not significantly different ($p \leq 0.05$) using the least significant difference comparison.
Athyrium filix-femina ‘Frizelliae’ (Linnaeus) – tatting fern

The tatting fern was studied for only the 2003 growing season. During that time, plants in the 80 percent shade treatment outperformed those in the 50 percent shade treatment in all growth indicator categories - surface area, length, width and fresh weight. Hoshizaki and Moran (2001) indicated that the genus Athyrium is adaptable to a range from low light to high light conditions. This research, however, strongly suggests that species within this genus prefer deeper shaded conditions. Lellinger (1985) discussed the wild species of the genus. From his work, he concluded that ferns of this genus tend to populate the more deeply shaded thickets in North America. This conclusion would seem to be supported by the tatting fern’s preference for shade in this study.

The tatting fern was found to be somewhat unique in this study because it showed a strong preference for 80 percent shade in all growth categories. The color of the tatting fern followed the trend observed for most of the ferns studied with darker, less brilliant, more green than yellow fronds produced in the 80 percent shade treatment.
Athyrium Filix-femina (Linnaeus) – lady fern

The lady fern was under study for the equivalent of three growing seasons. The results for all growth indicators (surface area, length, width and fresh weight) indicate that this species requires very deep shade (80 percent) to maximize growth. Lellinger (1985) points out that the northern variety of Athyrium filix-femina subspecies angustum (Willdenow) performs best in the deep shade of wooded thickets and that the southern variety, Athyrium filix-femina subspecies asplenioides (Michaux), prefers partial sun. This is not surprising as varied differences are to be expected in any species.

Again, as was found to be the case for the tatting fern which is in the same genus, it was the tendency of the lady fern to produce a significantly greater amount of foliage in all growth indicator categories. The lady fern was found to be somewhat unique in this study because it produced a significantly greater number of high quality fronds in the 50 percent shade than in the 80 percent shade. However, the lady fern expressed darker, duller, greener fronds under conditions of 80 percent shade than 50 percent shade. Based upon this observation, it may be that the lady fern, and perhaps other species within this genus, perform best at a shade level somewhere between 50 and 80 percent.
Athyrium niponicum Pictum (Mettenius) – Japanese painted fern, ‘Silver Falls’, and ‘Wildwood Twist’

These three taxa of the Athyrium niponicum Pictum will be discussed together due to their close genetic relationship to one another. The Japanese painted fern was studied for the equivalent of three growing seasons, ‘Silver Falls’ was studied over two growing seasons and ‘Wildwood Twist’ was studied for only one growing season. This research found some differences in growth responses in these varieties, but, for the most part, the three varieties responded similarly under the two shade conditions studied. When evaluated both in terms of the variety and species, the growth indicators; fresh weight, surface area, length and width suggested similarities relative to their shade needs. The only significant difference found in fresh weight was for one-year old ‘Silver Falls’ tissue cultivars tested in 2002 – plants grown in 80 percent shade outperformed those grown in 50 percent shade. ‘Silver Falls’ and ‘Wildwood Twist’ showed no preference for one shade condition over the other based upon surface area, length or width of fronds. Japanese painted tissue cultivars showed a slight preference for 80 percent shade over 50 percent shade but for the most part, even the Japanese painted, performed equally well at both shade levels. Hoshizaki and Moran (2001) suggest that this species prefers high light conditions. While all these varieties survived better than most other species in the full sun treatment (Appendix A and B), growth was impaired and overall quality was lacking. In general, it appears that the three taxa of this species that were tested require some shade to perform best. Moreover, they appear to perform equally well in either 50 or 80 percent shade.
Of the *Athyrium niponicum Pictum* taxa studied, the ‘Silver Falls’ and ‘Wildwood Twist’ cultivars expressed a tendency toward higher quality fronds in the 80 percent shade treatment. *Athyrium niponicum Pictum* tissue cultivars have slightly darker, slightly duller and slightly greener fronds in the 80 percent shade treatment.

*Athyrium otophorum* (Miquel) – articulate lady

The articulate lady fern was studied for two growing seasons, 2002 and 2003. It tended to have heavier, larger fronds in the 80 percent shade treatment than in the 50 percent shade treatment. While differences in growth responses (Table 4-7, 4-8, 4-10, 4-11) between the two treatments were not considered significant, the 80 percent shade did consistently produce the largest plants. Hoshizaki and Moran (2001) indicate that this species prefers medium light conditions but the findings from this research do not support this position.

The articulate lady fern does produce slightly higher quality fronds in 50 percent shade compared to 80 percent. However, it produces fronds that are darker, duller, and greener in the 80 percent shade treatment.

*Dryopteris celsa* (W. Palmer) – log fern

The log fern was studied for the equivalent of three growing seasons. The fresh weight, surface area, length and width were greater in 80 percent shade than 50 percent shade for one-year old plants tested in 2003 although significant differences were only found for fresh weight and surface area. However, for two-year old
nursery stock tested in 2003 and one-year old plants tested in 2002, quantitative and qualitative measurements taken suggest that there was a lack of preference demonstrated for the two shade levels studied. The possible exception to this was found in the two-year old plants tested in 2003. Plants grown in 50 percent shade were of such poor quality that it was impossible to get meaningful data on frond length and width. Hoshizaki and Moran (2001) report that this species performs best under medium shade. While the results for this species are inconclusive, it appears as though it might perform best in a deeper shade. Moreover, based upon the statistical comparison of the quality parameters studied, it is not possible to identify one shade level as being superior to the other for this species.

Dryopteris erythrosora (D.C. Eaton) – autumn fern

The autumn fern was studied for the equivalent of three growing seasons. This species preformed well as one-year old nursery stock tested in 2002 and as one-year old nursery stock tested in 2003. Two-year nursery stock tested in 2003 did not perform well. As one-year old nursery stock tested in 2002 and 2003, this species showed a strong tendency toward larger, heavier fronds when grown in the 80 percent shade treatment. Hoshizaki and Moran’s (2001) work suggests something quite different. They indicate that the autumn fern grows best under low to medium light. To further demonstrate the need for deep shade, the two-year old nursery stock tested in 2003 performed poorer in 50 percent shade than in 80 percent shade. While the results from the two-year old stock that was “over-wintered” may not be
conclusive due to, in general, poor growth. Plants did grow better in 80 than 50 percent shade. Hoshizaki and Moran (2001) indicate that some species of ferns do not respond well to heavy foliage removal. Prior to over-wintering and while the plants were still green, they were cut back to just above the growth medium level in the pots. This may have affected the second-year growth response. However, irrespective of the two-year old growth response, it is apparent that this species grows better in 80 than 50 percent shade and produces higher quality fronds that are darker, duller and greener in this deeper shade environment.

*Dryopteris marginalis* (Linnaeus) – eastern wood fern

The eastern wood fern was studied for only one growing season, that being 2003. Its performance showed little variance whether grown in 50 or 80 percent shade. Lellinger’s (1985) and Hoshizaki and Moran’s (2001) recommendation that this species performs best in partial sun to medium shade in combination with the findings of this study would seem to indicate a broad tolerance of light conditions for this species.

The eastern wood fern was able to produce only 12 percent high quality fronds in the 80 percent shade treatment. While very low, this was better than the 7 percent produced in the 50 percent shade treatment. The reason for poor frond quality is unknown since this was the observation under both shade conditions. It may well mean that poor quality is pervasive regardless of the environment making this species a poor choice for marketing. The eastern wood fern follows the typical
trend observed for other ferns studied of darker, duller, greener fronds in the 80 percent shade treatment.

Matteuccia struthiopteris (Linnaeus) – ostrich fern

The ostrich fern was studied only during the 2003 growing season. This species consistently grew best in the deepest shade (80 percent). Significantly greater fresh weight, surface area and width were produced in the 80 as compared to the 50 percent shade. Length of fronds was also greatest under conditions of 80 percent shade although not significantly so. Once again, the results of this study do not agree with those of Hoshizaki and Moran (2001) who reported that the ostrich fern does best under medium shade. Lellinger’s (1985) assessment that the ostrich fern grows and spreads very well under a variety of shaded settings is probably more correct since this research clearly shows it performs equally well under medium and deep shade environments.

The ostrich fern showed no difference in the quality of fronds grown in 50 or 80 percent shade. It also showed no preference for a specific shade level for frond color but did tend to produce fronds that were somewhat darker, duller, and greener under 80 percent shade conditions.

Polystichum acrostichoid (Michaux) – Christmas fern

The Christmas fern appears to be yet another species that can perform well under a wide variety of light conditions. This species was studied in the shade
laboratory for the equivalent of three growing seasons. As one-year old nursery stock tested in 2002 and as one-year old stock tested in 2003, the fresh weight, surface area, length and width tended to be greater when the plants were grown under 80 percent shade. However, as two-year old stock, the Christmas fern produced heavier fronds with greater surface area in the 50 percent shade treatment than in the 80 percent shade treatment. Lellinger (1985) and Hoshizaki and Moran (2001) report that the Christmas fern grows best in partial sun to medium light. Based upon the favorable response of this species to the 80 percent shade conditions in this study in combination with the report of Lellinger (1985) and Hoshizaki and Moran (2001), it is the author’s opinion that the Christmas fern, when provided sufficient moisture, will grow well from conditions of partial sun to deep shade.

The Christmas fern did express a preference for 80 percent shade for the production of high quality fronds that was darker, duller and greener than those produced in 50 percent shade.

EFFECTS OF SHADE (LIGHT) ON GROWTH INDICATORS

Environmental conditions associated with the 80 percent shade treatment in this study resulted in consistent, although not always significant, increases of frond surface area, length, and width in the fern varieties tested over both growing seasons. Frond surface area, length, and width in the 80 percent shade treatment were typically greater over both growing seasons, indicating the possibility of increased
photosynthesis or greater efficiency of the use of photosynthate produced under the deeper shade condition.

A plant's ability to undergo photosynthesis correlates well with its ability to grow. Ferns exposed to the full sun treatment in this study were unable to adapt and grow. Many of them died while those that were able to survive grew so poorly that they provided little measurable data. Powles (1984) explained that, “Plants genotypically adapted to deeply shaded habitats (shade plants) may not have the ability to acclimate and grow in full sun conditions.” Similarly, inhibition can occur in these plants when grown under intermediate light conditions such as in 50 percent shade. Powles and Critchley (1980) and Powles and Thorne (1981) clearly demonstrated this relationship. Photoinhibition of photosynthesis occurred when bean plants adapted to low light conditions were exposed to gradually increasing light conditions. Powles and Thorne (1981) also observed this phenomenon in the fronds of the shade fern *Lastreopsis microsora*. Several other studies have demonstrated similar results in terrestrial shade plants when they were exposed to high and intermediate light conditions (Björkman and Holmgren 1963; Björkman 1968; Gauhl 1975; Jurik et al. 1979).

Winter *et al.* (1986) studied the tropical epiphytic fern, *Pyrrrosia longifolia*, naturalized in full sun and very shaded conditions. They found that this species experienced an equal quantum yield of CO₂ dark fixation (photosynthesis) under conditions of both sites. The quantum yield of photosynthesis for the shade fern however was reduced by 60 percent when it was exposed to full sunlight for six hours.
All fern species are obviously not the same relative to light requirements. The Boston fern (*Nephrolepis exaltata* ‘Rooseveltii’) is an example of a more light-demanding species. Nowak *et al.* (2002) found that high light conditions actually helps the growth response of the Boston fern. They were able to accelerate growth of this species in microcuttings by applying high light conditions and a high nutrient solution concentration. Under normal growing conditions (i.e., under lower fertility conditions), the Boston fern prefers medium to high light conditions (Hoshizaki and Moran 2001).

While measurements of photosynthesis and respiration were not made in this study, variance in the data collected would seem to support the thesis that changes in both were occurring with changes in light availability. Although other factors such as changes in temperature, etc., may also have played a role in the differential responses under conditions of 50 and 80 percent shade, the intensity of light and its effect on photosynthesis and respiration was probably a major factor.

**EFFECTS OF SHADE (LIGHT) ON NECROTIC SPOTS**

Proposed reasons for the variation in the number of necrotic spots are purely speculative since no data specific to the causes of the necrotic spots on these ferns were recorded. The log fern showed an increase in the number of clean fronds in the 80 percent shade treatment from the first year to the second. However, it also showed a decline in the number of clean fronds produced in the 50 percent shade treatment during the same time period. One possible explanation is that this species
requires a full year to fully adapt to its growing conditions and performs best in
deep shade conditions. Another possibility is that an increase of spotting was due
to a concentration of spores resulting from the confined over-wintering process. Still
another explanation is that the increase was due to desiccation, salt buildup, or
temperature extremes. A field study should be conducted to determine if necrotic
spots has anything to do with shade conditions.

The average for all one-year old nursery stock fronds tested in 2002 is
approximately 50 percent considered clean (with zero to two necrotic spots). In
contrast, the two-year old stock, tested in 2003, dropped to an average of 38.8
percent of the fronds in both shade categories being classified as clean (with zero to
two necrotic spots). A possible explanation is that these ferns have experienced a
build-up of necrotic-spot-causing pathogens. Therefore, they were more affected in
the second year than in the first when grown in the same location (Stamps 1996;
Dunn and Crow 2001; Poole et al. 2005). This obviously does not, however, explain
the findings for the log fern. In the two-year old stock tested in 2003 the log fern
dramatically increased the number of clean fronds (with zero to two necrotic spots)
by 15.6 percent.

In general, the data suggests that 2003 was either not as good a year as 2002,
environmentally, for producing quality fronds or, for certain species, a build-up of
pathogens that caused necrotic spots occurred as alluded to in the above discussion.
Four of the five species tested as one-year old stock in 2002 and 2003 (autumn,
Christmas, lady, and log) showed dramatic reductions in the quality of fronds
produced in 2003 compared to 2002. The only exception was the Japanese painted
ferns which showed an increase in frond quality from 2002 to 2003. While it is impossible to discuss the reason for the general reduction in frond quality in certain species between 2002 and 2003, it is obvious that additional research is required before recommendations can be made to landowners.

EFFECTS OF SHADE (LIGHT) ON FROND COLOR

Shade played an obvious role in the color of the fronds produced in this study. The color in the 80 percent shade treatment was consistently darker green than that in the 50 percent shade treatment. Several possible explanations for this relationship exist.

Since chlorophyll is responsible for the green appearance of leaves, a direct effect of the amount of light on chlorophyll content and thus color, is to be expected. Shade can significantly affect the amount of chlorophyll a plant contains. Kirk and Tilney-Bassett (1967) and Rabinowitch (1945) explained that shade plants have richer chlorophyll than open grown plants. This is because shade plants have a higher ratio of chlorophyll b to chlorophyll a than plants grown under more illuminated conditions (Boardman 1977). Plants with a higher ratio of chlorophyll b to a appear to be a darker green in color. Moreover, Ludlow (1967) demonstrated that there is more total chlorophyll in the leaves of shade species than in the leaves of sun species. He also found a greater ratio of chlorophyll b to chlorophyll a in shade ferns than in sun ferns.
Also, Vézina and Boulter (1966) emphasized that light quality in the understory is different from that in the open and can have a significant effect on the color of the understory plant life. This is due to changes in light properties when it is reflected from the leaves of overstory plants which can vary depending on the overstory species present. For example, Toumey and Korstian (1947) found that conifers cast a dark shade allowing only a small percentage of the light to be reflected to the understory plants. The spectrum of light that gets through the overstory foliage correlates well with the color of the plants in the understory. The darker green color observed in many understory plants is a result of the darker green light rays that are available to them in the darker shade environment. Plants grown in less shaded areas tend to be lighter green than those grown in a more heavily shaded area.

While chlorophyll ratios were not measured in this study, a discussion on the relationship between chlorophyll, shade, and plant color provides insight into why differences were found in frond color in this study. In summary, shade plants contain a higher ratio of chlorophyll \( b \) compared to chlorophyll \( a \). Chlorophyll \( b \) is a yellowish-green color while chlorophyll \( a \) is blue-green (Salisbury 1985). A plant with a higher ratio of chlorophyll \( b \) to \( a \) reflects darker green foliage. And, more total chlorophyll may be present in the leaves of shade species than in the leaves of sun species.
CHAPTER VI
SUMMARY AND CONCLUSIONS

SUMMARY

Eleven fern species or cultivars were tested for their potential use in forest farming, an agroforestry practice. These were: Athyrium filix-femina ‘Frizelliae’ (Linnaeus) – tatting fern, Athyrium filix-femina (Linnaeus) – lady fern, Athyrium niponicum Pictum (Mettenius) – ‘Silver Falls’ fern, Athyrium niponicum Pictum (Mettenius) – ‘Wildwood Twist’ fern, Athyrium niponicum Pictum (Mettenius) – Japanese painted fern, Athyrium otophorum (Miquel) – articulate lady, Dryopteris celsa (W. Palmer) – log fern, Dryopteris erythrosora (D.C. Eaton) – autumn fern, Dryopteris marginalis (Linnaeus) – eastern wood fern, Matteuccia struthiopteris (Linnaeus) – ostrich fern, and Polystichum acrostichoid (Michaux) – Christmas fern. The purpose of this study was to quantify the effects of levels of shade (light) on selected fern species believed to have potential for use in the floral green and landscape industries. The treatments included full sun, 50 percent shade and 80 percent shade. These shade treatments were created using shade cloth placed over a greenhouse-type frame. Due to high mortality in the full sun treatment, this treatment was eliminated and comparisons made only between the 50 and 80 percent shade conditions.

Of the one-year old nursery stock tested in 2002, the differences in growth response (fresh weight, surface area, length, and width) between the two shade
treatments were not especially great. However, the autumn fern, Christmas fern and lady fern did perform significantly better in the 80 percent shade than in the 50 percent shade. Ferns grown in 2002 typically had fewer necrotic spots than ferns grown the following year. Ferns grown in the 80 percent shade treatment were consistently darker (luminosity), more dull than vivid (chroma), and more green than yellow (hue). The ferns that achieved a significant difference over their 50 percent shade counterparts when grown under 80 percent shade were: the articulate lady, autumn, Christmas, lady, and ‘Silver Falls.’

As two-year old stock tested in 2003 (i.e., the one-year old stock tested in 2002 was over-wintered and re-tested as two-year old stock in 2003), there was very little difference observed in the surface area, length and width between the ferns in the two shade treatments. Differences in surface area, length, and width were rarely significant and when they were, there was no discernable pattern. Significant differences in color were also rare. Only the articulate lady fern maintained its significantly darker (luminosity), more dull than vivid (chroma), and more green than yellow (hue) frond color in the 80 percent shade treatment.

Observations for one-year old stock tested in 2003 were somewhat similar to those for one-year old stock tested in 2002. The autumn, Japanese painted, lady, log, ostrich and tatting ferns were significantly larger in the 80 percent shade treatment than in the 50 percent shade treatment for one or more of the parameters measured (i.e., surface area, length or width of fronds). Furthermore, the color of the autumn, Christmas, eastern wood, and tatting ferns were darker, more dull than vivid, and more green than yellow in the 80 percent shade than in the 50 percent shade. The
lady and ‘Wildwood Twist’ ferns were darker and more dull than vivid in the 80 percent shade treatment but not necessarily more green than yellow.

CONCLUSIONS

As noted previously, ferns exposed to full sun grew so poorly and had such high mortality that meaningful data could not be collected. Because of the clear demonstration that the species being tested could not grow under conditions of full illumination, the full sun treatment was eliminated and all of the null hypotheses that suggested there would be no differences in the quality of ferns grown under the three light regimes (full sun, 50 percent and 80 percent shade) were rejected. More realistic new hypotheses that test differences in plants grown under 50 and 80 percent shade will serve as the basis for the conclusion section of this thesis.

Hypothesis 1 - - There is no difference in the amount of biomass measured in fresh weight for ferns grown under 80 percent shade and 50 percent shade.

Taken collectively, four out of seven one-year old ferns tested in 2002 showed no significant difference in fresh weight when grown under 50 and 80 percent shade conditions, although all yielded the most fresh weight under 80 percent shade. Only autumn, Christmas, and ‘Silver Falls’ showed a significant preference for 80 percent shade. In 2003, only three of the nine species (cultivars) that were tested showed no significant difference as one-year old plants, even though all three performed best in 80 percent shade. Autumn, Christmas, lady, log, ostrich and tatting ferns yielded significantly greater fresh weight in 80 percent shade. Of the one-year old plants
started in 2002, over-wintered and monitored as two-year old stock in 2003, only the articulate lady fern yielded more fresh weight in 80 percent shade.

In general, the majority of comparisons made demonstrated that the fern species (cultivars) tested preferred 80 percent over 50 percent shade. In the one-year old stock, nine out of sixteen species (cultivars) grown during 2002 and 2003, yielded the greatest fresh weight when grown in 80 percent shade. Two-year old stock grown in 2003 showed less preference for the deeper shade than did one-year old stock with only one species producing significantly greater fresh weight in 80 percent than 50 percent shade. However, in view of the poor overall performance of the two-year old stock, it is suspected that some damage may have occurred to these plants during over-wintering, making the results less than reliable. While differences were found in shade preferences between species, overall performance, measured as fresh weight produced, was better under 80 than 50 percent shade. Based upon this observation Hypothesis 1 is rejected - - ferns (taken collectively) grown under 50 and 80 percent shade do not produce equal amounts of fresh weight biomass.

Hypothesis 2 - - There is no difference in frond lengths of ferns grown under 80 percent shade and 50 percent shade.

Five of the seven species (cultivars) tested as one-year old stock in 2002, produced fronds of equal length under conditions of 50 and 80 percent shade. Only autumn and lady ferns showed a preference for 80 percent shade. Similarly, one-year old stock tested in 2003 showed little preference for one shade percentage over the other. The exception was found with Japanese painted, lady and tatting which all produced significantly longer fronds under the conditions of 80 percent shade. Of
the two-year old stock tested in 2003, Japanese painted and lady were the only two out of seven species (cultivars) tested that produced significantly longer fronds under 80 percent than 50 percent shade. Although the majority of the fern species (cultivars) tested showed no significant differences in frond length produced under 50 and 80 percent shade, obvious differences exist between species and the general hypothesis that ferns (taken collectively) grown under 50 and 80 percent shade will produce equal frond lengths is rejected. While this relationship appears to be true for some ferns included in the test, it does not hold true for all ferns tested.

Hypothesis 3 - - There is no difference in frond widths of ferns grown under 80 percent shade and 50 percent shade.

Five of the seven species (cultivars) tested as one-year old plants in 2002 showed equal preference for 50 and 80 percent shade conditions by producing fronds of equal width under both light conditions. Unlike 2002, five of the nine species (cultivars) tested in 2003 as one-year old plants, produced significantly wider fronds under 80 than 50 percent shade showing a relatively strong preference for the deeper shade. As two-year old stock in 2003, two species (Christmas and lady) produced fronds of greater width in 80 than in 50 percent shade. Comparisons made between species (cultivars) that performed best in 80 percent shade in both 2002 and 2003, show that only the lady fern yielded significantly wider fronds during both years under 80 percent shade. However, the tatting and ostrich, both of which showed superior responses in 80 percent shade were tested only in 2003. The Christmas fern produced significantly wider fronds under conditions of 80 percent than 50 percent shade in 2002 but not in 2003. As was found to be the case for frond length,
differential responses between species (i.e., some produced significantly wider fronds in 80 percent shade, some did not) results in a rejection of Hypothesis 3.

**Hypothesis 4** - - There is no difference in surface area of ferns grown under 80 percent shade and 50 percent shade.

Logically, one might assume that if significant differences exist between species for frond width and length (Hypotheses 2 and 3), similar differences will be found in surface area since it is a product of width and length. Such was the case. During 2002, three species (autumn, Christmas and lady) produced significantly more leaf surface area as one-year old plants under 80 percent shade than under 50 percent shade - - four species showed no preference. In 2003, five out of nine species (cultivars) tested as one-year old plants showed a preference for 80 percent shade. The autumn, lady, log, ostrich and tatting, all preferred the deeper shade associated with the 80 percent treatment. Interestingly, within the two-year old plants tested in 2003, only the articulate lady fern was found to produce significantly greater leaf surface area in 80 percent shade compared to 50 percent shade. While length and width for this species were greatest in 80 percent shade, significant differences were not observed for these measurements for plants grown under the two shade conditions. Other species (i.e., Japanese painted, lady, and Christmas) that had significant differences in either length or width did not have significant differences in surface area. Again, as with frond length and width, strong differences between species frond surface areas results in Hypothesis 4 being false and it is rejected.
Hypothesis 5 - - There is no difference in the number of necrotic spots of ferns that are potentially useful in the floral green and landscaping industries when grown under 80 percent shade and 50 percent shade.

All of the ferns in this study have potential in the floral greens industry and landscape markets. Furthermore, both shade treatments produced fronds with blemish free fronds although variation in the numbers of blemish free fronds was observed. One must consider the proposed use of the ferns and/or fronds when evaluating the significance of frond blemishes. If for instance, these ferns are to be used in the floral greens industry, then the producer will not want to harvest 100 percent of the green material - that could harm the plant (Hoshizaki and Moran 2001). Producers would be advised to harvest a few of the best fronds to sell and, as has been demonstrated in this research, many of the species studied produced a significant number of blemish-free fronds to accommodate a floral greens industry. On the other hand, ferns entering the landscape market are allowed to be less than perfect. Selections for this market would include the log fern in deep shade which produced the greatest number of blemish free fronds as two-year old nursery stock tested in 2003 and several other species that were tested. Based on the parameters of this study, Hypothesis 5 is accepted.

Hypothesis 6 - - There is no difference in the color of ferns that lend themselves to use in the floral green or landscaping industries when grown under 80 percent shade and 50 percent shade.

This hypothesis is accepted but, not because differences were not observed between species grown at the two light levels studied - - they were. Acceptance, i
this case, is more the result of perception. Even though some significant differences were expected in luminosity, chroma, and hue angle between species grown in 50 and 80 percent shade, the visual effect was not great enough to make a difference. Of the one-year old plants tested in 2002, only the Japanese painted and log ferns showed little or no change in color when grown under 50 and 80 percent shade conditions. Similarly, for one-year old plants tested in 2003, the Japanese painted, log, and ostrich ferns showed no effect from shade on color. For the two-year old plants tested in 2003, the Christmas, log, Japanese painted and a cultivar of Japanese painted, ‘Silver Falls’ showed no significant differences in color when grown in 50 and 80 percent shade. The lady fern had a significant difference in luminosity but not in chroma or hue angle. However, even for those species that showed significant differences based upon the parameters measured, the color of fronds to the “naked eye” were such that they could be marketed in either the floral green or landscape industries. Based upon this quality evaluation, Hypothesis 6 is accepted.

Critical evaluations (quantitative and qualitative) have been made on eleven fern species (cultivars) believed to have potential in establishing either a floral green or landscaping fern industry in Missouri. None of the species studied were able to produce quality fronds under full sun conditions. Although differences in quality were observed between plants grown in 50 and 80 percent shade, most species tested performed well enough under both shade conditions to be recommended for growing in our state for the landscape industry. In general though, performance was typically better under conditions of 80 percent than 50 percent shade. While requirements are more stringent for plant material entering the floral green industry than the landscape
industry, certain species that were studied appear to be suitable for the floral green market and merit additional evaluation. In particular, the Christmas fern has qualities that make it a viable species for the floral green market. The Christmas fern is an excellent example of a species that grows well in Missouri (it is native), has reasonable frond length and color and retains its fronds in excellent condition (color etc.) through the fall months and into early winter. In a survey conducted by Mater Engineering, Ltd. (1993), the Christmas fern was singled out as a species of considerable potential for the floral green industry in Missouri. The findings from this research support the contentions of Mater Engineering, Ltd.
LITERATURE CITED


APPENDIX A
Appendix Table A-1 - Percent mortality of each fern species tested in the shade laboratory during the 2002 growing season at the Horticulture and Agroforestry Research Center in New Franklin, Missouri.

<table>
<thead>
<tr>
<th>Species</th>
<th>Full Sun</th>
<th>50 percent shade</th>
<th>80 percent shade</th>
</tr>
</thead>
<tbody>
<tr>
<td>Articulate lady</td>
<td>43.8</td>
<td>14.6</td>
<td>2.1</td>
</tr>
<tr>
<td>Autumn</td>
<td>60.4</td>
<td>18.8</td>
<td>21.3</td>
</tr>
<tr>
<td>Christmas</td>
<td>58.3</td>
<td>16.7</td>
<td>12.2</td>
</tr>
<tr>
<td>Japanese painted</td>
<td>8.3</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Lady</td>
<td>40.4</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Log</td>
<td>75.0</td>
<td>14.6</td>
<td>21.7</td>
</tr>
<tr>
<td>‘Silver Falls’</td>
<td>20.4</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Averages</td>
<td>50.3</td>
<td>20.6</td>
<td>18.9</td>
</tr>
</tbody>
</table>
Appendix Table A-2 - Percent mortality of each fern species tested in the shade laboratory during the 2003 growing season at the Horticulture and Agroforestry Research Center in New Franklin, Missouri

<table>
<thead>
<tr>
<th>Species</th>
<th>Full Sun</th>
<th>50 percent shade</th>
<th>80 percent shade</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eastern wood</td>
<td>66.7</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Autumn</td>
<td>100</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Christmas</td>
<td>45.8</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Japanese painted</td>
<td>4.2</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Lady</td>
<td>32.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Log</td>
<td>29.2</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Ostrich</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Tatting</td>
<td>100</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>‘Wildwood Twist’</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Averages</td>
<td>29.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
</tbody>
</table>
options ls=100 ps=70;
data one; infile 'i:/kluthe/k2003/alld.csv' dsd firstobs=2 missover;
input year$ trt loc1 loc2$ sp ad ln wd nospot$ color$ ll a b df sura tfw tdw;

/*
qualcode=1;
if nospot>2 then qualcode=2;
if nospot>10 then qualcode=3;
if nospot=. then qualcode=.;
*/
L=LOC2+0;
YR=1;
IF L>100 THEN YR=3;
if substr(loc2,1,1)='0' THEN YR=2;
rep=1;
if loc1>3 then rep=2;
if loc1>6 then rep=3;
shade=0;
if loc1=2 or loc1=6 or loc1=7 then shade=80;
if loc1=3 or loc1=4 or loc1=8 then shade=50;
if shade=0 then delete;
if nospot='X' then nospot='99';
nospot=nospot+0;

/*
nscode=1;
if nospot>0 then nscode=2;
if nospot>2 then nscode=3;
if nospot>6 then nscode=4;
if nospot>9 then nscode=5;
*/
lsura=log10(sura);
ltfw=log10(tfw);
ltdw=log10(tdw);
lfd=log10(df+1);
lln=log10(ln);
lwd=log10(wd);
nscode=1;
if nospot>2 then nscode=2;
C=SQRT((a * a)+(b * b));
THETA = (ATAN(b/a)/6.2832) * 360;
IF a>0 AND b>=0 THEN h=THETA;
IF a<0 AND b>=0 THEN h=180+THETA;
IF a<0 AND b<0 THEN h=180+THETA;
IF a>0 AND b<0 THEN h= 360+THETA;
OUTPUT;
DROP a b THETA;
*proc print;
*var tfw tdw;
proc means;
/
PROC SORT; BY YR;
proc glm; classes rep shade sp; BY YR;
model SurA lsura TFw Tfw Tdw ltdw df ldf ln lln wd lwd ll c h=rep shade rep*shade sp
sh ade*sp rep(shade sp);
test h= shade e=rep*shade;
test h=sp shade*sp e=rep(shade sp);
means shade sp shade*sp ;
lsmeans shade/s p e=rep*shade;
lsmeans sp shade*sp/s p e=rep(shade sp);
/*
*/
PROC SORT; BY YR;
proc glm; classes rep shade sp YR;
model SurA lsura TFw Tfw Tdw ltdw df ldf ln lln wd lwd ll c h
=rep shade rep*shade sp shade*sp rep(shade sp) yr rep*yr shade*yr rep(shade yr) sp*yr
shade*sp*yr;
test h= shade e=rep*shade;
test h=sp shade*sp e=rep(shade sp);
test h=yr e=rep*yr;
test h=shade*yr e=rep(shade yr);
means shade sp shade*sp yr rep*yr shade*yr sp*yr shade*sp*yr;
means shade sp shade*sp ;
lsmeans shade/s p e=rep*shade;
lsmeans sp shade*sp/s p e=rep(shade sp);
lsmeans yr/s p e=rep*yr;
lsmeans shade*yr/s p e=rep(shade yr);
lsmeans sp*yr shade*sp*yr/s p;
/*
*proc print;
*var year yr loc2 sp shade nscode;
proc sort; by year sp;
proc freq; by year sp;
tables shade*nscode/expected chisq relrisk;

proc genmod; by sp;
class yr shade;
model nscode=shade yr shade*yr/link=logit dist=binomial type3;
lsmeans shade yr shade*yr/pdiff;
/
*/
qualcode=1;
if nospot>2 then qualcode=2;
if nospot>10 then qualcode=3;
if nospot=. then qualcode=.;
*/

data one; infile 'F:/kluthe/k2003/alld.csv' dsd firstobs=2 missover;
input year trt loc1 loc2$ sp ad ln wd nospot$ ll a b df sura tfw tdw;
L=LOC2+0;
YR=1;
IF L>100 THEN YR=3;
if substr(loc2,1,1)='0' THEN YR=2;
rep=1;
if loc1>3 then rep=2;
if loc1>6 then rep=3;
shade=0;
if loc1=2 or loc1=6 or loc1=7 then shade=80;
if loc1=3 or loc1=4 or loc1=8 then shade=50;
if nospot='X' then nospot='99';
nospot=nospot+0;
*proc print;
proc sort; by sp;
proc freq; by sp;
tables shade* ad/expected chisq;
run;

/*
   data three; set one;
   *if ln>253;
   proc sort; by rep shade sp;
   proc means; by rep shade sp;
   data two; set one;
   if shade=0 then delete;
   proc glm; classes rep shade sp;
   model ln wt nospot qualcode=rep shade rep*shade sp shade*sp rep(shade sp);
   test h= shade e=rep*shade;
   test h=sp shade*sp e=rep(shade sp);
   lsmeans shade/s p e=rep*shade;
   lsmeans sp shade*sp/s p e=rep(shade sp);

   */
*/
data two; infile 'g:/kluthe/byfern.csv' dsd firstobs=2 missover;
input Trt Loc1 Loc2 Sp ADFern Color noDfron SurA TotFwt Totdrywt;
rep=1;
if loc1>3 then rep=2;
if loc1>6 then rep=3;
shade=0;
if loc1=2 or loc1=6 or loc1=7 then shade=80;
if loc1=3 or loc1=4 or loc1=8 then shade=50;
proc print;
proc sort; by rep shade sp;
proc means; by rep shade sp;
data two; set two;
if shade=0 then delete;
proc glm; classes rep shade sp;
model noDfron SurA TotFwt Totdrywt=rep shade rep*shade sp shade*sp rep(shade sp);
test h= shade e=rep*shade;
test h=sp shade*sp e=rep(shade sp);
lsmeans shade/s p e=rep*shade;
lsmeans sp shade*sp/s p e=rep(shade sp);
run;

data two; infile 'g:/kluthe/pfd.csv' dsd firstobs=3 missover;
input Trt Loc1 Loc2 Sp Frond1-Frond5 dFrond1-dFrond5 ddFrond1-ddfrond5;
rep=1;
if loc1>3 then rep=2;
if loc1>6 then rep=3;
shade=0;
if loc1=2 or loc1=6 or loc1=7 then shade=80;
if loc1=3 or loc1=4 or loc1=8 then shade=50;
av1=mean(of frond1-frond5);
av2=mean(of dfrond1-dfrond5);
av3=mean(of ddfrond1-ddfrond5);
proc print;
proc glm; classes rep shade sp;
model av1 av2 av3=rep shade rep*shade sp shade*sp rep(shade sp);
test h= shade e=rep*shade;
test h=sp shade*sp e=rep(shade sp);
means rep shade rep*shade sp shade*sp;
lsmeans shade/s p e=rep*shade;
lsmeans sp shade*sp/s p e=rep(shade sp);
run;
*/