

Soil and Plant Water Stress in an Appalachian Oak Forest:
Its Relationship to
Topography and Forest Site Quality

by

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INTRODUCTION

There are a significant number of medium to low quality hardwood stands in the Appalachian Hardwood Region. As a result of its unique physiography, the Ridge and Valley Physiographic Province contains a high proportion of such stands. The site factors contributing to this lower productivity include steep slopes, shallow soils, nutrient-poor parent material and growth-limiting precipitation levels in the latter portion of the growing season. Previously of limited merchantability, this vast hardwood resource is steadily gaining attention as a potential energy source. With the price of fossil fuels continuing to rise, the recent increase in demand for fuelwood harvested from Ridge and Valley hardwood stands will undoubtedly increase.

To satisfy this projected demand and increase the wood production on these sites with a minimum of site deterioration, efficient and effective silvicultural management techniques must be formulated. Increased management intensity in these areas will necessitate the formulation of site evaluation techniques that identify potential productivity through site classification.

Although site index is the most commonly used measure of site productivity, many locations are presently non-forested or do not have stands suitable for direct determination of site index. Alternative approaches often approximate site index by relating it to one or more limiting factors. This usually involves selection of the environmental factors which may limit growth, or otherwise be related to site index. In most studies, soil factors or topographic factors that influence or reflect moisture supply have been important (Haig, 1929; Coile, 1953; Weitzman and Trimble, 1955).

In the Ridge and Valley Physiographic Province of the Appalachian Region, where annual rainfall is normally less than 102 cm (40 inches), it has been hypothesized that plant available soil moisture is the environmental factor most often limiting tree growth during the growing season (Rauscher, 1977; Wickham, 1975). Topographic variables which appear to strongly influence the available water for plant growth on a site are aspect, slope inclination and slope position. A Forest Site Quality Index was proposed by Smith and Burkhardt (1976) to predict site quality based on these three parameters. The index was improved by Wathen (1977) and found to be highly correlated with site index data of upland oaks in West Virginia and Maryland.

Correlations with mean annual increment have been reported by Ross et al. (1982) for the Ridge and Valley Physiographic Province of Virginia. In mountainous areas where moisture is often limiting to plant growth during the growing season, and within areas of uniform parent material, a classification scheme based on topographic parameters that reflect relative moisture availability would probably be comparable to site index as a measure of site quality and much easier to measure.

Limited soil moisture data have been collected on the forested Ridge and Valley study site located on Potts Mountain, in Craig County, Va. Martin et al. (1982) suggested that moisture accounts for major changes in phytomass across four sampled areas based on a hypothesized topographic moisture gradient. McEvoy et al. (1980) found that vegetative structure is strongly influenced by site relationships related to differences in moisture availability. Thus, quantitatively verifying the topographically proposed moisture gradient on the Potts Mountain study area would directly substantiate a number of previous studies which have hypothesized its existence (Morin, 1978; McEvoy et al., 1980; Martin et al., 1982; Ross et al., 1982). The objectives of this study were:

- (1) To determine the relationship among sites classified by topographic variables (aspect, slope inclination and slope position) and moisture gradients derived from repeated soil moisture and plant moisture stress determinations.
- (2) To examine the seasonal fluctuations of soil moisture and of plant moisture stress for selected hardwood species in a three-year-old clearcut and adjacent uncut stands.

This study is part of a comprehensive natural hardwood regeneration research project being conducted on the southeast face of Potts Mountain in Craig Co., Virginia. The overall objective of the project is to assess the effects of whole-tree harvesting with sky-line cable logging on the productivity of an Appalachian Oak Forest Ecosystem in the Ridge and Valley Physiographic Province of Virginia. Project studies have included: (1) soil nutrient status, (2) composition and structure of vegetation, (3) oak regeneration development, (4) biomass and nutrient levels in understory vegetation, (5) browse productivity, and (6) small mammal and bird population dynamics.

LITERATURE REVIEW

Forest site quality as defined by Spurr and Barnes (1980) is the sum of all of the factors affecting the capacity to produce forests or other vegetation, and includes climatic, soil and biological factors. These site factors are interdependent, interacting in a complex, dynamic ecosystem and therefore, their independent effects on forest growth potential are often difficult to quantify.

Traditional approaches to estimating forest productivity or site quality have evolved around the following alternatives (Spurr and Barnes, 1980):

- A. Vegetation of the Forest
 - 1. Trees (site index)
 - 2. Ground vegetation (indicator species and species groups)
 - 3. Overstory and understory vegetation in combination
- B. Factors of the Physical Environment
 - 1. Climate
 - 2. Soil and Topography
- C. Multiple Factor or Combined Methods

Site Index Approach

Site index is based on the assumption that height is the tree measure best related to the site productivity of a given species. It has been defined as the average height of the dominant portion of a forest stand at a specified base age, typically 50 years in eastern hardwoods (Jones, 1969).

The usual method of determining site index on the basis of tree heights depends upon the use of a height-over-age growth curve to estimate the height at a standard base age. Diversity in the forms of height growth curves is conditioned by different combinations of site factors, changes in limiting factors during stand development, genetic differences and history of the stand. The basic assumptions of site index include: (1) site index of a stand will not change during the stand's life; (2) height growth is not influenced by stand density; (3) height of the dominant and codominant trees have not been influenced by disease, windthrow, or other adversities; and (4) site index is species specific. For many forested areas, these basic assumptions cannot be met or stands are not amenable to site index measurement; therefore, alternative approaches to estimating site quality have been employed. A detailed discussion of the assumptions and weaknesses of the standard site index curve techniques can be found in Cajander (1926), Spurr (1956), and Carmean (1975).

Vegetation Approaches

The presence, spatial distribution, abundance and size of vegetation may be indicative of site quality in some instances. This approach received wide attention after Cajander (1926) subdivided the forest habitats of Finland into forest site-types. Areas having similar site-types were assumed to be relatively uniform in site quality. Present day techniques of classification and ordination seek to combine vegetation indicators of the overstory and ground cover with physical factors of the environment for site quality assessment (Spurr and Barnes, 1980).

Environmental Approaches

An analysis of the physical environment is often necessary to estimate site quality where the use of vegetation is not possible. In general, the most useful environmental factors for site quality estimation are those in short supply or otherwise limiting growth potential such that small changes in the supply of the factor will result in measurable changes in the growth of trees.

Since soil moisture is frequently a limiting factor in the latter portion of the growing season in the Ridge and Valley Physiographic Province of Virginia (Wickham, 1975; Rauscher, 1977), those factors which best

reflect the moisture regime of the site should be highly indicative of site quality. The topographic parameters of aspect, slope inclination and slope position have pronounced effects on the moisture availability of a site in this region and thus are potentially useful as indices of forest site quality.

Aspect determines the degree of exposure of a surface to solar radiation (Geiger, 1965). Under climatic conditions where low precipitation during the growing season results in plant moisture stress, the south-facing slopes will be less productive than north-facing slopes because of greater evapotranspiration rates on the southern aspects. The relatively greater evapotranspiration rates on the southern exposures will result in less available soil moisture, higher plant moisture stress, and reduced rates of plant growth.

Slope inclination affects soil profile development, degree of erodibility, texture and structure of the surface soil and subsoil, and lateral movement of soil water. In general, steeper sites have shallower soils, less soil profile development, greater erosional losses and less soil moisture available for plant growth. Slope position describes the position of the site with respect to the top and bottom of the entire slope. High convex surfaces have

little protection from drying winds, temperature extremes, and are subject to greater erosion and weathering than the more protected lower concave surfaces. The slope position is also related to microclimate and to the physical properties of the soil that govern soil moisture and aeration relationships. Many studies in mountainous regions have found slope position to be the single most useful factor in evaluating growth potential of forest trees (Ralston, 1964; Carmean, 1975, 1977).

The common procedure when relating soil and topographic factors to site quality is to measure a selected number of soil and site variables (e.g., soil depth, texture, slope position, aspect, slope percent) and relate these through multiple regression analyses to tree height or site index. The equations derived from soil-site studies are used for developing site prediction tables and graphs for estimating site index in the field (Spurr and Barnes, 1980).

In a soil-site study in the Douglas-fir Region of Washington, Carmean (1956) concluded that site quality is controlled by the amount of available soil moisture supplied to the tree roots during the growing season. Thus, the depth of that portion of the soil that is either occupied or capable of being occupied by tree roots has been

a significant factor in many soil-site studies (Auten, 1945; Einspahr and McComb, 1951; Coile, 1952; Doolittle, 1957). Lemmon (1955) listed effective soil depth, aspect and position on slope as the most useful factors in delineating site quality in the Douglas-fir region.

Classifying pine site quality in southern Arkansas and northern Louisiana in terms of soil and topographic characteristics, Zahner (1957) reported a significant relationship between site index and thickness or texture of the surface soil, texture of the subsoil and slope position. Shoulders and Tiarks (1980), working in Louisiana and Mississippi, concluded that relative height growth of major southern pines can be reliably predicted from precipitation data, slope percent and potential available moisture storage of the subsoil.

Studies of oak site quality in the Appalachians have indicated that productivity can be estimated from: (1) aspect (2) relative position from ridge top to cove (3) degree of slope and (4) total soil depth to bedrock (Trimble and Weitzman, 1956; Doolittle, 1957; Carmean, 1967; Yawney and Trimble, 1968). The soil depth variable was eliminated by Trimble (1964) because of its close relationship with slope position and slope inclination. Carmean (1967) found that equations based solely on topographic features

explained more than 75 percent of the variation in total height of black oak in southeastern Ohio.

Soil Moisture and Tree Growth

The rate of forest growth is generally known to be related to the amount of available water in the soil (Zahner, 1956). Available water for plant growth approximates that moisture retained by the soil between -0.01 and -1.5 MPa¹ of potential. Total potential of soil water is a thermodynamic term which quantitatively expresses the sum of component potentials affecting the capability of soil water to do work. This potential is a function of soil solids, dissolved solutes, gas pressure and the gravitational field. Theoretically, it represents the amount of work that must be done per unit quantity of water in order to transport reversibly and isothermally, an infinitesimal quantity of water from a pool of pure free water at specified elevation to the soil water at the point under consideration (Slatyer, 1967).

The loss of water from the plant leaf via transpiration lowers the potential energy of the water in the leaf. Water moves from the soil into the plant to replace those losses only if the potential energy of the water in the leaf is

¹MPa=megapascal (1MPa=10 bars)

lower than that in the soil (Gardner, 1965). Soil water potential at the root-soil interface, (Ψ root), appears to be the main soil characteristic controlling the availability of soil water for plant growth (Kramer, 1956; Gardner, 1960). The greatest resistance to liquid water movement occurs at the root-soil interface, resulting in a lag between water absorption and transpiration (Kramer, 1969).

The amount of available water varies in different soils, depending upon such factors as soil texture, structure, effective depth for root development, organic matter content and volume of the soil mass occupied by stones (Gaiser, 1951; Nash, 1963; Salter et al., 1966; Salter and Williams, 1969). Work on 26 soils of different textures showed that the available-water capacity (AWC) of a soil was negatively correlated with the percentage of coarse sand and positively correlated with the percentage of silt (Salter et al., 1966). Thus, medium to fine textured soils tend to have more available water storage capacity than coarse textured soils (Kramer, 1969).

The removal of water from soil can be understood by considering potential evapotranspiration as the maximum moisture that can be removed from the ground when the surface is completely covered by vegetation and the soil is at field capacity (Zahner, 1956). As soil moisture

decreases, the rate of evapotranspiration decreases proportionally. Actual evapotranspiration is the amount of moisture removed when vegetation is not at full stocking or when soil moisture content is at some value less than field capacity (Nash, 1963).

Tree Water Stress

Water stress occurs whenever transpiration exceeds the rate of absorption. Major factors controlling transpiration rate include leaf area and structure, stomatal opening, and atmospheric factors which control the rate of moisture exchange at the leaf-air interface (i.e. wind velocity, temperature, and vapor pressure) (Kramer, 1969). The absorption rate is a function of solutes in the soil solution, water potential of the soil solution, transpiration rate, extent and efficiency of the root system, soil aeration and temperature, and soil physical properties that affect water movement (Kramer, 1969).

Physiological adaptation to an environment can markedly influence the point at which water stress occurs (Hsiao, 1973). Temporary midday water deficits occur in rapidly transpiring plants because the resistance to water movement to and through roots causes absorption to lag behind transpiration even in moist soils (Kramer, 1969). Most

injury to plants occurs as water becomes progressively limiting and unable to replace transpirational losses over an extended period of time. Slatyer (1967) has suggested that zero turgor pressure associated with leaf wilting is a function of the osmotic characteristics of the leaf sap; therefore, permanent wilting percentage varies considerably from plant to plant.

Water stress affects nearly every process in a plant and produces substantially different effects at different stages in the growth cycle. Apical, radial, and reproductive growth of trees, as well as seed germination and seedling establishment are highly correlated with environmental moisture stress (Zahner, 1968). While mild stress may result in stomatal closure which reduces the assimilation of CO_2 by impeding its influx, more severe stress causes disruption of physiological processes which may ultimately lead to death by desiccation. At the cellular level, dehydration of the protoplasm is responsible for most of the effects of water stress other than those caused directly by loss of turgor.

In addition to reducing total growth, water deficits have also frequently changed growth patterns (Kramer, 1963). Common observations have involved an increased root-to-shoot ratio and decreased cell size, intercellular volume and leaf

area. Increased thickness of both palisade layers and degree of cutinization, hairiness, vein density and greater stomatal frequency have also been noted (Spurr and Barnes, 1980).

METHODS

Description of the Study Area

The study area is located within the Ridge and Valley Physiographic Province on the southeast face of Potts Mountain in Craig County, Virginia. The site is approximately 45 miles northeast of Blacksburg in the New Castle District of the Jefferson National Forest. The main ridge of Potts Mountain is oriented in a northeast-southwest direction with elevations in the study area ranging from 640 to 820 meters above mean sea level. Slopes vary from 14-50 percent, while aspect varies from NE to SW.

The residual soil parent material is of the Clinton formation, formed in the Silurian geologic period, which began approximately 430 million years ago. The nutrient content of these soils is relatively low, largely attributable to development from nutrient poor white orthoquartzite sandstone with some interbedded shale outcroppings. The soils are largely Typic Hapludults, coarse textured, siliceous, shallow, and with gravel-sized sandstone fragments common throughout the profile (Morin, 1978).

The climate of the area is characterized as humid, continental with elevational modification, cool summers (average July temperature 22° C) and moderately cold winters (average January temperature 0.6° C) (Carden, 1973). During the growing season, temperatures range from 10° C to 32° C. The range during the dormant season is -4° C to 7° C (Crockett, 1972).

Rainfall is well distributed throughout the year, with a maximum in July and a minimum in November. The annual precipitation in nearby New Castle, Virginia averages 965 mm, and is evenly distributed throughout the year. However, the intervals between rainfall events often exceed one week. The frost-free growing season on Potts Mountain is approximately 160 days (Ross et al., 1982). In the summer, the predominating storm types are orographic and convectional, yielding small amounts of precipitation. Winter storms are generally frontal and yield larger amounts of precipitation (Crockett, 1972).

Second growth forests on Potts Mountain are typical of those found on thousands of hectares of the more exposed mountain slopes in the Appalachians (Braun, 1950). The stands are generally the same age having originated approximately 60 years ago. They vary in composition and structure from mesophytic hardwoods of coves to nearly pure

stands of pine on spur ridges of SW aspect (McEvoy et al., 1980). Although stand structure and species composition vary with aspect, slope inclination and slope position, four major vegetation types are recognizable on the study site. In order from moist to dry site, these include: (1) mixed hardwoods with sparse heath understory, (2) mixed oak with light to moderate heath understory, (3) mixed oak and pine with moderate to heavy heath understory, and (4) mixed pine with heavy heath understory. Types 2 and 3 occupy the majority of the site, although type 1 accounts for a disproportionately high amount of tree biomass and productivity (McEvoy et al., 1980; Martin et al., 1982).

Selection of Study Areas

The study areas were chosen using topographic features of aspect, slope position and slope inclination. These parameters were chosen because of their probable pronounced influence on the water regime of a site, especially since water is often a major limiting factor to plant growth during a portion of the growing season in the Ridge and Valley Physiographic Province. Smith and Burkhart (1976) proposed a Forest Site Quality Index (FSQI) based on aspect, slope position, and slope inclination. They assigned an ordinal ranking of relative site quality to each of the

three parameters. The highest ranks were assigned to the divisions of the parameters which were subjectively rated as highest in relative site quality. The Forest Site Quality Index was then defined as the unweighted sum of the ordinal values. Tables 1 and 2 present the rankings for aspect and slope inclination respectively. Figure 1 illustrates the slope position rankings (Wathen, 1977).

A preliminary investigation of the site revealed a gradient of index values from 5 (most xeric) to 14 (most mesic). To adequately sample the range of existing moisture conditions on the site, a series of four plots based on a gradient of site quality index values of 5, 8, 11, and 14 was established in the uncut stands. Three replications of the series were established in the cutover areas with the exception of the 14 ranking, where only one was used because of a lack of suitable sites. Hence, a total of fourteen plots were established on the study area, ten in the three-year-old clearcut areas, and the remaining four reference plots in the adjacent uncut areas. Table 3 illustrates the Forest Site Quality Index ranking for the selected study plots. The majority of the study area contained FSQI values in the range of five to eight.

The fourteen sample plots were oriented parallel to the slope contour with individual size being dictated by

Table 1. Aspect rankings for Forest Site Quality Index (Wathen, 1977).
A rank of 1 is the aspect of lowest site quality.

| ASPECT SECTOR RANKING | AZIMUTH RANGE |
|--------------------------|------------------|
| 1 | 196-260 |
| 2 | 166-195, 261-280 |
| 3 | 146-165, 281-340 |
| 4 | 0-20, 341-360 |
| 5 | 81-145 |
| 6 | 21-80 |

Table 2. Ranking of slope percent for Forest Site Quality Index (Wathen, 1977). Slopes in excess of 60% receive a ranking of 1 and are lowest in site quality.

| SLOPE PERCENT | RANKING |
|---------------|---------|
| 0-14% | 5 |
| 15-29% | 4 |
| 30-44% | 3 |
| 45-59% | 2 |
| > 60% | 1 |

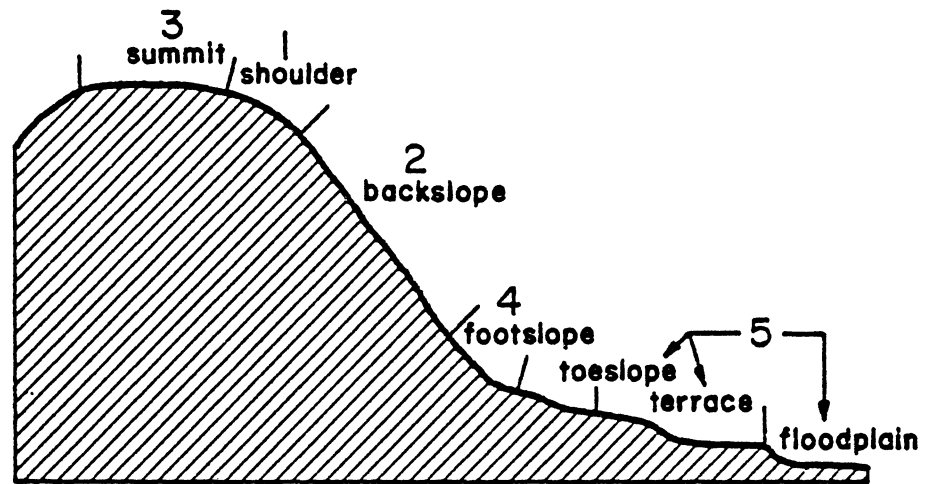


Figure 1. Ranking of slope position for Forest Site Quality Index (Wathen, 1977).

Table 3. Summary of plot variable values using the Forest Site Quality Index ranking scheme, Potts Mountain, Va.

| Plot No.* | Aspect (deg. azi.) | Rank | Slope Position | Rank | % Slope | Rank | Rank Sum (FSQI VALUE) |
|-----------|-----------------------|------|-------------------|------|---------|------|--------------------------|
| 5C1 | 205 | 1 | shoulder | 1 | 33 | 3 | 5 |
| **5C2 | 220 | 1 | shoulder | 1 | 34 | 3 | 5 |
| 5C3 | 230 | 1 | shoulder | 1 | 36 | 3 | 5 |
| 5U | 210 | 1 | backslope | 2 | 50 | 2 | 5 |
| 8C1 | 164 | 3 | backslope | 2 | 35 | 3 | 8 |
| **8C2 | 150 | 3 | backslope | 2 | 38 | 3 | 8 |
| 8C3 | 174 | 2 | backslope | 2 | 25 | 4 | 8 |
| ** 8U | 154 | 3 | backslope | 2 | 32 | 3 | 8 |
| 11C1 | 060 | 6 | backslope | 2 | 37 | 3 | 11 |
| **11C2 | 070 | 6 | backslope | 2 | 36 | 3 | 11 |
| 11C3 | 130 | 5 | backslope | 2 | 27 | 4 | 11 |
| 11U | 100 | 5 | backslope | 2 | 25 | 4 | 11 |
| 14C | 082 | 5 | footslope | 4 | 14 | 5 | 14 |
| 14U | 078 | 6 | footslope | 4 | 26 | 4 | 14 |

*Plot No. Code

1st digit indicates Forest Site Quality Index number

2nd digit indicates treatment; cut (c), uncut (u)

3rd digit indicates replication number

**Predawn plant moisture stress measurements taken

homogeneity of vegetation and the range of topographic variation allowed within the index value designated for a particular sample area. Sample plot sizes ranged from 10.5 x 10.5 m to 15 x 15 m. Soil sampling points within the plots were established using a 2.25 m² grid, resulting in a 1.5 m area between sampling points to minimize disturbance.

Soil Moisture Determination

Soil moisture content was determined gravimetrically. Moisture content was expressed as percent moisture based on oven-dry weight. This method was the most feasible considering the shallowness and degree of stones present throughout the profile.

Soil moisture samples were taken at 10 day intervals, from May 1, 1981 and continuing through October 31, 1981. Three sample points were randomly chosen for moisture measurement within each of the variable sized plots every sample collection day. Sampling depths of 0-10 and 20-30 cm were chosen based on accessibility and adequate coverage of the major portion of the range of rooting depths of plants found in the study soils. The number of samples necessary to estimate soil moisture within $\pm 0.1\%$ at the 95% level calculated from tables of Dixon and Massey (1969) was sufficient at both depths.

The soil profile was exposed and the sample collected at the proper depth. Any stones found in the sample were discarded. Soil samples were placed in metal containers (5cmx9cm), sealed and taken to the laboratory and weighed. The sample was then oven dried at 110°C for 48 hours. The percent moisture content (oven-dry weight) was determined as follows:

$$\text{Percent Moisture Content} = \frac{\text{Wet wt.} - \text{O.D. wt.}}{\text{O.D. wt.}} \times 100$$

Where O.D. wt. = oven-dry weight of sample

Soil moisture release curves were prepared for four plots covering the moisture gradient predominating in the study area. Soil samples were collected from the 0-10 and 20-30 cm depths. They were air dried, then passed through a 2 mm sieve. Any stones present were discarded. The pressure plate was used for -0.01, -0.03 and -0.1 MPa determinations. The acetate membrane extractor was used for -0.3, -0.5, -1.0, and -1.5 MPa extractions (Richards, 1949). For each extraction, duplicate samples from each depth were used. The extraction determination was also repeated at each potential. These curves were used to relate moisture content to soil water potential for the conventional range

of available soil water, -0.01 MPa of potential to -1.5 MPa of potential. Available soil water for each soil moisture sample was defined as the difference between the moisture content of the sample and the moisture content at -1.5 MPa of potential (Kramer, 1969).

Plant Moisture Stress Determinations

Plant moisture stress was measured using the pressure chamber technique (Scholander et al., 1965). The procedure involves severing a small section of twig (2-5 mm diameter) and placing it in the chamber with the cut end protruding through a seal. Pressure is exerted on the leaves, forcing the water column back to the cut surface. The pressure (with a negative sign) at which water is observed is assumed to be the tension on the water column prior to severing (Waring and Cleary, 1967).

Preliminary evaluation of the 14 soil study plots led to the selection of three hardwood tree species common to all the plots. These were chestnut oak (Quercus prinus L.), scarlet oak (Quercus coccinea Muenchh.) and sassafras (Sassafras albidum Nutt.). These species are among the highest in their contribution to above-ground biomass of all tree species encountered in the understory of both cut and uncut stands. Three plots were chosen in the cutover areas

for plant stress determinations on the three selected tree species, representing FSQI values of 5, 8, and 11. The three plots selected for this portion of the study covered the moisture gradient predominating in the study area.

Predawn stress measurements (base P) were taken every 10 days for six months, the approximate length of the growing season, in conjunction with the soil moisture sampling. Samples of both seedling and sprout origin were measured. Height, diameter, stump size (where applicable) and sample stem position were recorded.

Statistical Design

Analyses of variance were done to test for statistical differences between soil moisture content and soil water potential by forest site quality index value, depth and date. Forest site quality index value and date are random effects, while depth is a fixed effect. Data from the clearcut and uncut plots were analyzed separately. Interaction terms were not included in the model for uncut plots due to a lack of replication.

The mixed model, three-level ANOVA used was as follows:

$$Y_{ijkl} = \mu + \alpha_i + \beta_j + \gamma_k + (\alpha\beta)_{ij} + (\alpha\gamma)_{ik} + (\beta\gamma)_{jk} + (\alpha\beta\gamma)_{ijk} + \epsilon_{ijkl}$$

where $i = 1, 2, \dots, a$ ($a=3$: FSQI effect)

$j = 1, 2, \dots, b$ ($b=2$: Depth effect)

$k = 1, 2, \dots, c$ ($c=19$: Date effect)

$l = 1, 2, \dots, n$ ($n=9$: soil moisture content, soil water potential)

Analyses of variance were also conducted to test for statistical differences between predawn plant water potential by forest site quality index, tree species and date. The forest site quality index (FSQI) and date are random effects. Tree species is a fixed effect.

The mixed model, three-level ANOVA used was as follows:

$$Y_{ijkl} = \mu + \alpha_i + \beta_j + \gamma_k + (\alpha\beta)_{ij} + (\alpha\gamma)_{ik} + (\beta\gamma)_{jk} + (\alpha\beta\gamma)_{ijk} + \epsilon_{ijkl}$$

where $i = 1, 2, \dots, a$ ($a=3$: FSQI effect)

$j = 1, 2, \dots, b$ ($b=3$: species effect)

$k = 1, 2, \dots, c$ ($c=14$: date effect)

$l = 1, 2, \dots, n$ ($n=2$: predawn plant water potential)

The Statistical Analysis System was used for computations (Barr and Goodnight, 1979).

RESULTS

Soil Moisture

Seasonal soil moisture trends within the three-year old clearcut plots at the 0-10 cm depth illustrate the relationship between soil moisture content (percent oven-dry weight) and the corresponding Forest Site Quality Index (FSQI) throughout the study period (Figure 2). In general, a gradient of increasing soil moisture content with increasing FSQI is apparent. An analysis of variance showed a significant difference ($=.01$) between FSQI, depth and date (Table 4). Significant interaction ($=.01$) was found for the FSQI*DATE term. A plot of the interacting terms showed that on 7 of 19 sampling dates, mean soil moisture content for FSQI of 11 was below that of FSQI of 8, occurring primarily in the early part of the growing season. For the other 12 sampling dates, soil moisture content for FSQI of 11 exceeded that of FSQI of 8 as expected.

Soil moisture means for the four site quality index values tested on nineteen sampling dates are presented in

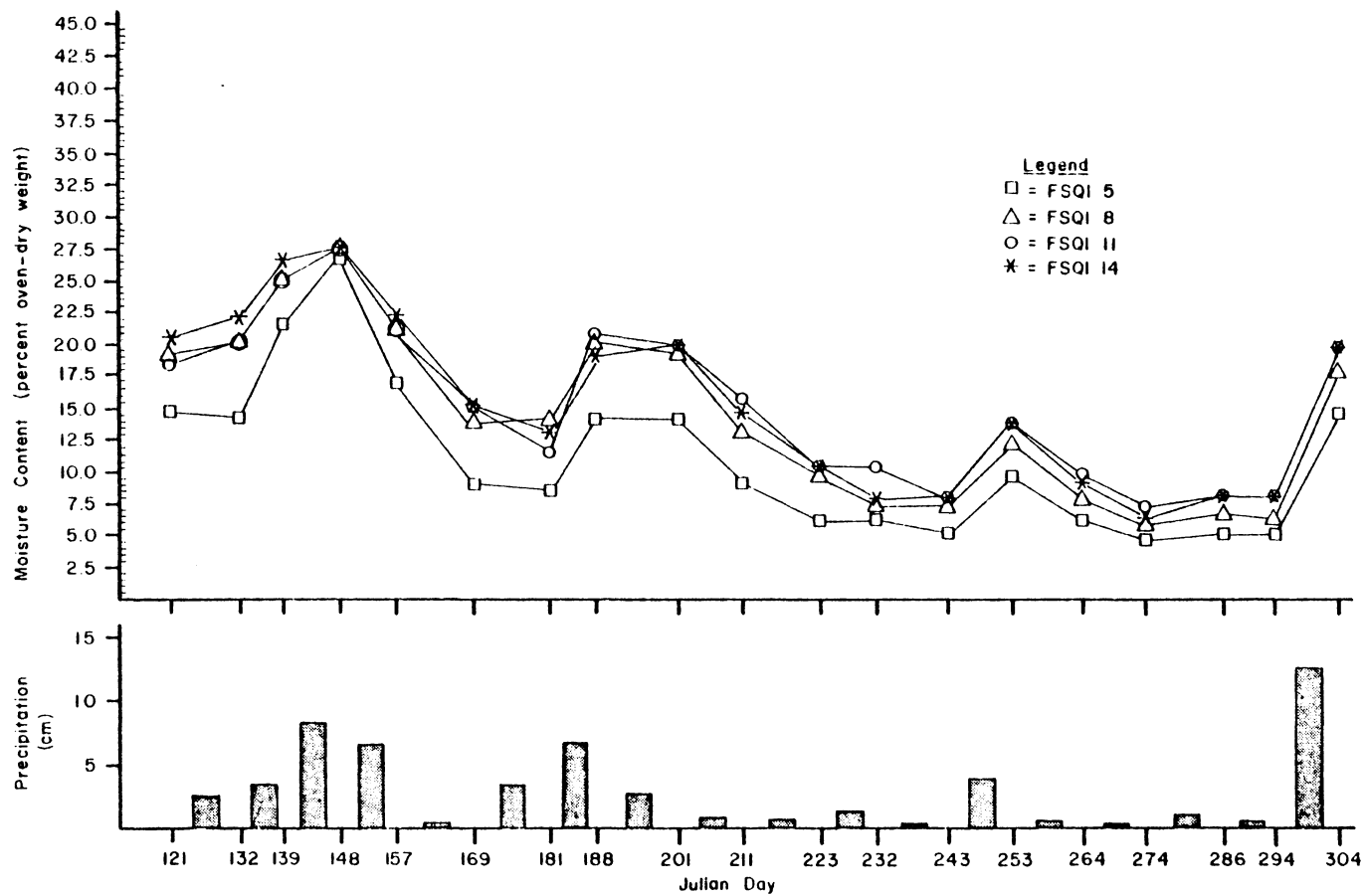


Figure 2. Seasonal soil moisture trends (percent oven-dry weight) at 0-10 cm depth and precipitation from May 1, 1981 through October 31, 1981 in three-year-old clearcut plots with Forest Site Quality Index (FSQI) values of 5, 8, 11, and 14, Potts Mountain, Va.

Table 4. F values from analysis of variance for forest site quality index, depth and date on soil moisture content and soil water potential; and forest site quality index, species and date on predawn plant water potential.

| Variable | FSQI | DEPTH | DATE | FSQI*DEPTH | FSQI*DATE | DEPTH*DATE |
|---|----------|---------|----------|--------------|-----------|--------------|
| Soil moisture content (clearcut plots) | 170.38** | 27.40** | 251.02** | 2.21 | 2.08** | 1.36 |
| Soil moisture content (uncut plots) | 199.94** | 11.90** | 89.55** | -- | -- | -- |
| Soil water potential (clearcut plots) | 107.63** | 2.72 | 90.78** | 4.07* | 7.68** | 1.80* |
| | FSQI | SPECIES | DATE | FSQI*SPECIES | FSQI*DATE | SPECIES*DATE |
| Predawn plant water potential | 11.70** | 2.84 | 36.59** | 0.82 | 1.84* | 0.39 |

** Significant at 1% probability level

* Significant at 5% probability level

Table 5. Although the trend of increasing soil moisture with increasing forest site quality index value was evident, differences were not large between the index values of eight and eleven. On all sampling dates, the forest site quality index of five had the lowest soil moisture content. On a seasonal basis, the lowest soil moisture content was recorded on October 1, ranging from 4-7%. The maximum values recorded occurred on May 28, with all four index values indicating 27% moisture content.

Seasonal soil moisture trends at the 20-30 cm depth revealed a similar relationship with forest site quality index values (Figure 3). A slight decrease (1-2%) in soil moisture content was found at the lower sampling depth. Fewer significant differences between forest site quality index values were found compared to the 0-10 cm depth; however, a general trend of increasing soil moisture content along the FSQI gradient was evident (Table 6). The minimum and maximum soil moisture content occurred on the same dates as the 0-10 cm depth, ranging from 4-7% and 22-26% respectively.

Soil moisture trends were also examined in uncut stands adjoining the noncontiguous clearcut areas. The gradient relationship between soil moisture and FSQI values was more evident at both depths (Figures 4 and 5) compared to

Table 5. Soil moisture (percent oven-dry weight) for four forest site quality index (FSQI) values in three-year-old clearcut plots at 0-10 cm depth by date, Potts Mountain, Va.

| DATE/Julian Day | | | | |
|-----------------|-------------|--------------|--------------|-------------|
| FSQI | May 1/121 | May 12/152 | May 19/139 | May 28/148 |
| 5 | 14.8 a* | 14.3 a | 21.5 a | 27.1 a |
| 8 | 18.7 b | 19.9 b | 25.1 a | 27.3 a |
| 11 | 18.6 b | 20.2 b | 24.9 a | 27.7 a |
| 14 | 20.5 b | 21.8 b | 26.3 a | 27.4 a |
| ----- | | | | |
| FSQI | June 7/157 | June 18/169 | June 30/181 | July 9/188 |
| 5 | 17.3 a | 9.0 a | 8.4 a | 14.0 a |
| 8 | 21.1 b | 15.7 b | 13.6 b | 19.8 b |
| 11 | 21.2 b | 14.9 b | 11.7 b | 20.7 b |
| 14 | 21.8 b | 15.1 b | 12.8 b | 19.1 ab |
| ----- | | | | |
| FSQI | July 20/201 | July 30/211 | Aug. 11/223 | Aug. 20/232 |
| 5 | 14.1 a | 8.7 a | 5.8 a | 5.6 a |
| 8 | 19.2 b | 12.8 b | 9.3 b | 7.1 ab |
| 11 | 19.7 b | 15.5 c | 10.3 b | 10.0 b |
| 14 | 19.4 b | 14.6 bc | 9.8 b | 7.4 ab |
| ----- | | | | |
| FSQI | Aug. 31/243 | Sept. 10/253 | Sept. 21/264 | Oct. 1/274 |
| 5 | 4.9 a | 9.5 a | 5.8 a | 4.6 a |
| 8 | 7.2 b | 12.2 b | 7.7 ab | 5.6 a |
| 11 | 7.3 b | 15.6 b | 9.4 b | 7.0 b |
| 14 | 7.4 b | 13.5 b | 8.9 b | 6.1 ab |
| ----- | | | | |
| FSQI | Oct. 13/286 | Oct. 21/294 | Oct. 31/304 | |
| 5 | 4.8 a | 4.8 a | 14.6 a | |
| 8 | 6.4 b | 5.9 ab | 17.5 b | |
| 11 | 7.9 b | 8.0 c | 19.4 b | |
| 14 | 7.7 b | 7.7 bc | 19.5 b | |

*Means with the same letter are not significantly different ($\alpha = .05$).

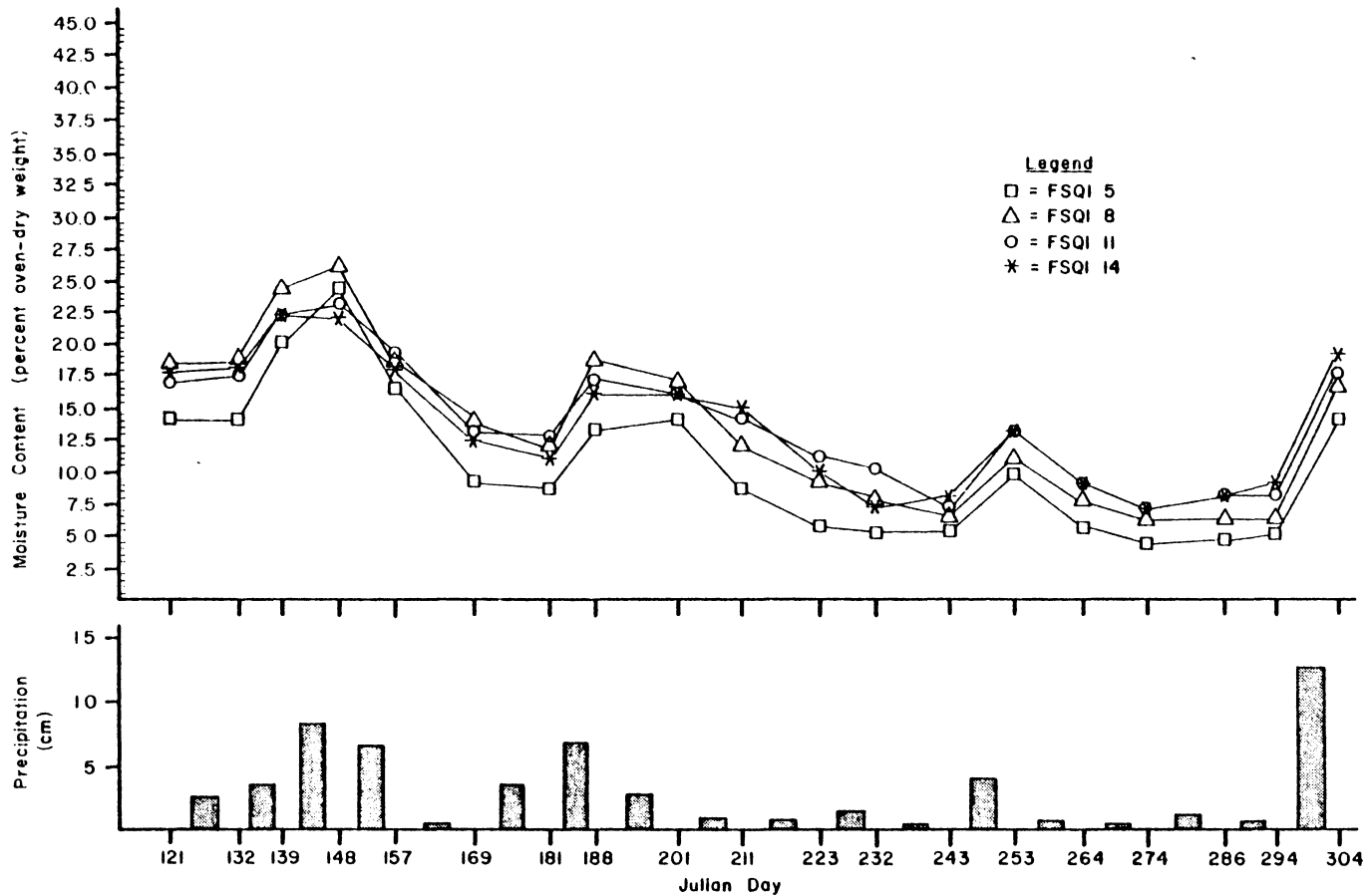


Figure 3. Seasonal soil moisture trends (percent oven-dry weight) at 20-30 cm depth and precipitation from May 1, 1981 through October 31, 1981 in three-year-old clearcut plots with Forest Site Quality Index (FSQI) values of 5, 8, 11, and 14, Potts Mountain, Va.

Table 6. Soil moisture (percent oven-dry weight) for four forest site quality index (FSQI) values in three-year-old clearcut plots at 20-30 cm depth by date, Potts Mountain, Va.

| DATE/Julian Day | | | | | |
|-----------------|-------------|-------------|-------------|--------------|--------------|
| FSQI | May 1/121 | May 12/132 | May 19/139 | May 28/148 | June 7/157 |
| 5 | 14.1a* | 13.8 a | 20.2 a | 24.1 a | 16.4 a |
| 8 | 18.3 b | 18.7 b | 23.9 b | 26.0 a | 18.4 ab |
| 11 | 17.1 b | 17.3 b | 21.7 ab | 23.0 a | 18.8 b |
| 14 | 17.4 b | 17.9 b | 21.9 ab | 22.1 a | 18.3 ab |
| ----- | | | | | |
| FSQI | June 18/169 | June 30/181 | July 9/188 | July 20/201 | July 30/211 |
| 5 | 9.1 a | 8.5 a | 12.9 a | 14.0 a | 8.6 a |
| 8 | 13.5 b | 12.2 b | 18.6 b | 16.8 a | 12.2 b |
| 11 | 13.3 b | 12.6 b | 16.8 b | 16.2 a | 14.0 b |
| 14 | 12.7 b | 11.7 ab | 16.1 ab | 15.8 a | 14.8 b |
| ----- | | | | | |
| FSQI | Aug. 11/223 | Aug. 20/232 | Aug. 31/243 | Sept. 10/253 | Sept. 21/264 |
| 5 | 5.7 a | 5.2 a | 4.7 a | 9.5 a | 5.5 a |
| 8 | 9.2 b | 7.7 ab | 6.5 b | 10.9 ab | 7.7 ab |
| 11 | 10.7 b | 9.8 b | 7.0 b | 13.2 b | 8.9 b |
| 14 | 9.8 b | 7.5 ab | 8.0 b | 13.0 ab | 9.3 b |
| ----- | | | | | |
| FSQI | Oct. 1/274 | Oct. 13/286 | Oct. 21/294 | Oct. 31/304 | |
| 5 | 3.8 a | 4.5 a | 4.8 a | 13.8 a | |
| 8 | 5.7 b | 6.1 ab | 6.0 a | 16.3 b | |
| 11 | 6.6 b | 7.9 b | 8.3 b | 17.6 b | |
| 14 | 6.9 b | 8.0 b | 9.3 b | 18.7 b | |

*Means with the same letter are not significantly different ($\alpha = .05$).

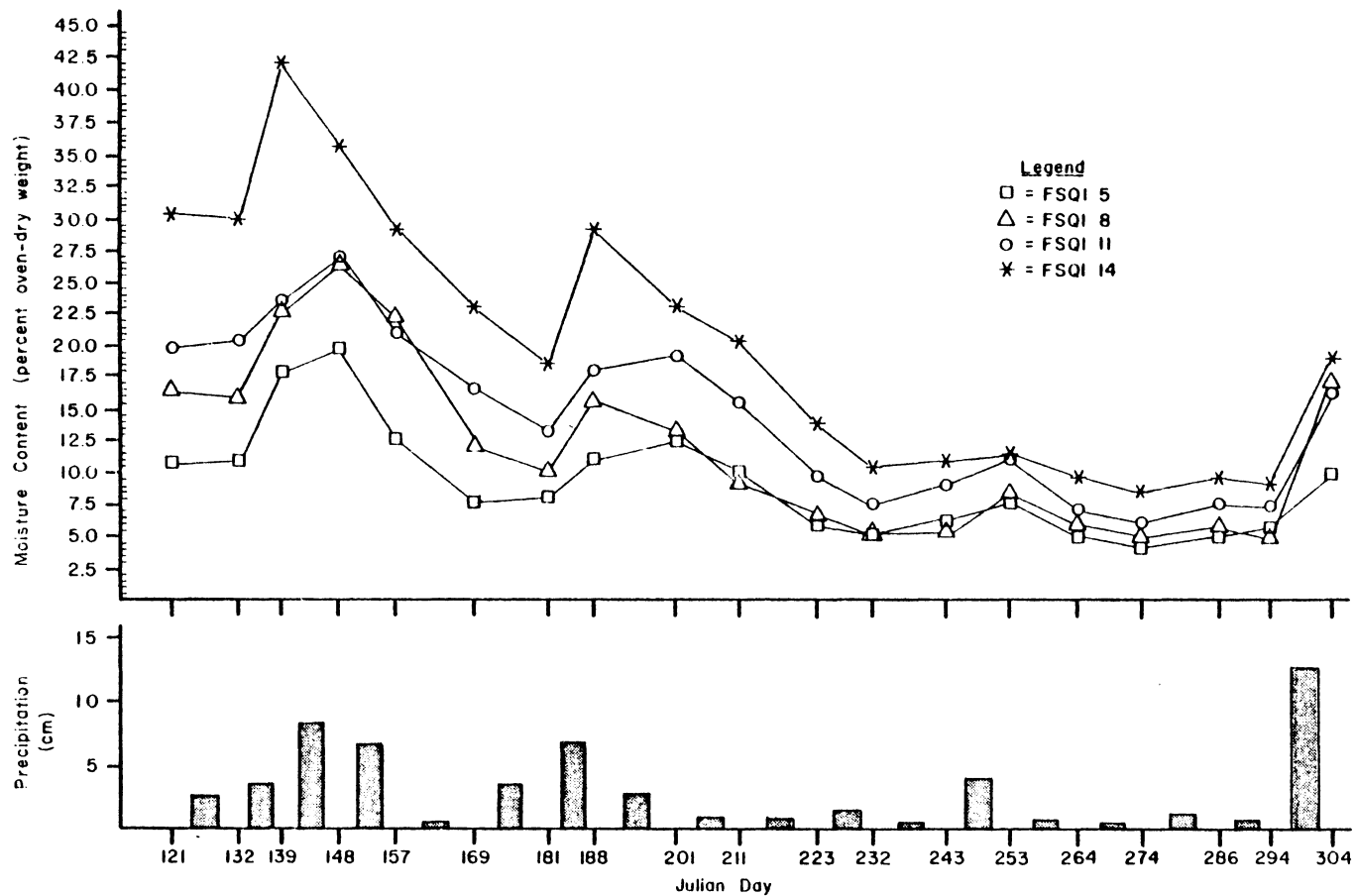


Figure 4. Seasonal soil moisture trends (percent oven-dry weight) at 0-10 cm depth and precipitation from May 1, 1981 through October 31, 1981 in uncut plots with Forest Site Quality Index (FSQI) values of 5, 8, 11, and 14, Potts Mountain, Va.

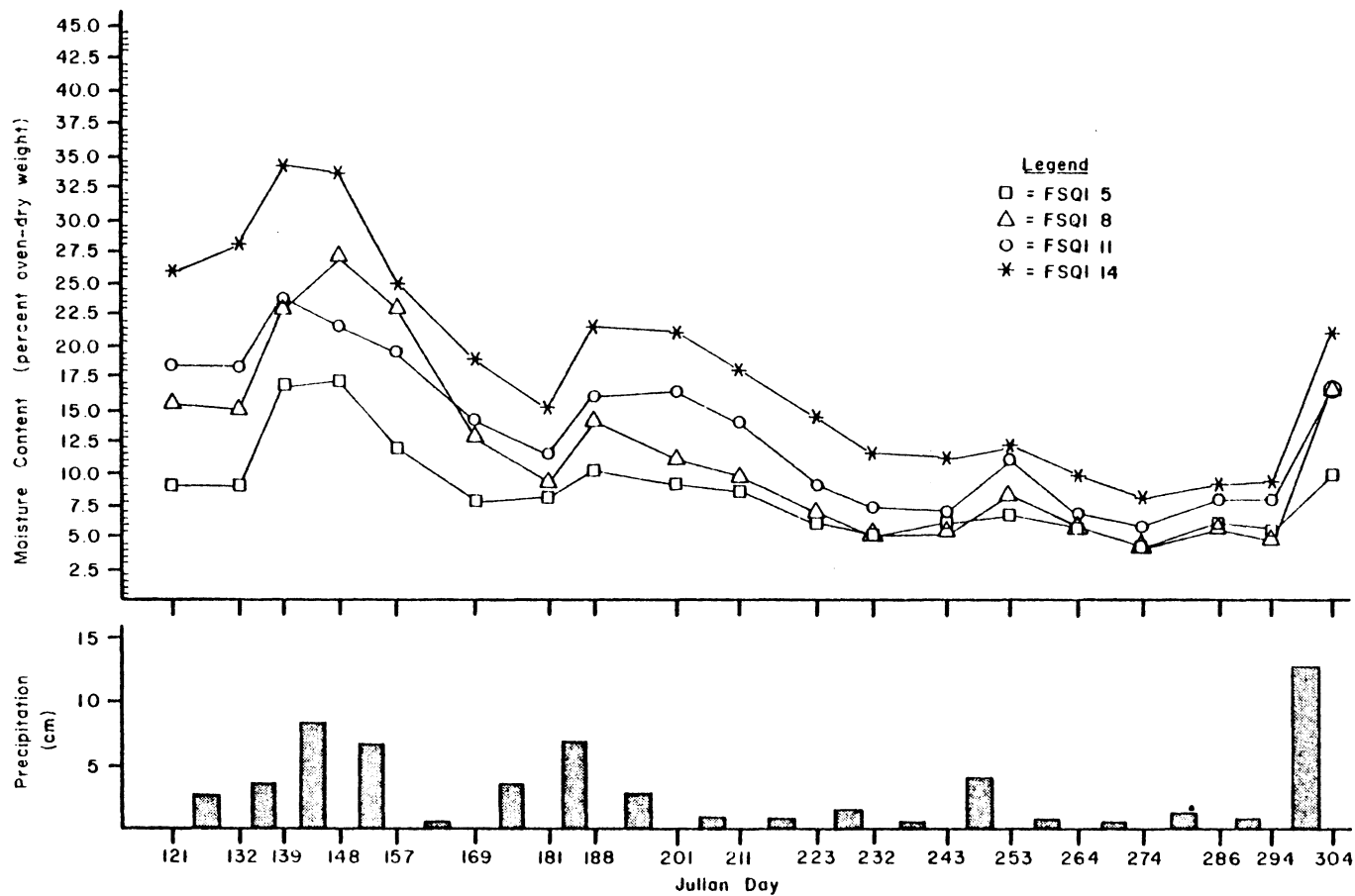


Figure 5. Seasonal soil moisture trends (percent oven-dry weight) at 20-30 cm depth and precipitation from May 1, 1981 through October 31, 1981 in uncut plots with Forest Site Quality Index (FSQI) values of 5, 8, 11, and 14, Potts Mountain, Va.

clearcut areas. An analysis of variance showed a significant difference ($\alpha=.01$) between FSQI, depth and date (Table 4). Significant differences in soil moisture means at the 0-10 cm depth are shown in Table 7. Although few significant differences were found between the FSQI values of eight and eleven, the general trend of increasing soil moisture content with increasing forest site quality is evident. This relationship is also evident in Table 8, where the 20-30 cm depth exhibited a significant difference between the forest site quality index values of eight and eleven on 5 of 19 sampling dates. Soil moisture content was generally greater (1-2%) at the 0-10 cm depth than at the 20-30 cm depth. The lowest soil moisture content recorded in the uncut plots was 4% on October 1 for FSQI of 5, while the highest occurred on May 19 at 42% for the FSQI of 14.

A summary of the soil moisture content at the 0-10 cm depth for both clearcut and uncut plots is presented in Table 9. In general, the clearcut areas representing forest site quality index values of 5, 8 and 11 had higher soil moisture than uncut areas of the same FSQI values. However, the uncut plot with forest site quality index of 14 showed consistently higher moisture than the clearcut plot of the same value. The same relationships are evident in Table 10 for the 20-30 cm depth.

Table 7. Soil moisture (percent oven-dry weight) for four forest site quality index (FSQI) values in uncut plots at 0-10 cm depth by date, Potts Mountain, Va.

| DATE/Julian Day | | | | | |
|-----------------|-------------|-------------|-------------|--------------|--------------|
| FSQI | May 1/121 | May 12/132 | May 19/139 | May 28/148 | June 7/157 |
| 5 | 10.6 a* | 10.8 a | 17.8 a | 19.6 a | 12.5 a |
| 8 | 16.7 b | 15.9 b | 22.4 a | 26.0 ab | 22.2 b |
| 11 | 19.9 b | 20.6 b | 23.5 a | 26.7 ab | 20.9 b |
| 14 | 30.5 c | 29.8 c | 42.0 b | 35.6 b | 29.0 c |
| ----- | | | | | |
| FSQI | June 18/169 | June 30/181 | July 9/188 | July 20/201 | July 30/211 |
| 5 | 7.7 a | 8.2 a | 10.7 a | 12.3 a | 9.9 a |
| 8 | 12.1 ab | 10.0 ab | 15.5 ab | 12.8 a | 9.2 a |
| 11 | 16.4 b | 13.1 b | 18.0 b | 19.1 ab | 15.5 b |
| 14 | 22.7 c | 18.4 c | 28.7 c | 22.7 b | 20.5 c |
| ----- | | | | | |
| FSQI | Aug. 11/223 | Aug. 20/232 | Aug. 31/243 | Sept. 10/253 | Sept. 21 264 |
| 5 | 6.2 a | 5.3 a | 6.0 a | 7.7 a | 5.2 a |
| 8 | 6.4 a | 5.1 a | 5.1 a | 8.2 ab | 5.6 a |
| 11 | 9.6 a | 7.6 a | 8.7 ab | 10.9 ab | 6.7 a |
| 14 | 14.1 b | 10.6 b | 11.1 b | 11.6 b | 9.4 b |
| ----- | | | | | |
| FSQI | Oct. 1/274 | Oct. 13/286 | Oct. 21/294 | Oct. 31/304 | |
| 5 | 4.3 a | 5.0 a | 5.4 a | 9.7 a | |
| 8 | 4.5 ab | 5.6 a | 4.7 a | 17.0 b | |
| 11 | 5.7 b | 7.5 b | 7.3 ab | 16.5 b | |
| 14 | 8.3 c | 9.4 b | 9.2 b | 19.0 b | |

*Means with the same letter are not significantly different ($\alpha = .05$).

Table 8. Soil moisture (percent oven-dry weight) for four forest site quality index (FSQI) values in uncut plots at 20-30 cm depth by date, Potts Mountain, Va.

| DATE/Julian Day | | | | | |
|-----------------|-------------|-------------|-------------|--------------|--------------|
| FSQI | May 1/121 | May 12/132 | May 19/159 | May 28/148 | June 7/157 |
| 5 | 9.0 a | 8.7 a | 16.9 a | 17.0 a | 11.9 a |
| 8 | 15.4 b | 15.3 b | 22.9 a | 27.1 b | 23.2 b |
| 11 | 18.4 b | 18.5 b | 23.3 a | 21.6 ab | 19.5 b |
| 14 | 26.0 c | 27.9 c | 33.9 b | 33.5 c | 25.3 b |
| ----- | | | | | |
| FSQI | June 18/169 | June 30/181 | July 9/188 | July 20/201 | July 30/211 |
| 5 | 7.4 a | 7.9 a | 10.2 a | 8.9 a | 8.5 a |
| 8 | 12.4 b | 8.7 a | 14.0 b | 11.0 a | 9.5 a |
| 11 | 13.8 b | 11.6 b | 15.8 b | 16.7 b | 13.8 b |
| 14 | 19.2 c | 14.9 c | 21.5 c | 21.0 c | 17.7 b |
| ----- | | | | | |
| FSQI | Aug. 11/223 | Aug. 20/232 | Aug. 31/243 | Sept. 10/253 | Sept. 21/264 |
| 5 | 6.0 a | 5.3 a | 5.9 a | 6.5 a | 5.4 a |
| 8 | 6.4 a | 5.1 a | 4.9 a | 3.2 ab | 5.4 a |
| 11 | 9.2 a | 7.0 a | 6.6 a | 10.7 bc | 6.4 a |
| 14 | 14.3 b | 11.3 b | 11.0 b | 11.9 c | 9.3 b |
| ----- | | | | | |
| FSQI | Oct. 1/ 274 | Oct. 13/286 | Oct. 21/294 | Oct. 31/304 | |
| 5 | 4.0 a | 6.0 a | 4.9 a | 9.7 a | |
| 8 | 3.9 a | 5.4 a | 4.6 a | 16.3 bc | |
| 11 | 5.4 b | 7.4 ab | 7.6 b | 16.4 bc | |
| 14 | 8.0 c | 8.9 b | 9.1 b | 21.0 c | |

*Means with the same letter are not significantly different ($\alpha = .05$).

Table 9. Mean soil moisture (percent oven dry weight) in three-year-old clearcut and uncut stands with forest site quality index (FSQI) values of 5, 8, 11 and 14 at 0-10 cm depth, Potts Mountain, Va.

| Date | Forest Site Quality Index (FSQI) | | | | | | | |
|--------------|----------------------------------|-------|----------|-------|----------|-------|----------|-------|
| | 5 | | 8 | | 11 | | 14 | |
| | clearcut | uncut | clearcut | uncut | clearcut | uncut | clearcut | uncut |
| | -----percent----- | | | | | | | |
| May 1 | 14.8 | 10.6 | 18.7 | 16.7 | 18.6 | 19.9 | 20.5 | 30.5 |
| May 12 | 14.3 | 10.8 | 19.9 | 15.9 | 20.2 | 20.6 | 21.8 | 29.8 |
| May 19 | 21.5 | 17.8 | 25.1 | 22.4 | 24.9 | 23.5 | 26.3 | 42.0 |
| May 28 | 27.1 | 19.6 | 27.3 | 26.0 | 27.7 | 26.7 | 27.4 | 35.6 |
| June 7 | 17.3 | 12.5 | 21.1 | 22.2 | 21.2 | 20.9 | 21.8 | 29.0 |
| June 18 | 9.0 | 7.7 | 13.7 | 12.1 | 14.9 | 16.4 | 15.1 | 22.7 |
| June 30 | 8.4 | 8.2 | 13.6 | 10.0 | 11.7 | 13.1 | 12.8 | 18.4 |
| July 9 | 14.0 | 10.7 | 19.8 | 15.5 | 20.7 | 18.0 | 19.1 | 28.7 |
| July 20 | 14.1 | 12.5 | 19.2 | 12.8 | 19.7 | 19.1 | 19.4 | 22.7 |
| July 30 | 8.7 | 9.9 | 12.8 | 9.2 | 15.5 | 15.5 | 14.6 | 20.5 |
| August 11 | 5.3 | 6.2 | 9.3 | 6.4 | 10.3 | 9.6 | 9.8 | 14.1 |
| August 20 | 5.6 | 5.5 | 7.1 | 5.1 | 10.0 | 7.6 | 7.4 | 10.6 |
| August 31 | 4.9 | 6.0 | 7.2 | 5.1 | 7.3 | 8.7 | 7.4 | 11.1 |
| September 10 | 9.5 | 7.7 | 12.2 | 8.2 | 13.6 | 10.9 | 13.5 | 11.6 |
| September 21 | 5.8 | 5.2 | 7.7 | 5.6 | 9.4 | 6.7 | 8.9 | 9.4 |
| October 1 | 4.6 | 4.3 | 5.6 | 4.5 | 7.0 | 5.7 | 6.1 | 8.3 |
| October 15 | 4.8 | 5.0 | 6.4 | 5.6 | 7.9 | 7.5 | 7.7 | 9.4 |
| October 21 | 4.8 | 5.4 | 5.9 | 4.7 | 8.0 | 7.3 | 7.7 | 9.2 |
| October 31 | 14.6 | 9.7 | 17.5 | 17.0 | 19.4 | 16.5 | 19.5 | 19.0 |

Table 10. Mean soil moisture (percent oven dry weight) in three-year-old clearcut and uncut stands with forest site quality index (FSQI) values of 5, 8, 11 and 14 at 20-30 cm depth, Potts Mountain, Va.

| Date | Forest Site Quality Index (FSQI) | | | | | | | |
|--------------|----------------------------------|-------|----------|-------|----------|-------|----------|-------|
| | 5 | | 8 | | 11 | | 14 | |
| | clearcut | uncut | clearcut | uncut | clearcut | uncut | clearcut | uncut |
| | -----percent----- | | | | | | | |
| May 1 | 14.1 | 9.0 | 18.3 | 15.4 | 17.1 | 18.4 | 17.4 | 26.0 |
| May 12 | 13.8 | 8.7 | 18.7 | 15.3 | 17.3 | 18.5 | 17.9 | 27.9 |
| May 19 | 20.2 | 16.9 | 23.9 | 22.9 | 21.7 | 23.3 | 21.9 | 33.9 |
| May 28 | 24.1 | 17.0 | 26.0 | 27.1 | 23.0 | 21.6 | 22.1 | 33.5 |
| June 7 | 16.4 | 11.9 | 18.4 | 23.2 | 18.8 | 19.5 | 18.3 | 25.3 |
| June 18 | 9.1 | 7.4 | 13.5 | 12.4 | 13.3 | 13.8 | 12.7 | 19.2 |
| June 30 | 8.5 | 7.9 | 12.2 | 8.7 | 12.6 | 11.6 | 11.7 | 14.9 |
| July 9 | 12.9 | 10.2 | 18.6 | 14.0 | 16.8 | 15.8 | 16.1 | 21.5 |
| July 20 | 14.0 | 8.9 | 16.8 | 11.0 | 16.2 | 16.7 | 15.8 | 21.0 |
| July 30 | 8.6 | 8.5 | 12.2 | 9.5 | 14.0 | 13.8 | 14.8 | 17.7 |
| August 11 | 5.7 | 6.0 | 9.2 | 6.4 | 10.7 | 9.2 | 9.8 | 14.3 |
| August 20 | 5.2 | 5.3 | 7.7 | 5.1 | 9.8 | 7.0 | 7.5 | 11.3 |
| August 31 | 4.7 | 5.9 | 6.5 | 4.9 | 7.0 | 6.6 | 8.0 | 11.0 |
| September 10 | 9.5 | 6.5 | 10.9 | 8.2 | 13.2 | 10.7 | 13.0 | 11.9 |
| September 21 | 5.5 | 5.4 | 7.7 | 5.4 | 8.9 | 6.4 | 9.3 | 9.3 |
| October 1 | 3.8 | 4.0 | 5.7 | 3.9 | 6.6 | 5.4 | 6.9 | 8.0 |
| October 13 | 4.5 | 6.0 | 6.1 | 5.4 | 7.9 | 7.4 | 8.0 | 8.9 |
| October 21 | 4.8 | 4.9 | 6.0 | 4.6 | 8.3 | 7.6 | 9.3 | 9.1 |
| October 31 | 13.8 | 9.7 | 16.3 | 16.3 | 17.6 | 16.4 | 18.7 | 21.0 |

To aid in interpreting soil moisture and plant stress data, precipitation was recorded at 10 day intervals on the Potts Mountain study site. Monthly precipitation from May, 1981 through October, 1981 for Potts Mountain and nearby New Castle, Virginia differed by less than 2 cm for the six month period (Table 11). New Castle was included as a reference station because of its proximity and the availability of daily and average rainfall data. Precipitation during the study period was 7.5 cm less than average (1954-1980) with a maximum in May (13.97 cm) and a minimum in August (2.16 cm).

Soil Water Potential

Moisture retention curves were formulated for the forest site quality index values of 5, 8 and 11, enabling the conversion of soil moisture percent by weight to soil water potential in negative MPa (Figure 6). The curves at both the 0-10 and 20-30 cm depth were of the same shape. The FSQI of 5 exhibited the lowest moisture content for a given potential, while the highest moisture content was generally the FSQI of 11.

Soil water potentials for the 0-10 and 20-30 cm depths within the clearcut plots are summarized in Table 12 and 13

Table 11. Monthly precipitation from May, 1981 through October, 1981 for Potts Mountain and nearby New Castle, Craig, Co., Va.

| Month | Potts Mountain | New Castle | |
|-----------|-------------------------|-------------------------|----------------------------|
| | 1981 cm ^a | 1981 cm ^b | Average cm ^b |
| May | 13.97 | 15.47 | 12.40 |
| June | 10.38 | 9.52 | 11.40 |
| July | 9.96 | 11.18 | 9.20 |
| August | 2.16 | 3.12 | 8.04 |
| September | 4.55 | 3.63 | 10.83 |
| October | <u>13.69</u> | <u>12.93</u> | <u>10.30</u> |
| Total | 54.71 | 55.85 | 62.17 |

^aCollected in study area at 10 day intervals.

^bAverage computed from monthly rainfall data (1959-1981) U.S. Forest Service, New Castle District, New Castle, Va.

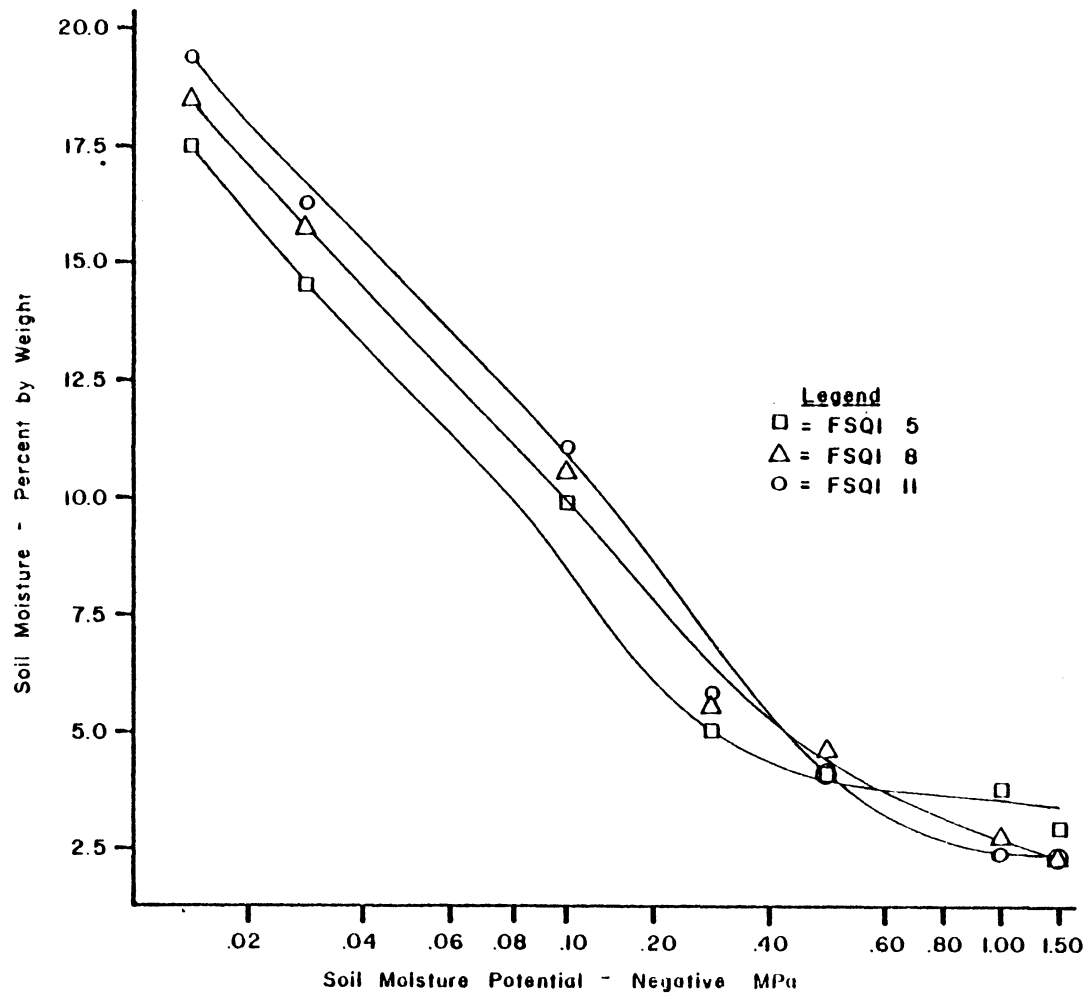


Figure 6. Moisture retention at the 0-10 cm depth by the soils in three-year-old clearcut plots with Forest Site Quality Index (FSQI) values of 5, 8, and 11, Potts Mountain, Va.

Table 12. Soil water potentials (-MPa) for three forest site quality index (FSQI) values in three-year-old clearcut plots at 0-10 cm depth by date, Potts Mountain, Va.

| DATE/Julian Day | | | | | |
|-----------------|-------------|-------------|-------------|--------------|--------------|
| FSQI | May 1/121 | May 12/132 | May 19/139 | May 28/148 | June 7/157 |
| 5 | 0.03 a* | 0.04 a | 0.01 a | 0.01 a | 0.01 a |
| 8 | 0.02 ab | 0.01 b | 0.01 a | 0.01 a | 0.01 b |
| 11 | 0.02 b | 0.01 b | 0.01 a | 0.01 a | 0.01 b |
| ----- | | | | | |
| FSQI | June 18/169 | June 30/181 | July 9/188 | July 20/201 | July 30/211 |
| 5 | 0.15 a | 0.16 a | 0.05 a | 0.04 a | 0.16 a |
| 8 | 0.06 b | 0.06 b | 0.01 b | 0.01 b | 0.08 b |
| 11 | 0.05 b | 0.11 ab | 0.01 b | 0.01 b | 0.05 b |
| ----- | | | | | |
| FSQI | Aug. 11/235 | Aug. 20/232 | Aug. 31/243 | Sept. 10/255 | Sept. 21/264 |
| 5 | 0.28 a | 0.33 a | 0.60 a | 0.14 a | 0.29 a |
| 8 | 0.16 b | 0.23 b | 0.24 b | 0.08 b | 0.21 b |
| 11 | 0.14 b | 0.18 b | 0.24 b | 0.07 b | 0.19 b |
| ----- | | | | | |
| FSQI | Oct. 1/274 | Oct. 15/286 | Oct. 21/294 | Oct. 31/304 | |
| 5 | 0.50 a | 0.42 a | 0.37 a | 0.03 a | |
| 8 | 0.32 b | 0.30 ab | 0.43 a | 0.03 a | |
| 11 | 0.27 b | 0.23 b | 0.22 a | 0.01 a | |

*Means with the same letter are not significantly different ($\alpha = .05$).

Table 13. Soil water potential (-MPa) for three forest site quality index (FSQI) values in three-year-old clearcut plots at 20-30 cm depth by date, Potts Mountain, Va.

| DATE/Julian Day | | | | | |
|-----------------|-------------|-------------|-------------|--------------|--------------|
| FSQI | May 1/121 | May 12/132 | May 19/139 | May 28/148 | June 7/157 |
| 5 | 0.04 a* | 0.04 a | 0.01 a | 0.01 a | 0.02 a |
| 8 | 0.01 b | 0.01 b | 0.01 b | 0.01 a | 0.01 a |
| 11 | 0.02 b | 0.02 ab | 0.01 ab | 0.01 a | 0.01 a |
| ----- | | | | | |
| FSQI | June 18/169 | June 30/181 | July 9/188 | July 20/201 | July 30/211 |
| 5 | 0.13 a | 0.15 a | 0.05 a | 0.04 a | 0.14 a |
| 8 | 0.05 b | 0.08 b | 0.02 b | 0.02 a | 0.07 b |
| 11 | 0.06 b | 0.07 b | 0.02 b | 0.02 a | 0.05 b |
| ----- | | | | | |
| FSQI | Aug. 11/223 | Aug. 20/232 | Aug. 31/243 | Sept. 10/255 | Sept. 21/264 |
| 5 | 0.27 a | 0.35 a | 0.52 a | 0.14 a | 0.44 a |
| 8 | 0.16 b | 0.22 b | 0.28 b | 0.11 ab | 0.22 b |
| 11 | 0.10 c | 0.16 b | 0.22 b | 0.06 b | 0.19 b |
| ----- | | | | | |
| FSQI | Oct. 1/274 | Oct. 13/286 | Oct. 21/294 | Oct. 31/304 | |
| 5 | 0.94 a | 0.63 a | 0.41 a | 0.04 a | |
| 8 | 0.32 b | 0.34 b | 0.35 a | 0.04 a | |
| 11 | 0.26 b | 0.19 b | 0.18 b | 0.14 b | |

*Means with the same letter are not significantly different ($\alpha = .05$).

respectively. An analysis of variance showed significant differences ($\alpha = .01$) between FSQI and date (Table 4). However, fewer significant differences between forest site quality index values were found compared to differences noted in soil moisture content. Significant interaction was found for the FSQI*DATE term. On 12 of 19 sampling dates, soil water potentials were lower for the FSQI of 8 compared to the FSQI of 11. For the other 7 sampling dates the reverse trend occurred. Interaction was also significant for the FSQI*DEPTH and DEPTH*DATE terms. Although FSQI values of 5 and 8 showed higher soil water potentials at the 0-10 cm depth, higher potentials for the FSQI of 11 occurred at the 20-30 cm depth. DEPTH*DATE interaction resulted from potential values being lower at the 0-10 cm depth on 8 of 19 sampling dates, while the 20-30 cm depth showed lower potentials on 11 of 19 sampling dates. The lowest soil water potential found was -0.94 MPa on October 1 at the 0-10 cm depth, approximately 0.6 MPa above the critical level (-1.5 MPa) presumably limiting availability of water to plants. Several sampling dates in early spring had soil water potentials above field capacity (-0.01 MPa), indicating the presence of gravitational water.

Soil and Plant Water Relationships

Predawn plant water potentials were below soil water potentials by a mean of 0.83 MPa over the 14 sampling dates for FSQI of five (Figure 7). Both plant water potentials and soil water potentials were the highest in early spring (mid-late May), when precipitation peaked for the growing season (14.8 cm). Soil water potential and plant water potential follow a direct seasonal relationship, with minimum values of -0.48 MPa and -2.46 MPa respectively on October 1. Seasonal means of -0.22 MPa for soil water potential and -1.05 MPa for plant water potential were the lowest of the three FSQI values measured. Predawn plant water potentials for Quercus prinus and Quercus coccinea with an FSQI of 5 first dropped below the critical level (-1.5 MPa) on August 11, 1981 (Table 14). Total frequency of this occurrence included 6 sampling dates for each species, all residing in the latter portion of the growing season. Sassafras albidum dropped below the critical level on only 1 of 14 sampling dates.

Similar relationships were noted for FSQI of 8, with plant water potential below soil water potential an average of 0.77 MPa over the sampling period (Figure 8). Seasonal means of -0.92 MPa and -0.15 MPa for plant water potential and soil water potential respectively were found, with

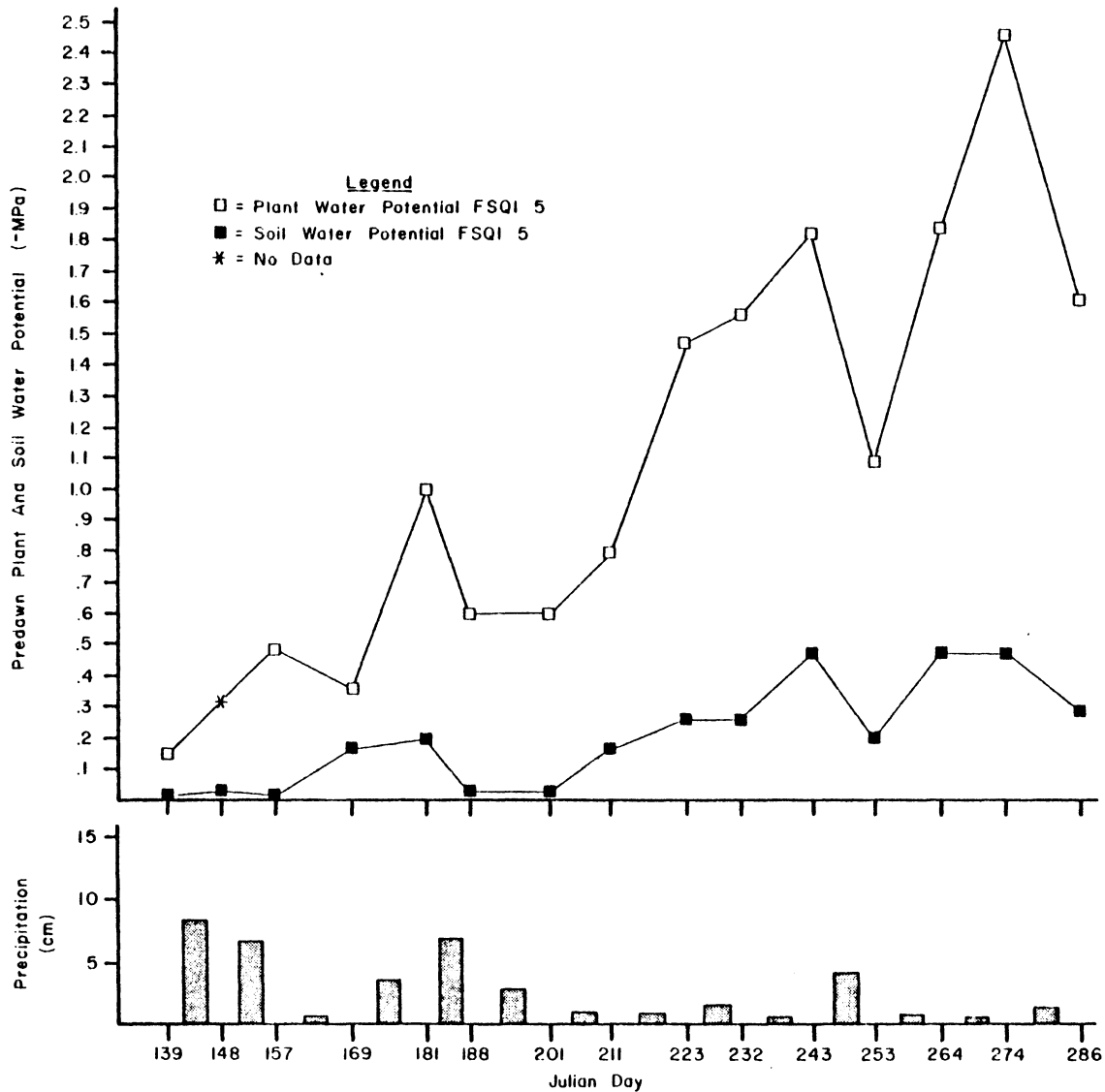


Figure 7. Predawn plant water potential (-MPa) and soil water potential (-MPa) and precipitation from May 19, 1981 through October 13, 1981 in three-year-old clearcut plots with Forest Site Quality Index (FSQI) of 5, Potts Mountain, Va.

Table 14. Date of first occurrence and frequency of occurrence where predawn plant water potential (-MPa) dropped below the critical level (-1.5 MPa) for 14 sampling dates (Julian Day) in clearcut plots with FSQI values of 5, 8, and 11, Potts Mountain, Va.

| FSQI | SPECIES | FIRST OCCURRENCE Date/Julian Day | FREQUENCY |
|------|--------------------------|-------------------------------------|-----------|
| 5 | <u>Quercus prinus</u> | Aug. 11/223 | 6 |
| | <u>Quercus coccinea</u> | Aug. 11/223 | 6 |
| | <u>Sassafras albidum</u> | Oct. 1/274 | 1 |
| 8 | <u>Quercus prinus</u> | Aug. 31/243 | 4 |
| | <u>Quercus coccinea</u> | Aug. 31/243 | 4 |
| | <u>Sassafras albidum</u> | Sep. 21/264 | 2 |
| 11 | <u>Quercus prinus</u> | Aug. 11/223 | 6 |
| | <u>Quercus coccinea</u> | Aug. 11/223 | 3 |
| | <u>Sassafras albidum</u> | Aug. 20/232 | 4 |

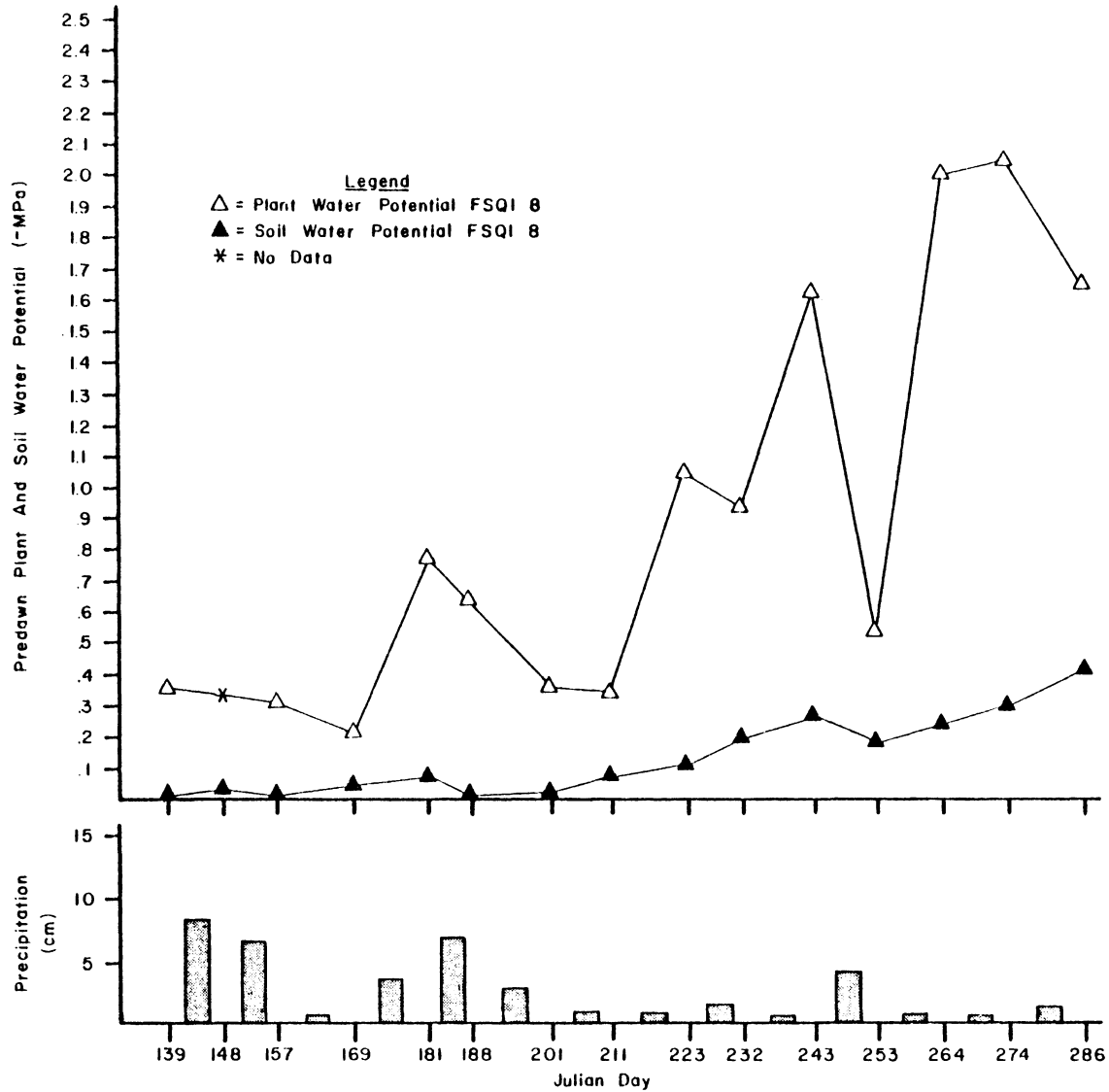


Figure 8. Predawn plant water potential (-MPa) and soil water potential (-MPa) and precipitation from May 19, 1981 through October 13, 1981 in three-year old clearcut plots with Forest Site Quality Index (FSQI) of 8, Potts Mountain, Va.

maximum values occurring on June 18 for plant water potential (-0.22 MPa) and May 19 for soil water potential (-0.01 MPa). The first plant water potential drop below the critical level for the FSQI of 8 occurred on August 31, 1981 for both Quercus prinus and Quercus coccinea, but did not occur for Sassafras albidum until September 21, 1981 (Table 14). Total frequency was less than that reported for FSQI of 5, with Quercus prinus and Quercus coccinea dropping below the critical level on 4 of 14 sampling dates while Sassafras albidum fell below on only 2 sampling periods.

Although mean soil water potential (-0.14 MPa) for FSQI of 11 was slightly above the value reported for the FSQI of 8 (-0.15 MPa), mean plant water potential was intermediate among the index values at -1.01 MPa. Maximum seasonal plant water potential and soil water potential occurred on June 7, with values of -0.22 and -0.01 MPa, while minimum values were recorded on October 1 at -2.05 and -0.31 MPa respectively (Figure 9). Predawn plant water potentials for Quercus prinus and Quercus coccinea first dropped below the critical level on August 11, 1981 for the FSQI of 11, the same date as the FSQI of 5 (Table 14). Sassafras albidum followed the same trend of late season occurrence.

An analysis of variance showed a significant difference ($\alpha = .01$) between FSQI and date for predawn plant water

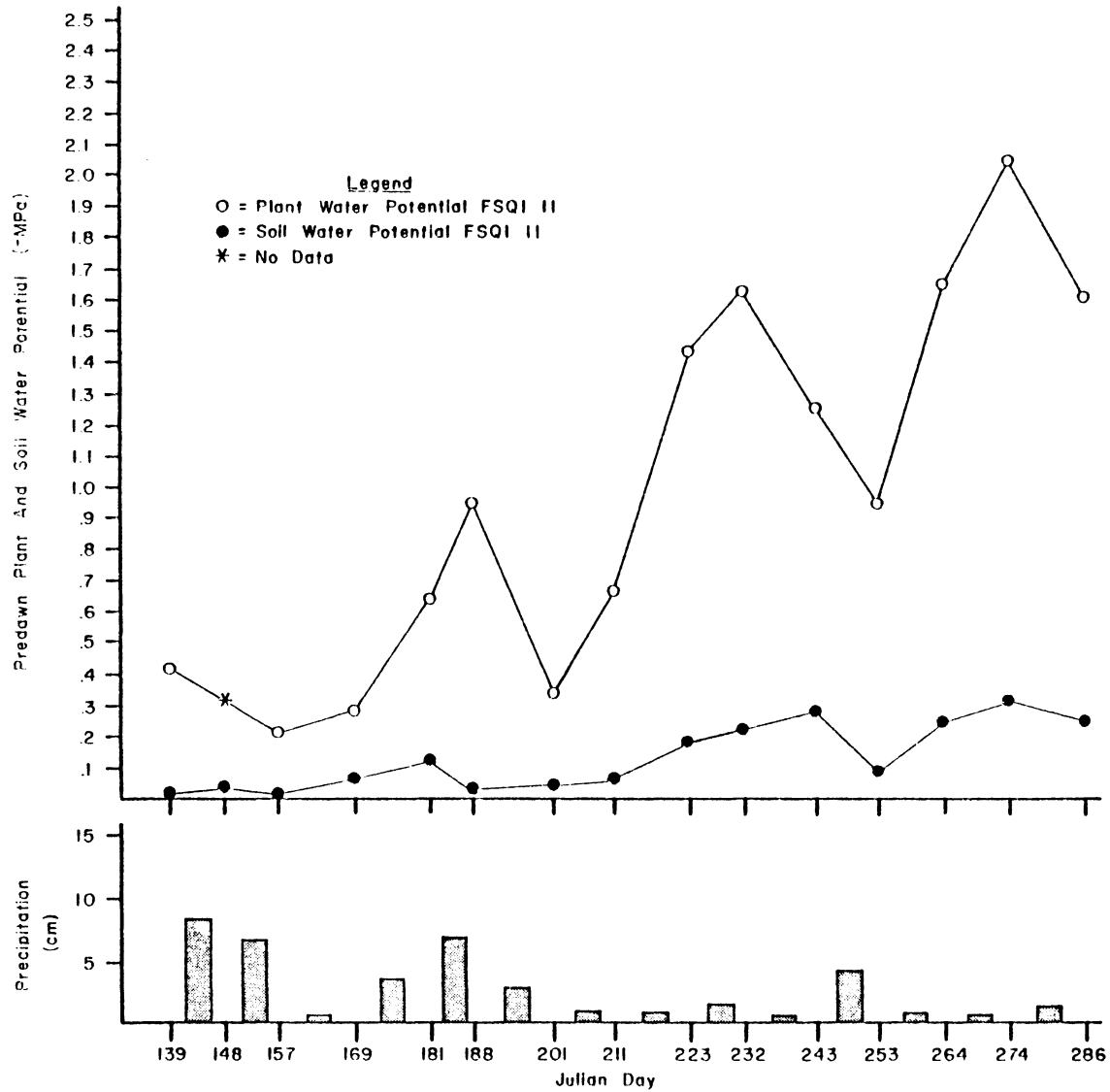


Figure 9. Predawn plant water potential (-MPa) and soil water potential (-MPa) and precipitation from May 19, 1981 through October 13, 1981 in three-year old clearcut plots with Forest Site Quality Index (FSQI) of 11, Potts Mountain, Va.

potential although species was not significant (Table 4). Significant interaction ($\alpha=.05$) was found for the FSQI*DATE term. A plot of the interacting terms showed that on only 3 of 14 sampling dates, mean predawn plant water potential for FSQI of 8 was below the FSQI of 11 as expected, while the reverse trend occurred on the other 6 sampling dates. Of the three hardwood species sampled (Quercus prinus, Quercus coccinea, Sassafras albidum), none showed a consistent pattern of higher or lower potentials compared to the other two species for a given FSQI value (Table 15). In general, FSQI values followed a pattern of declining plant water potential in the order of 8, 11 and 5.

Few consistent trends were noted between plant water potential values from seedling and sprout origin (Table 16). For the FSQI of 5, 12 of 14 sampling dates showed lower plant water potentials for seedlings. However, for FSQI of 8 and 11, lower water potential values for seedlings occurred on only 50% of sampling dates.

Diurnal plant water potentials (-MPa) were recorded on August 26, 1981 at 2 hour intervals on 2 clearcut plots with FSQI values of 5 and 11 (Table 17). For the FSQI of 5, minimum plant water potentials were reached by 3 p.m. for all three hardwood tree seedlings measured. Water potentials dropped below the critical level (-1.5 MPa) by 9

Table 15. Predawn plant water potential (-MPa) by month for three hardwood tree seedlings in three-year-old clearcut plots with forest site quality index (FSQI) values of 5, 8 and 11, Potts Mountain, Va.

| Month | FSQI | <u>Quercus</u> | <u>Quercus</u> | <u>Sassafras</u> |
|-----------|------|------------------|-----------------|------------------|
| | | <u>prinus</u> | <u>coccinea</u> | <u>albidum</u> |
| | | -----(-MPa)----- | | |
| May | 5 | 0.15 | 0.15 | 0.15 |
| | 8 | 0.30 | 0.35 | 0.37 |
| | 11 | 0.35 | 0.40 | 0.27 |
| June | 5 | 0.53 | 0.73 | 0.65 |
| | 8 | 0.42 | 0.33 | 0.28 |
| | 11 | 0.30 | 0.48 | 0.53 |
| July | 5 | 0.68 | 0.70 | 0.53 |
| | 8 | 0.33 | 0.33 | 0.47 |
| | 11 | 0.62 | 0.73 | 0.60 |
| August | 5 | 2.15 | 1.90 | 1.42 |
| | 8 | 1.08 | 1.38 | 1.05 |
| | 11 | 1.58 | 1.15 | 1.48 |
| September | 5 | 2.20 | 2.22 | 1.55 |
| | 8 | 1.38 | 1.87 | 1.52 |
| | 11 | 1.58 | 1.60 | 1.30 |

Table 16. Predawn plant water potential (-MPa) of three hardwood species of seedling and sprout origin in three-year-old clearcut plots with forest site quality (FSQI) values of 5, 8, and 11, Potts Mountain, Va.

| Date | FSQI | Seedling | Sprout |
|--------------|------|-------------------|--------|
| | | ----- (-MPa)----- | |
| May 19 | 5 | 0.15 | 0.15 |
| | 8 | 0.40 | 0.32 |
| | 11 | 0.42 | 0.44 |
| June 7 | 5 | 0.60 | 0.32 |
| | 8 | 0.35 | 0.25 |
| | 11 | 0.22 | 0.21 |
| June 18 | 5 | 0.41 | 0.25 |
| | 8 | 0.22 | 0.22 |
| | 11 | 0.28 | 0.29 |
| June 30 | 5 | 1.05 | 1.02 |
| | 8 | 0.47 | 1.25 |
| | 11 | 0.82 | 0.40 |
| July 9 | 5 | 0.73 | 0.40 |
| | 8 | 0.53 | 0.80 |
| | 11 | 0.85 | 1.13 |
| July 20 | 5 | 0.45 | 0.82 |
| | 8 | 0.28 | 0.50 |
| | 11 | 0.37 | 0.50 |
| July 30 | 5 | 0.73 | 0.87 |
| | 8 | 0.32 | 0.40 |
| | 11 | 0.73 | 0.57 |
| August 11 | 5 | 1.65 | 1.20 |
| | 8 | 1.02 | 1.12 |
| | 11 | 1.28 | 1.67 |
| August 20 | 5 | 1.63 | 1.42 |
| | 8 | 0.83 | 1.12 |
| | 11 | 1.57 | 1.72 |
| August 31 | 5 | 2.18 | 1.25 |
| | 8 | 1.67 | 1.55 |
| | 11 | 1.37 | 1.10 |
| September 10 | 5 | 1.08 | 1.07 |
| | 8 | 0.60 | 0.45 |
| | 11 | 0.78 | 1.15 |
| September 21 | 5 | 2.08 | 1.45 |
| | 8 | 2.13 | 1.80 |
| | 11 | 1.70 | 1.57 |
| October 1 | 5 | 2.80 | 1.95 |
| | 8 | 2.03 | 2.02 |
| | 11 | 2.00 | 2.12 |
| October 13 | 5 | 1.67 | 1.50 |
| | 8 | 1.62 | 1.67 |
| | 11 | 1.57 | 1.67 |

Table 17. Diurnal plant water potential (-MPa) on August 26, 1981 for three hardwood tree seedlings in three-year-old clearcut plots with FSQI values of 5 and 11, Potts Mountain, Va.

| FSQI | TIME | <u>Quercus prinus</u> | <u>Quercus coccinea</u> | <u>Sassafras albidum</u> |
|------|------|-----------------------|-------------------------|--------------------------|
| 5 | 7 | 1.0 | 2.0 | 1.3 |
| | 9 | 1.9 | 1.5 | 1.8 |
| | 11 | 1.6 | 2.6 | 1.9 |
| | 13 | 1.2 | 2.4 | 2.1 |
| | 15 | 3.2 | 3.2 | 2.4 |
| | 17 | 2.5 | 2.7 | 1.8 |
| | 11 | 8 | 1.7 | 1.9 |
| 10 | | 2.6 | 2.0 | 2.3 |
| 12 | | 2.0 | 2.7 | 1.9 |
| 14 | | 2.9 | 3.1 | 2.4 |
| 16 | | 2.1 | 2.0 | 2.1 |

a.m. for the FSQI of 5 and remained below that level for the duration of the sampling period. Minimum plant water potentials for the FSQI of 11 were obtained by 2 p.m. for all three hardwood tree seedlings measured. Water potentials below the critical level were encountered with the first measurement at 8 a.m. and also remained below -1.5 MPa for the duration of the measurement period.

DISCUSSION

The major assumption supporting the use of topographic parameters as estimators of forest site quality in the central and southern Appalachians is their inherent ability to reflect moisture supply, generally considered to be the most critical environmental factor affecting forest growth in this physiographic region. The Forest Site Quality Index (FSQI) delineation of a soil moisture gradient requires caution to avoid an oversimplification of the numerous complex processes involved in the ultimate expression of site quality (i.e. plant growth). Since the physiological processes which control plant growth are strongly influenced by plant water potential and are only indirectly related to soil water potential (Kramer, 1969), it was necessary to establish the soil and plant water relationships along the topographically proposed moisture gradient.

Soil Moisture

Soil moisture levels followed consistent seasonal trends among the four site quality index values evaluated for both clearcut and uncut plots. Beginning in late spring, soil moisture generally declined throughout the growing season, fluctuating with rainfall events (Figures 2,3,4, and 5). Previous studies in the Ridge and Valley Physiographic Province support this trend of high soil moisture levels in the early portion of the growing season followed by a gradual depletion as frequency and duration of rainfall events decline and evapotranspiration increases in mid to late summer (Stephenson, 1982; Wickham, 1975; Helvey et al., 1972; Yawney and Trimble, 1968; Tryon and True, 1958).

Although the Forest Site Quality Index (FSQI) revealed the topographically-derived moisture gradient, a lack of statistical differences in soil moisture (percent oven-dry weight) between FSQI of 8 and 11 was evident at both depths and within both stand types-clearcut and uncut (Tables 5,6,7 and 8). An evaluation of the topographic parameter values represented by FSQI rankings may offer some explanation. Similar slope positions can be noted for all replications of both FSQI values 8 and 11 (Table 3). Likewise, mean slope inclination differs by only 1 percent between the two

values. Therefore, the major topographic difference separating these sites into their discrete site quality index values was aspect. While the FSQI of 8 represents an azimuth range of 150-174 (SE), the FSQI of 11 represents 60-130 (NE-SE). However, the actual aspect values comprising the FSQI of 11 (Table 3), approached extremes within the aspect ranking category (Table 1), (i.e. FSQI of 11 being a low 11) and therefore, the site quality may be quite close to the FSQI of 8. Thus, it appears possible that for plots used in this study, similarities may exceed differences in areas selected to represent intermediate positions along the hypothesized site quality gradient and thus, could account for the lack of statistical differences. Perhaps increasing the number of sample points would insure greater mid-range ranking positions and result in more statistically significant site quality differences.

Following three years of natural hardwood regrowth, slightly higher (2-3%) soil moisture levels in the clearcut areas over adjacent uncut stands at both depths was found for FSQI values of 5, 8 and 11 (Tables 9 and 10). The trend was reversed for the FSQI of 14 where a natural drainage intersected a significant portion of the plot in the uncut stand. Other authors have reported that water yield increases following heavy thinning or clearcutting due to

reduced evapotranspiration have persisted 2 to 7 or more years depending on climate, soil storage capacity, type of regrowth and size of cut (Sartz and Knighton, 1972; Troendle, 1970; Lull and Reinhart, 1967).

After 4 years of regrowth, Sartz and Knighton (1972) reported that clearcut treatments depleted only 35 percent as much water as the uncut forest on the Coulee Experimental Forest in southwestern Wisconsin. They attributed the persistent increased water yields to the herbaceous regrowth, with its less expansive root system and smaller transpiring surface. The relatively small difference in soil water content between clearcut and uncut plots on Potts Mountain after 3 years of natural hardwood regrowth is probably partially attributable to the large number of tree sprouts using developed root systems of parent trees to extract more water from the soil. In addition, primary factors controlling the total moisture storage capacity on Potts Mountain suggest a limited hydrologic depth. These factors include the generally coarse soil texture, granular structure, shallow depth of the soil mantle and gravel-sized sandstone fragments limiting availability of space to hold water. Soil water levels within the two stand types will probably approach a common value by the fifth growing season (1983) as increased evapotranspirational demands in the clearcut areas diminish slight additional yields.

Large differences in soil water depletion between forested and clearcut areas on the Fernow Experimental Forest in West Virginia became negligible within two years (Troendle, 1970). The rapid reduction in depletion differences was also attributed to type of regrowth; particularly tree sprouts, seedlings and herbaceous plants and significantly higher rainfall levels resulting in rapid development of lush regrowth.

Soil Moisture Retention

Potts Mountain soils as described by Morin (1978) are largely of coarse-loam texture and probably experience minimal shrinkage upon drying. Thus, air will replace the water in the pore spaces creating air-water interfaces. The soil matrix potential is dependent upon the curvature of the meniscus at the air-water interface where the surface tension in these curved interfaces balances the tension or pressure exerted on the water. Within the range of available water (approximately -0.01 MPa to -1.5 MPa) the degree of availability will decline as soil water potential declines. In general, a decrease in soil water potential to -1.5 MPa is accompanied by a decrease in hydraulic conductivity to about one-thousandth of the value at field capacity (Kramer, 1969).

At a given soil water potential the FSQI of 5 usually had the lowest moisture content of the three FSQI values measured, with less available water for tree growth at each decrease in potential (Figure 6). Since soil textural differences within the study area are assumed to be small, lower retention levels for the FSQI of 5 was most likely attributable to less effective depth, characteristic of shoulder slope positions. Seasonal trends in available water can be found in Tables 12 and 13. The soil water potential values in these tables are probably more indicative of the upper limits of water availability since they were based on a bulk measurement technique for determining soil moisture content. Thus, bulk soil water potential can be considerably higher than the soil water potential at the root-soil interface where a strong tension gradient exist with distance from the root. Therefore, the soil near the roots may approach water potential levels of -1.5 MPa even though the soil several centimeters away may be near field capacity (Satterlund, 1972). The steepness of the gradient is closely correlated to physical properties of the soil, especially texture. The predominately sandy texture of the soils on Potts Mountain will expediate the development of steep tension gradients at the soil-root interface when water potential drops below field capacity.

The rapid decline in water movement below field capacity in sandy soils is related to their greater non-capillary pore space which limits retention storage and small capillaries which are largely responsible for most water movement in the soil at tensions above -1.5 MPa.

The level of water deficiency where plant growth is adversely affected will vary with plant species and soil type. Bassett (1964) reported that soil water potentials below -0.1 MPa in the upper 30 cm of the profile appreciably slowed diameter growth of southern pines. Growth became negligible when the potential dropped below -0.4 MPa. Apical growth of several hardwood seedlings stopped when soil water potential was less than -0.35 MPa (Bonner, 1967).

Soil water potentials on the Potts Mountain study site indicate decreasing availability throughout the growing season. Probable growth-limiting levels within the upper 30 cm of the profile began to occur in late July and continued throughout the months of August, September and October. These results are supported by soil moisture studies previously conducted in the Ridge and Valley Physiographic Province (Rauscher, 1977; Wickham, 1975).

In addition to soil factors, the amount of water plants absorb from soil is also influenced by plant and atmospheric factors such as stage of growth, degree of turgor, rooting

habit, plant resistance to drought, air temperature and humidity. Kramer (1969) warns that effects of various levels of soil moisture on plant growth can be evaluated accurately only if plant water potentials are measured.

Soil and Plant Water Relationships

Similar seasonal patterns of decreasing predawn plant water potentials (base P) with decreasing soil water potential were found for the three FSQI values measured (Figures 7,8 and 9). The consistently lower plant water potential values compared to "bulk" soil water potential illustrate the gradient in water potential from soil to roots and leaves. Although the daily cycle in water stress is primarily controlled by the rate of transpiration and stem capacitance, long-term decrease in plant water potential is controlled chiefly by soil water potential and soil water conductivity. Thus, in the early portion of the growing season when precipitation was more frequent, a small gradient in water potential could maintain adequate water supply for the plants due to higher hydraulic conductivity in the soil and allow recovery overnight to the condition where $\Psi_{\text{plant}} = \Psi_{\text{soil}}$. As Ψ_{soil} continued to decline throughout the latter portion of the growing season,

transpirational losses increasingly exceeded supply. On the morning of September 10, 1981 differences in base P and soil water potential for FSQI of 5 reached -1.99 MPa. Differences in base P and Ψ soil reached -1.76 MPa and -1.74 MPa on September 20, 1981 for FSQI of 8 and 11 respectively.

It is apparent from late season base P levels (July-September), that overnight recovery was not occurring and growth limiting stress levels were probably prevalent throughout the latter portions of the growing season. This observation is supported by data in Table 14 which shows the consistent mid to late growing season occurrence of predawn plant water potentials below the critical level (-1.5 MPa). However, Boyer (1967) suggests several sources of error in the pressure chamber technique that may be particularly applicable to species tested on Potts Mountain. The large vessels of these species were probably partially empty as available soil water declined throughout the growing season. During the pressure measurements water may have moved into voids resulting in erroneous over-estimates of water potential.

It is essential that both stress severity and duration be considered when examining water stress effects. While specific water stress effects cannot be determined from xylem water potential measurements alone, numerous water

relations studies indicate stress levels recorded on Potts Mountain are probably significantly affecting growth (Cheung et al., 1975; Hinckley and Bruckerhoff, 1975; Hsiao, 1973; Boyer, 1968; Slatyer, 1957).

Thompson and Hinckley (1977) found that as the soil dried in an oak-hickory forest in Missouri in August, plant stress progressively reached its daily minimum earlier in the morning and maintained that level later in the afternoon. Diurnal plant stress measurements on Potts Mountain on August 26, 1981 reached -2.60 MPa by 11 a.m. and maintained that stress level until 5 p.m. (Table 17).

Although base P levels for the FSQI of 5 were significantly different and exceeded those of FSQI 8 and 11 as expected, the gradient was not significant. An explanation for the lack of differences in stress levels between the FSQI of 8 and 11 is probably related to the lack of significant differences in soil moisture noted for those index values (Tables 12 and 13). Apparently, similar levels of available soil water accounted for consistently similar base P levels. Thompson and Hinckley (1977), using a step-wise regression, found that for white oak (Quercus alba L.), sugar maple (Acer saccharum Marsh), and sunflower (Helianthus strumosus L.), soil moisture in the upper 30 cm of the soil profile was the only important environmental

variable in changing base P. However, since other important environmental (radiation load, humidity, leaf and air temperatures, vapor pressure deficit) and physiological factors (internal resistances) were not measured, this explanation is only partial.

Wide variations in water content among various plant parts, stages of development and between species requires that measurements of plant moisture stress be standardized. Under conditions of similar age (three-year-old seedlings), exposure, and position of removal from plant, base P levels for chestnut oak (Quercus prinus), scarlet oak (Quercus coccinea), and sassafras (Sassafras albidum) were not significantly different (Table 14). Presumably similar vascular anatomy, age, and relative root mass may account for similar moisture movement and storage mechanisms. The lack of statistical differences among the species sampled may constitute an important advantage of the FSQI over site index in predicting site quality, the latter being species specific.

Limitations and Applications of the Forest Site Quality Index

The Forest Site Quality Index (FSQI) is a rapid and easy measure based on aspect, slope inclination and slope position for evaluating relative site quality. In general, use of the FSQI is restricted to parts of the eastern and southern United States where rainfall is critical to plant growth during the growing season. A topographic restriction requires that an area have slopes in excess of 10 percent to assure that topography will affect the available water of a site.

Perhaps the most critical constraint of the FSQI is that chemical and physical properties of the soil parent material within a designated area of measurement must be similar. This limitation is necessary to minimize differences in inherent nutritional content and weathering products so that resulting soils are of similar site quality potential. It is especially difficult to quantify adherence to this limitation, particularly in the Ridge and Valley Physiographic Province, where lithologic discontinuities from past geologic processes has resulted in vertical nonuniformity in parent material in many areas. Where moderate to steep slopes are common, discontinuities can result from additions of colluvium (downslope transport origin) over residual materials.

The following modifications to the FSQI are offered as suggestions which might expand the usefulness and applicability of the index.

1. Accounting for textural differences in soils by stratifying the major textural classes based on their ability to supply water for plant growth during critical periods.
2. Adding a ranking for land form to account for exposure and/or protection and shading which influence climate and energy partitioning effects.
3. Ranking elevation to include modifications in climate and energy partitioning along elevational gradients.

CONCLUSIONS

The soil moisture trends and plant water potentials demonstrated that for all FSQI values representing the topographically derived moisture gradient, available soil moisture and plant stress levels probably seriously decrease or inhibit tree growth from the middle of July to the end of the growing season.

The direct seasonal relationships found between soil water potential and plant water potential suggest available soil water is probably the most important environmental factor controlling base P levels.

The Forest Site Quality Index delineated the soil moisture gradient within the study area and should serve as a useful tool in predicting relative site quality within its stated limitations previously described and on those sites where soil moisture has been demonstrated as being the limiting factor of tree growth.

Establishment of the soil moisture and plant moisture stress relationships on Potts Mountain will play an integral role in the comprehensive natural hardwood regeneration research project being conducted on the site. Information

on moisture relations will aid particularly in understanding the corresponding relationships between differences in moisture regime and spatial distribution and structure of vegetation on the site, which are currently under analysis.

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SOIL AND PLANT WATER STRESS IN AN APPALACHIAN OAK FOREST:
ITS RELATIONSHIP TO
TOPOGRAPHY AND FOREST SITE QUALITY

by

Tina Marie Meiners

(ABSTRACT)

A forest site quality index (FSQI) based on topographic parameters of aspect, slope inclination and slope position was used to investigate soil moisture and plant water stress relationships on the southeast face of Potts mountain in Craig County, Virginia. Topographical effects on available water are especially pronounced during low late season rainfall levels encountered in the Ridge and Valley physiographic province of Virginia. The soil moisture trends and plant water potentials demonstrated that for all forest site quality index values representing the topographically derived moisture gradient, available soil moisture and plant stress levels probably seriously decrease or inhibit tree growth from the middle of July to the end of the growing season.

The Forest Site Quality Index (FSQI) delineated the soil moisture gradient within the study area most successfully in the more xeric areas, supporting its use for predicting relative site quality on those sites where soil moisture has been demonstrated as being the limiting factor of tree growth. The FSQI is a rapid and easy measure based on topographic parameters for evaluating relative site quality but is restricted in use to areas where rainfall is critical to plant growth during the growing season.