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# Color aerial photography as a guide to foliar nutrient levels and site index in loblolly pine plantations

Alan D. Lyons

To the Graduate Council:

I am submitting herewith a thesis written by Alan D. Lyons entitled "Color aerial photography as a guide to foliar nutrient levels and site index in loblolly pine plantations." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Forestry.

Edward R. Buckner, Major Professor

We have read this thesis and recommend its acceptance:

Ronald L. Hay, Eyvind Thor, John B. Rehder

Accepted for the Council:
Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

To the Graduate Council:

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Accepted for the Council:

L. Evans Roth

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Graduate Studies and Research

A

# COLOR AERIAL PHOTOGRAPHY AS A GUIDE TO FOLIAR NUTRIENT LEVELS AND SITE INDEX IN LOBLOLLY PINE PLANTATIONS

A Thesis

Presented for the

Master of Science

Degree

The University of Tennessee, Knoxville


Alan D. Lyons


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## ABSTRACT

Color aerial photographs were obtained during the winter of 1979-80 of extensive areas of loblolly pine plantations in Franklin County, Alabama, and Wayne County, Tennessee. Three separate interpreters using acetate overlays drew boundaries between color classes that could be detected within and among these plantations as seen on the aerial photographs. Interpreters identified three Munsell color classes (2.5 G 3/4, 2.5 GY 5/4, and 2.5 GY 6/6) into which the range of loblolly pine crown colors detected on photographs were coded. Foliar nitrogen, site index, and basal area were positively correlated with increasing greenness in these Munsell color classes.

This technique permitted evaluation of productivity (site index) and foliar nutrient status from color aerial photographs, enabling more efficient land classification and possibly more efficient use of fertilizers for increasing productivity.

TABLE OF CONTENTS

LIST OF TABLES

## LIST OF FIGURES

# CHAPTER I

## INTRODUCTION

Rapid expansion in the forest products industry in the South over the last decade has greatly increased the demand for roundwood, especially pine. To satisfy this demand industries have generally intensified efforts to increase productivity on present ownerships rather than incur the high acquisition and maintenance costs of acquiring additional land. Research has indicated that forest fertilization can provide one means of accomplishing this goal where suitable species-site relationships exist. However, wide variation in response to fertilization has demonstrated that the identification of species-site situations in which fertilization will be effective poses a major problem.

Adequate foliar nutrient levels, especially for nitrogen, are usually associated with dark-green foliage, indicating high chlorophyll concentrations. Chlorosis (yellowing) is commonly related to low foliar nitrogen levels (Pritchett, 1979).

Winter yellowing of loblolly pine (*Pinus taeda* L.) foliage, a common phenomenon throughout much of the South, has been related to foliar nutrient levels, especially nitrogen and phosphorus. Blinn (1978) color coded loblolly pine foliage to one of six discrete Munsell color signatures. As foliage color changed from yellow to dark-green there was a stepwise increase (highly significant) in both nitrogen and phosphorus. While positive correlations were found with both elements, the nitrogen relationship was most discrete. Nitrogen is generally the limiting element restricting tree growth in the Southeast. These high correlations between foliage color and nutrient concentrations suggest that color aerial photographs might be useful for determining foliar nutrient levels within and among loblolly pine plantations.

The objectives of this study were: (1) to code the range of colors detected in loblolly pine plantations as observed on color aerial photographs, and (2) to relate the color units detected to site index, basal area and soil and foliar nutrient levels.

# CHAPTER II

# LITERATURE REVIEW

## Visual Deficiency Symptoms

Plants require seventeen elements for normal development. Nitrogen, phosphorus, potassium, calcium and magnesium, the macro-nutrients, are needed in relatively large quantities while only small quantities of the others, the micronutrients, are required (Tisdale and Nelson, 1975). If one of these essential nutrients is deficient a characteristic symptom generally develops. To associate specific symptoms in a species with the deficiency of a specific nutrient, a great deal of observation (and photography), description, experimentation, and chemical analysis are needed (Leaf, 1968).

The detection of visual deficiency symptoms is one of the most commonly used methods of diagnosing plant nutrient deficiencies (Pritchett, 1979). Deficiency symptoms take many forms, such as reduced vegetative growth, abnormal morphology of plant parts, reduced or increased fruit production and unusual foliage coloration. Foliage color is usually the most sensitive indicator of suboptimal nutrient levels (Lyle, 1969). Armsom (1977) also states that foliage discoloration and growth abnormalities are usually the first outward signs of deficiency observed in plants. However, growth reduction due to nutrient deficiencies usually takes place before visual symptoms appear. Where forests are managed intensively the emphasis should be on anticipating and correcting possible deficiencies rather than waiting to treat them after they occur.

In loblolly pine, as with many other plants, the universal symptom for nitrogen deficiency appears to be the yellowing of foliage (Addoms, 1937; Fowells and Krause, 1959). Addoms (1937) described the symptom for loblolly as a yellowing of needles while Fowells and Krauss (1959) described it as short, stiff yellow-green needles. Miller (1966a) studied winter yellowing of loblolly pine on a somewhat poorly drained alluvial soil. He found no differences in nutrient levels but found a prominent difference between total chlorophyll content of normal foliage and discolored foliage; normal foliage contained three times more chlorophyll. Blinn (1978) color coded loblolly pine foliage to one of six discrete Munsell color signatures. As foliage color changed from yellow to dark-green there was a stepwise increase in both nitrogen and phosphorus. While positive correlations were found with both elements the nitrogen relationship was most discrete.

Deficiency of phosphorus in coniferous stock usually results in the development of a pink or reddish color in the lower needles. Deciduous seedlings may develop purplish tints on the twigs and the petioles of the leaves, while the leaves show purple pigmentation and bronzing. Phosphorus deficiencies cause the leaves of certain species to be shed prematurely (Wild and Voigt, 1952). Fowells and Krauss (1959) found no foliage discoloration in phosphorus deficient loblolly pine but did report early needle abscission.

Hobbs (1944) found that potassium deficiency in pines resulted in bluish-green coloration of foliage with shorter than normal needles. Chlorosis occurred occasionally but was not common or typical. Sucoff (1961) described severe potassium deficiency in loblolly pine as purple or brown coloration of older primaries with the rest of the needles grayish-green. As the deficiency progressed the uppermost needles became purple and tufted with spiralling around the terminal. For less severe deficiencies the needles looked as though they had been painted with water colors in shades of purples, brown, yellows and greens.

A deficiency of calcium manifests itself in the failure of the terminal buds to develop (Tisdale and Nelson, 1975). Davis (1949) employed nutrient solutions to study the effects of calcium levels on the development of loblolly pine. He noted that the needles were yellow-green to brown, twisted, stiff, one to two inches long and the tips of many were dead. The terminal bud was brown and appeared dead. The lateral buds were alive, but were not actively growing.

Stone (1953) studied magnesium deficiency in northern pines and concluded that the most characteristic symptom in all pines is the yellowing of the tips of the current year's needles. This chlorosis appears near the close of the growing season. Sucoff (1961) lists the symptoms for severe magnesium deficiency in loblolly pine as brown tips, yellow middle and a dark-green base in secondary needles. After a period of time all of the needle turns brown except for the basal 1 or 2 centimeters, which remains dark green.

Under field conditions, visual symptoms may be difficult to interpret because environmental factors are variable and constantly affect the tree (i.e., severe climate, soil conditions, and/or rodents, insects and diseases). Also multiple deficiencies may occur which complicate symptom diagnosis (Leaf, 1968). Sometimes symptoms for two or more elements are so similar that it is difficult to distinguish between them. In these cases, chemical analysis of the plant tissues will usually identify the deficient element (Hacskaylo et al., 1969). Sucoff (1961) warned that visual symptoms alone should not be completely trusted in determining the cause of deficiency. However, visual symptoms checked by foliar analysis should provide for rapid and accurate diagnosis of nutritional diseases.

## Color Aerial Photography

One of the most important developments in aerial photography over the last decade has been the widespread use of true color and color infrared (false color) film. During this time the operational use of color film became more practical due to technological improvements, such as faster film emulsions (Latham and McCarty, 1972). True color and color infrared films differ in their sensitivity to the various wavelengths of electromagnetic energy. True color aerial photographs record vegetation in varying hues of green and yellow-green or much the same as the normal eye sees. Color infrared pictures show healthy vegetation as various shades of red while dead or stressed vegetation is brown (Heller and Bega, 1973).

True color film is composed of three emulsion layers which are sensitive to overlapping bands (blue, green and red) of the visible portion (.4-.7 um) of the electromagnetic spectrum. If properly exposed and processed color film reproduces natural color faithfully (Hilborn, 1976). Aerial color film can be purchased as either reversal or negative film. Reversal films, when processed, yield a positive transparency that provides a close approximation of the image values and tone of the original scene. Negative color films yield a negative in which the image's values and tones are reversed. Negative prints generally record the color values and tone of the scene closer than prints made from reversal films (Eastman Kodak Company, 1968).

Forest resource managers have expressed a need for low cost applications of aerial photography to reduce expensive field measurements (Mead and Rasberry, 1980). Color aerial photography, both true color and color infrared, have been used to more effectively manage agricultural and forest lands. Swell and Allen (1973) found a strong relationship between fallow soil moisture level and fallow soil reflectance at visible and near infrared wavelengths. Alexander (1971) studied the use of aerial photography to distinguish between different soil series. He discovered that color infrared photographs usually did not have an advantage over true color photographs for identifying variations in soil color.

The use of color aerial photographs is becoming an increasingly valuable tool for assessing damage to forest trees by insects and diseases (Murtha and Harris, 1970). Foliar symptoms, reflecting the development of basal canker of white pine, were readily detected on true color and color infrared (CIR) transparencies; color infrared provided the most striking differences (Houston, 1972). Eagar (1978) used color infrared aerial transparencies to locate and determine the size and intensity of balsam wooly aphid attacks within the Great Smokey Mountains National Park.

In dealing with color photographs the interpreter is confronted with a diversity of photos taken with a variety of cameras, filters and film emulsions under many different atmospheric conditions and lighting intensities. Valid comparisons among imagery sets require standardization of the photographic process with frequent calibration to assure uniformity (Dana, 1971). Vleck (1972) listed four groups of factors that affect photographic sensing:

1. Ground illumination and object reflectance effects;
2. Atmospheric effects;
3. Camera effects;
4. Film processing effects.

He points out that some of these factors, such as illumination and atmospheric conditions, are beyond control. However, limited control can be exercised by waiting until a time when such conditions have the least effect. Light fall-off toward the edge of the image format, caused by the camera lens, produce constant effects which can be contended with. Film processing, although under laboratory control, varies widely due to lax procedures (Vleck, 1972). Standards for color control and calibration of color aerial photographs should be carefully considered. If a universal set of controls is not adopted, each interpreter will develop his own techniques and possibly have his own problems in reproduction (Egan, 1969).

The use of standards to document color depends on the type of color described, whether physical, psychophysical or psychological. In each type the definition of color varies. Physical color is an aspect of radiant energy, while psychophysical color is a response of the retina to physical stimuli. Psychological color is that aspect of visual perception that enables one to differentiate otherwise identical objects. Systems based on the psychological method, such as the Munsell color system and Ridgeway Color Standards, are the most widely used, with the Munsell color system almost exclusively used in biological work (Rib, 1968).

Although the color of natural scenes can never be exactly copied, color photographs can provide useful and long-lasting approximations. The use of remote sensing techniques to identify color abnormalities of plants due to deficiencies of certain elements appears to have some value (Pritchett, 1979).

Blinn (1978) correlated winter yellowing of loblolly pine with low nutrient levels. He suggested that detection of low levels of elements over large areas might be possible from color aerial photographs. If low levels reflect nutrient need then more efficient utilization of fertilizers in forestry might be possible.

Cress (1974) used a 70 millimeter multispectral system to determine if different nitrogen levels in fertilized loblolly pine plantations could be detected. Using a microdensitometer to scan photographs obtained in the spring and fall, he was unable to distinguish crown color differences related to foliar nutrient levels in fertilized and unfertilized pine plantations. He suggested that winter photography might provide more definitive results, since this is the time when color contrasts between nutrient deficient and healthy foliage is greatest.

<u>Soil Analysis</u>

Soil analysis begins with the collection of soil samples. This is a critical step because, regardless of analytical precision, the soil test will be of little value if the sample is not representative of the field (Cameron et al., 1971). Spurway (1933) states that the collection of composite soil samples are preferable to single samples, except that samples from widely different soil locations, soil classes, and/or soil types should not be mixed together for chemical testing.

Soil analysis has traditionally been used to measure the extent to which soil nutrient levels are sufficient to supply plant needs. Its primary limitation is that the essential elements present are not totally available to plants. This has resulted in the development of "availability" analysis that attempts to simulate the extent to which soil nutrients are extracted by plants.

In soil testing there are three major sources of variation: laboratory, seasonal and spatial or field (Cameron et al., 1971). There is disagreement over the importance of variation in laboratory analysis. In several studies, laboratory variation was found to be small relative to field variation (Cline, 1944; Hammon et al., 1958). In contrast, its evaluation was considered essential for complete understanding of the sources of error in other tests (Holland, 1965; Keogh and Maples, 1967; Mountier et al., 1966). Variation over time, especially when short term, is often hidden by random field variation (Frankland et al., 1963). Longer term variation is more easily measured; Collins et al. (1970) found rather large shifts in soil pH during a four-month period. However, the largest and most significant variation in soil analysis is spatial or field variation (McIntyre, 1967).

Mader (1963) found that the coefficients of variability for soil nutrient levels in several forestry sites tended to be higher when quantities were low. He suggested that the cause may have been greater analytical error with low soil nutrient levels. Hemingway (1955) also found that low levels of essential elements tend to give higher variation relative to their means. The standard error for phosphorus and potassium in some instances increased with the mean of nutrient values and in others was proportionally greater when nutrient values were low (Mountier et al., 1966).

Rogers (1979) analyzed sixty soil samples, representing twenty soil series by each of three soil testing procedures: Double Acid, the Tennessee soil testing procedure, and the new Mehlich procedure. Using six soil to solution extracting ratios for P, K, Ca, Mg, Mn and Zn, he found very little, if any, real differences in the extraction effectiveness of the Double Acid or Tennessee procedures, with the new Mehlich extractant only slightly less effective. He also found that decreasing the soil to extracting solution ratio significantly increased the amount of P, K, Ca, Mg, Mn and Zn measured in a soil sample.

## Foliar Analysis

Foliar analysis is based on the assumption that the elemental composition of plant tissues reflect the ability of a soil to supply the nutrient needs of plants and also the ability of the plant to extract nutrients from the soil. As a diagnostic procedure it is a direct approach, for it "asks" the plant about its nutrient problems (Ulrich and Hills, 1967).

Foliar analysis has several obvious advantages over soil analysis. First, foliar analysis measures amounts of nutrients that are "in hand" and available for metabolism, while soil analysis measures nutrients that may or may not be available to plants. This makes plant analysis a more direct measure of nutrient availability. A second advantage is that foliar analysis can be directly related to visual deficiency symptoms such as color and morphology. These characteristics can be organized into an easy to read table for direct field diagnosis (Gessel and Walker, 1958). Foliar analysis often permits the detection of nutrient deficiencies that limit growth and yield when visual deficiency symptoms are not apparent. This condition has been termed "Hidden Hunger" (Howlett and Cahoon, 1964).

Collection and analysis of foliage is not without its problems. Determining the proper procedures and standardization of these procedures is essential if meaningful results are to be obtained (Everard, 1973; Leaf, 1973; White, 1954). The following variables should be standardized: (1) season of collection, (2) crown class sampled, (3) position in crown, and (4) tissue age (Blinn, 1978).

The best time for foliage collection is when the level of all essential elements are most diagnostic of the nutrient status of the tree (Wells and Metz, 1963). However, it has been shown that this time varies depending on the element in question. Furthermore, instability during periods when levels are most diagnostic often results in sampling during periods when levels are relatively stable rather than when they are most indicative of nutrient status. White (1954) found a decline in the percentage of nitrogen, phosphorus and potassium in the needles of white pine and red pine from an early summer maximum to a fairly constant level during the winter months. This trend advocates fall and winter sampling of foliage. Wells (1969) claimed that loblolly pine should be sampled during the winter. He further explained that temperature extremes do not have an important influence upon elemental content in loblolly pine. Miller (1966b) studied seasonal trends in foliar nitrogen, phosphorus and potassium of loblolly pine in Mississippi; he found that fall and winter levels of these elements were not as stable as reported in other works.

Dominant and codominant trees generally show closer nutrient relationships with growth and yield than other crown classes. Needle samples should be collected in the upper one-third of the live crown and from the first growth flush of the previous spring (Wells, 1969). Foliar analysis of current year's growth is preferred because of high correlation between nutrient concentrations and site index (Lowery and Averd, 1969), availability of soil nutrients (Lavender and Carmichael, 1966) and shoot length (Leyton and Armson, 1955).

Foliage should be oven dried at 70° C as soon as possible after sampling, then ground and stored free from contaminants (Gessel and Walker, 1958; Thomas, 1945). However, Blinn (1978) reported that refrigeration of loblolly pine foliage for five months did not result in significant shifts in nutrient status or tissue color.

## CHAPTER III

## METHODS AND MATERIALS

### Selection of the Study Area

The coastal plain of Georgia and South Carolina was initially selected as the study area because of the large acreages in older pine plantations. After discussions with foresters familiar with this region, however, it became apparent that separation of loblolly pine from slash pine (*Pinus elliotti*) on aerial photographs of this area would present a major problem to interpretation. Also, loblolly pine plantations older than fifteen years were not common in this area.

At the suggestion of foresters with Champion Timberlands the North-Alabama and Middle Tennessee area was chosen because most forest plantings were loblolly pine, and they were established on a variety of sites (Table 1).

### Imagery Acquisition

During the winter of 1979-80 true color aerial photographs were obtained by Continental Aerial Surveys of loblolly pine plantations in Franklin County, Alabama, and Wayne County, Tennessee. Imagery acquisition began on December 19, 1979, but due to alternator failure, the flight was discontinued after photographing approximately thirty frames. Poor weather prevented completing imagery acquisition until February 28, 1980. Table 2 gives weather conditions on the days imagery was obtained.

Table 1. Description of Loblolly Pine Plantations Sampled

| Plantation Location | Soil Types* | Plantation Age | Aerial Photo Color Units Detected |
|---|---|---|---|
| Franklin County, Alabama | | | |
| 1. Russellville | Mine Pits and Dumps | 39 years | 2.5 GY 6/6 |
| 2. Russellville | Lindside Silt Loam | 29 years | 2.5 G 3/4 |
| 3. Russellville | Slickens | 35 years | 2.5 GY 5/4 |
| 4. Russellville | Slickens | 34 Years | 2.5 GY 5/4 |
| 5. Guinn Cross Roads | Cuthbert and Ruston | 10 years | 2.5 G 3/4 |
| | | | 2.5 GY 6/6 |
| 6. Guinn Cross Roads | Ruston Fine Sandy Loam | 18 years | 2.5 GY 6/6 |
| | Cuthbert and Ruston | | 2.5 G 3/4 |
| Wayne County, Tennessee | | | |
| 1. Tie Camp Hill | Unmapped | 25 years | 2.5 GY 5/4 |
| 2. O'neale Tract | Mountview Cherty Silt Loam | 22 years | 2.5 GY 6/6 |
| | Dickson Silt Loam | | 2.5 GY 5/4 |

*See Appendix A.

Table 2. Weather Bureau Weather Data from Closest Station at Approximate Time Imagery was Obtained

| Type of Condition | December 19, 1979 | February 28, 1980 |
|---|---|---|
| Visability | 10 miles (16.09 kilometers) | 15 miles (24.14 kilometers) |
| Temperature | 37° F (2.8° C) | 63° F (17.2° C) |
| Dew Point | 22° F (-5.6° C) | 39° F (3.9° C) |
| Relative Humidity | 54% | 51% |
| Wind | 180° at 5 miles/hour (8.05 kilometers/hour) | 260° at 16 miles/hour (25.75 kilometers/hour) |

Photographs were taken with a Wild RC-10 aerial mapping camera, six inch (152.4 millimeters) focal length, mounted in a Cessna 411 aircraft. Kodak Aerocolor Negative film 2445 (.4-.7 um) ester base in a 9 x 9 inch (3.54 x 3.54 centimeters) format size was used. Photographs were taken at three altitudes to determine the upper limits that nutrient deficiencies could be detected within and among loblolly pine plantations. Image scales included: (1) 1:10,000, (2) 1:20,000 and (3) 1:30,000 or mean altitudes above mean ground level of 5,000, 10,000 and 15,000 feet (1,524, 3,048, 4,572 meters) respectively.

Photographic Printing and Analysis

Color shifts commonly occur in color prints. If large, such shifts would seriously affect study results. To minimize this problem printing was closely supervised to assure the truest possible rendition of colors.

Before printing, a test was conducted using one negative to determine the correct filter combination to use in the Log-Etronic Mark IV printer. By adding or subtracting different color filters the print was adjusted to duplicate the true color of the scene as closely as possible. After five test prints had been made, using different filter combinations, a print was chosen by three individuals as having the truest color based on their experience with color aerial photographs. This filter combination was then used in printing the remaining negatives.

Because color perception varies among individuals each color print was analyzed by three separate aerial photo interpreters. Color coding was done under fluorescent light to standardize lighting effect. Using acetate overlays interpreters drew boundaries separating the three Munsell color classes, as they were detected within loblolly pine plantations on color aerial photographs.

### Ground Truth

Field sampling was done between January 15, 1980, and March 15, 1980, prior to the period in which spring greening generally occurs. Three plots in every color unit identified in study plantations were randomly located. Foliage was collected from the upper one-third of four trees in each plot and composited to make one sample. Samples were sealed in plastic bags and placed in a cooler with ice until returning to the laboratory where they were transferred to a freezer. Soil samples were collected from the 0 to 4 inch and 4 to 8 inch depths near each sample tree and composited to make one soil sample for each of the two depth classes. Additional data collected from each plot included: site index, basal area, average diameter growth over the last five years, aspect and percent slope.

In the laboratory foliage samples were cleaned and needles removed from the first growth flush of the previous spring. Needles were placed between screens and dried in a force-draft oven at 70 degrees centigrade until weight remained constant. After drying, needles were ground in a Wiley mill to pass a 20 mesh screen. Ground tissue was stored in sterilized glass jars and placed in a cool, dark area until digestion.

Nitrogen was determined by the Kjeldahl method using a Tecator distilling unit and titrator. Phosphorus was determined colormetrically, while potassium, calcium and magnesium were determined by atomic absorption spectrometry. Soil phosphorus, potassium and pH were determined at the Tennessee Agricultural Extension Service Soil Testing Laboratory. To determine the variation in test results that might be expected between different test facilities, companion samples of both foliage and soil were sent to North Carolina State by Champion Timberlands personnel (Appendix B).

## CHAPTER IV

## RESULTS AND DISCUSSION

### Photography

Three distinct color classes were identified within and among loblolly pine plantations by three aerial photo interpreters on color aerial photographs obtained from 5,000 feet (1,524 meters; scale of 1:10,000). These were: green (2.5 G 3/4), yellow-green (2.5 GY 5/4) and yellow (2.5 GY 6/6) (Figures 1 and 2). The smaller scales tested from 10,000 feet (3,048 meters; scale of 1:20,000) and 15,000 feet (4,572 meters, scale of 1:30,000) would increase the number of acres included in a photograph; however, crown color classes were washed out by atmospheric haze (Figure 3). On photographs taken at the 5,000 foot altitude (1,524 meters) color discrimination was possible with visibility as low as ten miles (16.09 kilometers) at the time of photography. Detection of crown color classes at higher altitudes might be possible using color infrared photography due to the haze penetrating characteristic of this film.

Light fall-off toward the edge of photographs, caused by camera lens distortion, reduced the usable coverage. This was a constant effect that was generally limited to one inch (2.54 centimeters) around the border. Overlap for most photographic coverage is such that all areas are included within the middle 70 percent of a frame. In an attempt to economize, the first photographic mission had an overlap of 20 percent, which was inadequate. On the second flight photographs were made with 50 percent overlap, which provided satisfactory results.

Figure 1. Color aerial photograph of loblolly pine crown color units 2.5 GY 5/4 (yellow-green) and 2.5 G 3/4 (green).

Figure 2. Color aerial photograph of loblolly pine crown color units 2.5 G 3/4 (green) and 2.5 GY 6/6 (yellow).

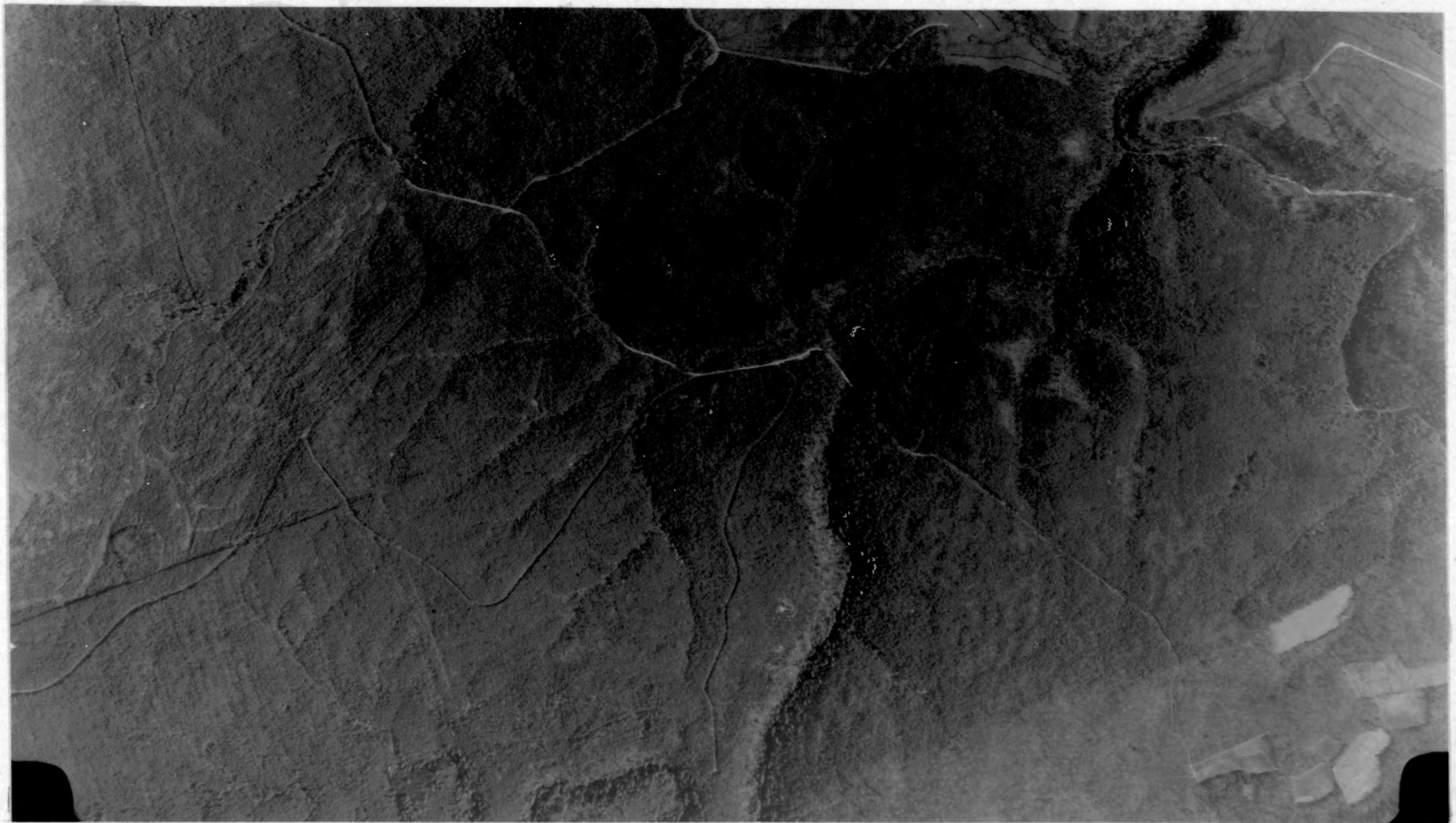
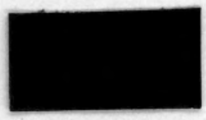


Figure 3. Color aerial photograph of a loblolly pine plantation taken at 10,000 feet (ratio 1:20,000) with visibility approximately 10 miles.

## Crown Color-Foliar Nutrient Relationships

Foliar analysis revealed a significant relationship (.05 level)[1] between the nitrogen content of foliage and crown color classes on aerial photographs (Table 3). The average nitrogen content of tree crowns coded green was 1.58 percent, yellow-green averaged 1.33 percent and yellow areas averaged 1.20 percent (Table 3; Figure 4). The R-square (0.55) for the foliar nitrogen-aerial photo crown color correlation was the highest of the foliar nutrient-crown color relationships (Appendix C, Table C-3).

Table 3. Foliar Nutrient Means for Aerial Photo Color Units

| Munsell Color | 2.5 GY 6/6 | 2.5 GY 5/4 | 2.5 G 3/4 |
|---|---|---|---|
| |  |  |  |
| Nutrient | → Increasing Greenness → | | |
| | (Percent) | | |
| N | 1.20 a | 1.33 b | 1.58 c |
| P | 0.15 a | 0.14 a | 0.17 b |
| K | 0.38 a | 0.41 ab | 0.44 b |
| Ca | 0.31 a | 0.27 a | 0.27 a |
| Mg | 0.10 a | 0.09 a | 0.09 a |
| No. of Samples | 12 | 13 | 10 |

Note: For each element, nutrient averages followed by the same letter are not significantly different at the .05 level.

[1] When "significance is used in the following discussion, it indicates that differences were statistically analyzed at the .05 level of significance.

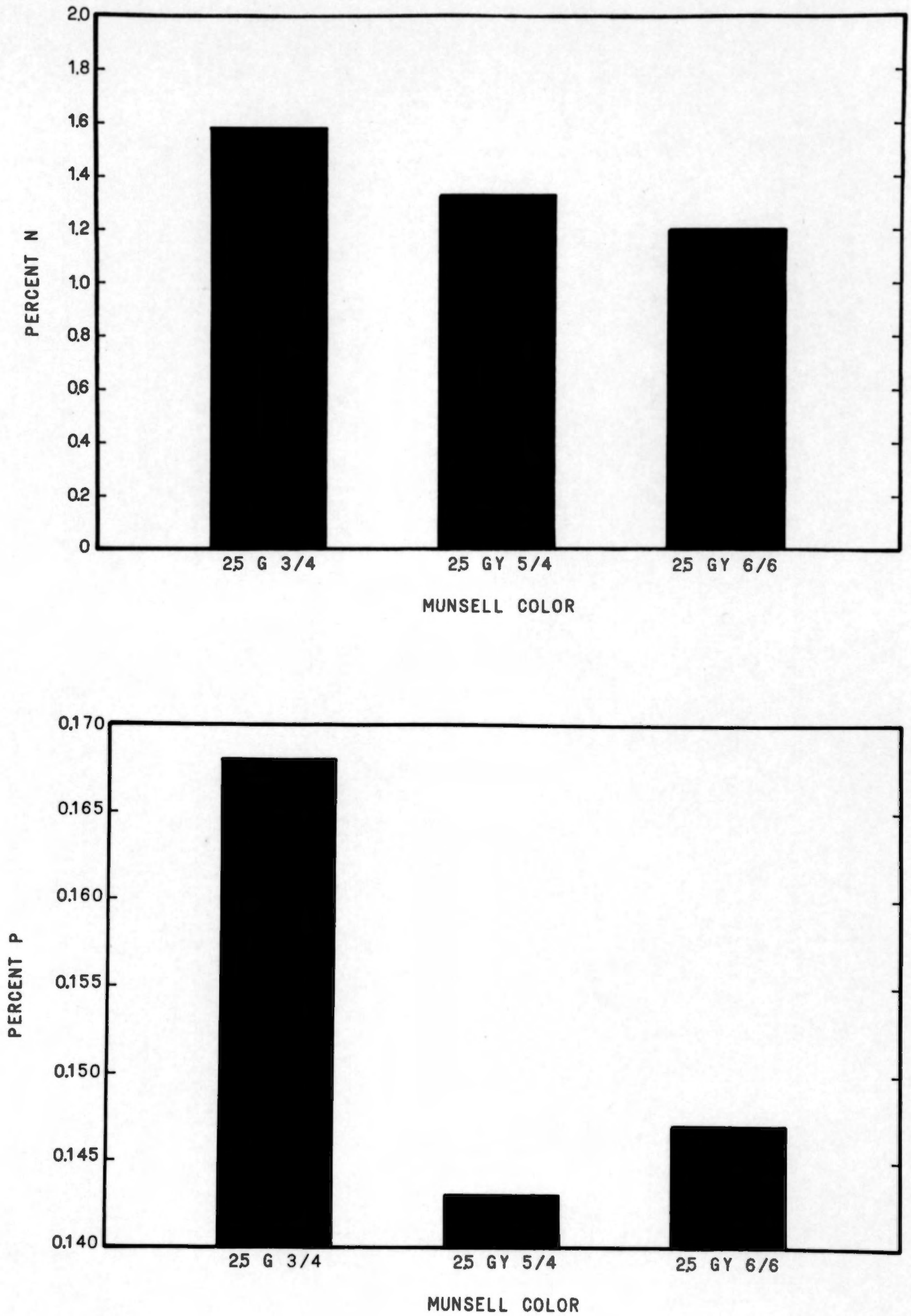



Figure 4. Munsell color means for foliar N and P in loblolly pine crown classes.

Foliar phosphorus in green crowns was significantly higher than that of the two yellower classes (Table 3). Although tree crowns in the yellow class had a slightly higher phosphorus level than those coded yellow-green (Figure 4), this difference was not statistically significant (Table 3).

Foliar potassium decreased stepwise from 0.44 percent in green crown classes to 0.41 and 0.38 percent in the yellow-green and yellow classes. Significant differences existed only between the green and yellow crown color classes (Table 3).

Foliar calcium and magnesium were not significantly different among crown color classes (Table 3). R-square values for the two elements were 0.06 and 0.11, respectively, the lowest of the foliar nutrient-crown color relationships (Appendix C, Table C-3).

The detection of nutrient levels in loblolly pine, especially nitrogen and phosphorus indicates that this method could be useful in determining areas that would respond to forest fertilization. Fertilizer applied to areas within the green and yellow crown classes may not yield adequate growth responses to justify costs. Trees in the green class had sufficient nutrients; fertilization should not be warranted. The yellow crown class was generally on disturbed sites, such as strip mines and old eroded fields. Although these trees were low in nutrients, the sites were limiting in other ways which would limit response. The greatest response will probably be obtained from trees in the yellow-green class on sites where low nutrient levels are the primary factors limiting growth.

These assumptions will need to be tested through designated experiments that will determine the aerial photo color unit(s) that will yield the greatest volume and/or financial gain from fertilization.

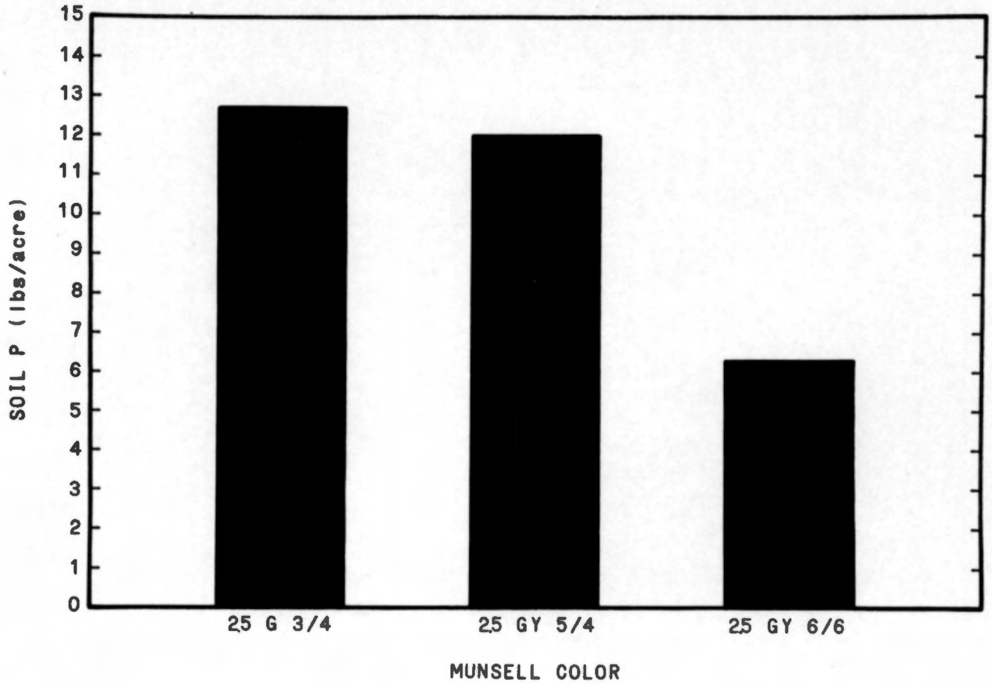
Crown Color-Soil Nutrient Relationships

In general, available soil phosphorus and potassium were higher in soils supporting trees having green crowns and decreased stepwise with increasing yellowing (Figure 5).

In the 0 to 4 inch (0 to 10.16 centimeter) soil samples phosphorus tested 5.3 pounds per acre (5.9 kilograms per hectare) for both the green and yellow-green color classes. Where foliage was yellow the phosphorus level was 3.3 pounds per acre (3.7 kilograms per hectare); however this decline was not statistically significant (Appendix C, Table C-2).

At the 4 to 8 inch (10.16 to 20.32 centimeter) depth soil phosphorus was: 7.4 pounds per acre (8.3 kilograms per hectare) for areas supporting green foliage, 6.7 pounds per acre (7.5 kilograms per hectare) for those supporting yellow-green foliage and 3.0 pounds per acre (3.3 kilograms per hectare) where crowns were yellow. The 3.7 pound (4.10 kilogram) difference between the yellow-green and yellow classes was significant (Appendix C, Table C-2).

Available soil potassium also decreased stepwise from green to yellow in both the 0 to 4 inch (0 to 10.16 centimeter) and 4 to 8 inch (10.16 to 20.32 centimeter) depths (Table 4). However, these differences were not statistically significant (Appendix C, Table C-2), and R-square values were extremely low (Appendix C, Table C-3).



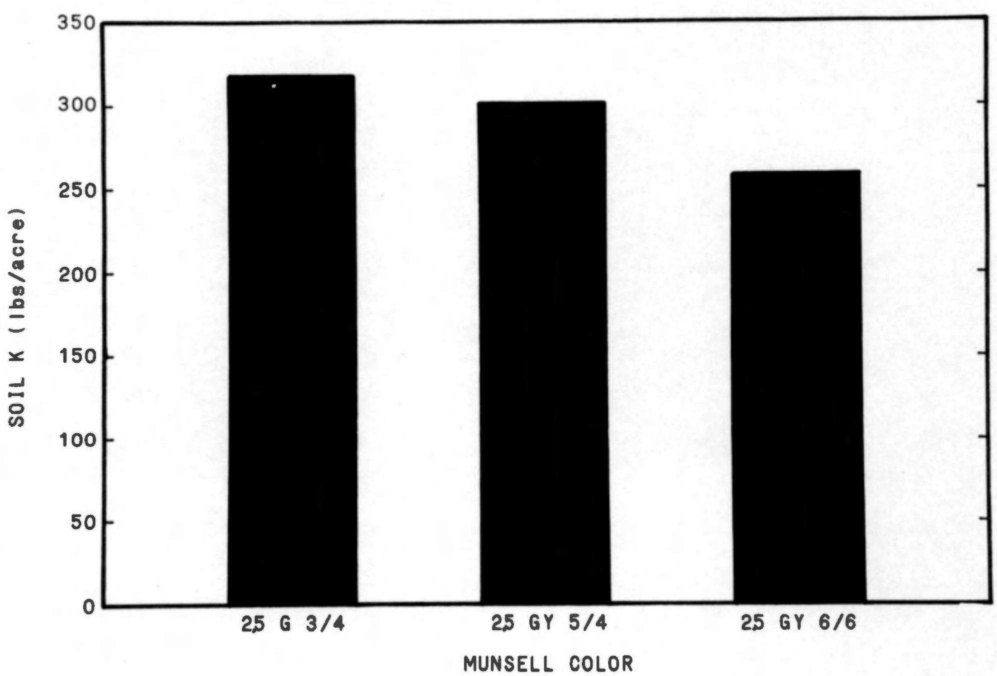




Figure 5. Munsell color means for total soil P and K in loblolly pine crown classes.

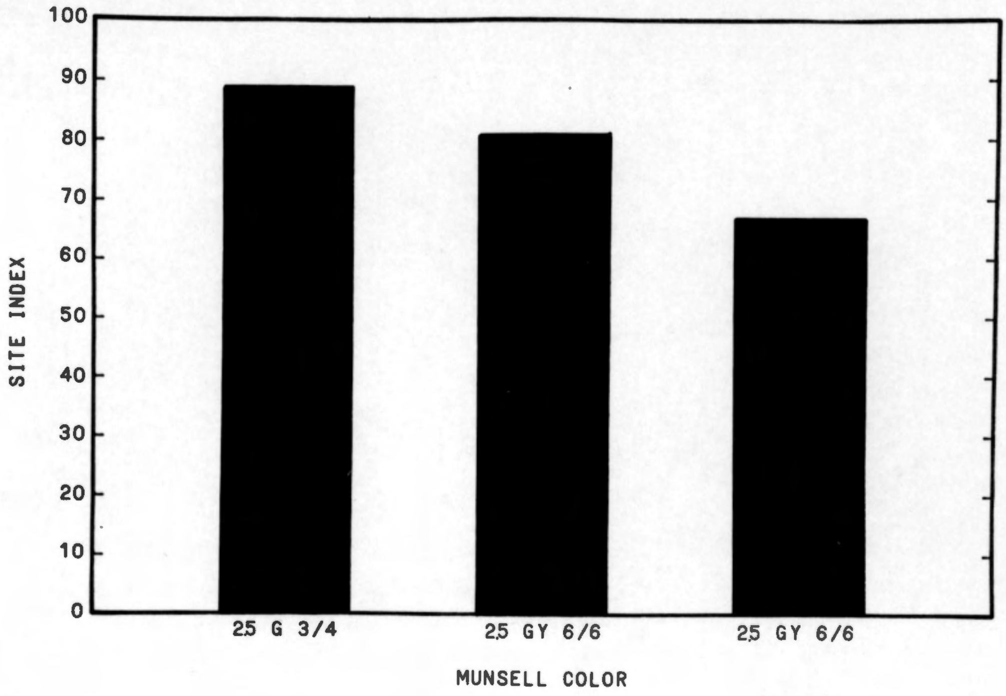
Table 4. Soil Nutrient and pH Means for Aerial Photo Color Units

| Munsell Color | 2.5 GY 6/6 | 2.5 GY 5/4 | 2.5 G 3/4 |
|---|---|---|---|
| Nutrient | → | Increasing Greenness | → |
| | Lbs./Acre (kg/ha) | | |
| P 0-4" | 3.3 (3.7) | 5.3 (5.9) | 5.3 (5.9) |
| P 4"-8" | 3.0 (3.3) | 6.7 (7.5) | 7.4 (8.3) |
| Total P | 6.3 (7.0) | 12.0 (13.4) | 12.7 (14.2) |
| K 0-4" | 138 (154.6) | 167.0 (187.1) | 177.0 (198.4) |
| K 4"-8" | 120 (134.5) | 133.0 (149.0) | 141.0 (158.0) |
| Total K | 258 (289.1) | 300 (336.1) | 318.0 (336.1) |
| pH 0-4" | 5.6 | 5.0 | 5.4 |
| pH 4"-8" | 5.6 | 5.1 | 5.2 |
| No. of Samples | 12 | 13 | 10 |

Crown Color-Site Index Relationship

Site index ranged from a high of 100 (base 50) in one of the green areas to a low of 40 in one of the yellowest crown classes. Average site index for the color classes were: 90 for the green, 82 for the yellow-green and 68 for the yellow (Figure 6). These averages were significantly different according to Duncan's Multiple Range Test (Appendix C, Table C-2). The R-square for site index (0.52) was relatively high (Appendix C, Table C-3).

These high correlations suggest that color aerial photographs could be useful to classify forest land productivity (site quality). Conventional methods of obtaining data necessary for such classification systems (site index, soil chemical and physical characteristics) are time consuming and expensive. This technique could eliminate a large portion of the field measurements required to make these classifications.



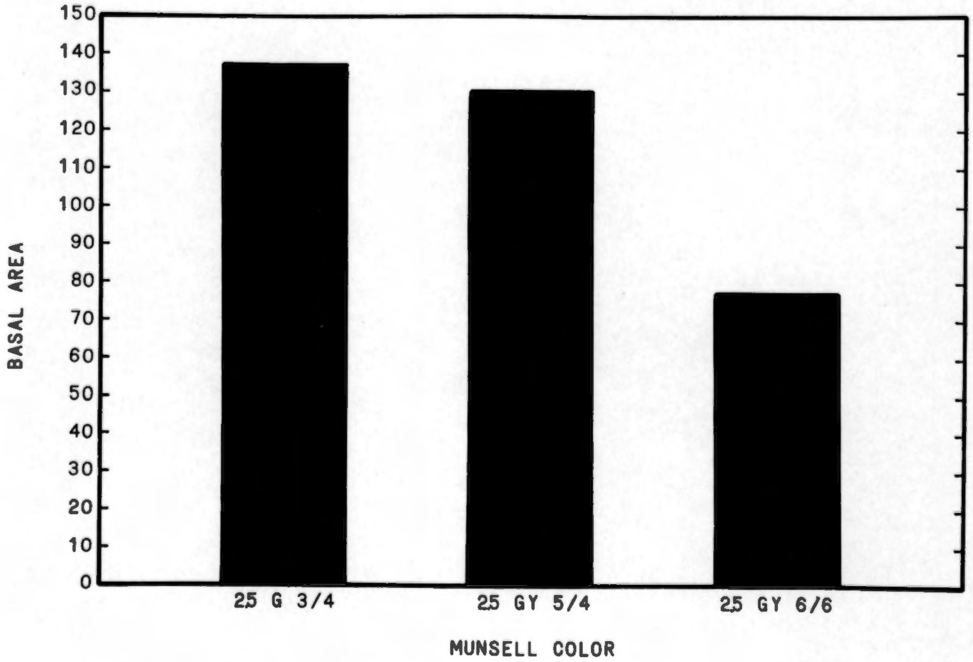




Figure 6. Munsell color means for site index and basal area in loblolly pine crown classes.

Crown Color-Basal Area Relationship

Basal area decreased slightly from 137 square feet per acre (31.45 square meters per hectare) in green areas to 130 square feet per acre (29.84 square meters per hectare) in areas supporting yellow-green crowns. The larger drop to 77 square feet per acre (17.67 square meters per hectare) in stands having yellow crowns was statistically significant (Table 5). The open crown canopies associated with these low basal areas were easily detected on most photographs (Figure 2, p. 21). The R-square (0.56) for the basal area-crown color relationship was the highest of the variables studied (Appendix C, Table C-3).

Table 5. Site Index, Basal Area and Growth (Last Five Years) Averages for Aerial Photo Color Units

| Munsell Color | 2.5 GY 6/6 | 2.5 GY 3/4 | 2.5 G 3/4 |
|---|---|---|---|
| Measure | ——→ Increasing Greenness ——→ | | |
| Site Index (Base 50) | 68 a | 82 b | 90 |
| Basal Area (Square feet per acre) | 77 a | 131 b | 137 b |
| Last 5 Years Growth (inches) | .74 a | .61 a | 1.02 b |

Note: Measurement averages followed by the same letter are not significantly different at the .05 level.

The significantly low basal area in the yellow-crowned stands would not allow sufficient volume gains from fertilization to warrant the cost. Inadequate stocking in these stands, and probably several other factors other than low nutrients, are responsible for total stand productivity. Greater gains from fertilization could be realized in more fully stocked stands in which nutrient deficiencies are the limiting growth factor.

# CHAPTER V

## SUMMARY AND CONCLUSIONS

Findings relevant to this study were:

1. Color aerial photographs taken from 5,000 feet (1,524 meters; scale of 1:10,000) provided the most definitive results and can be obtained with visibilities as low as ten miles (16.09 kilometers).

2. Color aerial photographs taken from 10,000 and 15,000 feet (3,048 and 4,572 meters) at a scale of 1:20,000 and 1:30,000 when visibility was ten miles (16.09 kilometers) had blueish-green color distortions that washed out differences that might have been caused by nutrient deficiencies.

3. The colors detected on loblolly pine plantations as viewed on color aerial photographs could be coded into three distinct Munsell color classes.

4. In general, foliar nitrogen, phosphorus and potassium were higher in the green crown class.

5. Basal area was significantly lower (.05 level) in the yellow crown class, a condition that was generally evident on the color photographs.

6. Positive correlations (significant at the .05 level) existed between increasing greenness and: (a) foliar nitrogen and (b) site index.

7. Soil phosphorus and potassium increased stepwise from yellow to green; however these differences generally were not statistically significant.

The detection of foliar nutrient levels and site index from color aerial photographs enable more efficient land classification and possibly more efficient use of fertilizers for increasing productivity.

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## LITERATURE CITED

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APPENDICES

## APPENDIX A

## DESCRIPTION OF SOILS

Cuthbert and Ruston soils, 15 to 25 percent slopes:

These soils are low in natural fertility and content of organic matter, and they are strongly acid to very strongly acid. These steep soils are susceptible to severe erosion. They have rapid surface runoff, slow to medium infiltration, and a low available moisture capacity. These extensive soils make up about 12.2 percent of Franklin County and occur chiefly in the western half. They are mostly in forest, their best use (Sherard et al., 1965).

Dickson Silt Loam, 2 to 5 percent slopes:

In this soil a mottled fragipan begins at a depth of about 2 feet. A few areas are severely eroded, and in these places the surface layer is generally slightly more clayey in texture. This soil is low in natural fertility and is very strongly acid. It has medium available water holding capacity. It is permeable to plant roots, air and water above the fragipan but very slowly permeable in the fragipan (True et al., 1968).

Linside Silt Loam:

This is a moderately well drained soil on first bottoms. Natural fertility and the content of organic matter are medium; this soil is slightly to medium acid. Tilth is good and available moisture capacity is high. Excess water is a moderate hazard (Sherard et al., 1965).

Mountview Cherty Silt Loam, 5 to 12 percent slopes:

The surface layer of this soil consists of 8 to 10 inches of brown, very friable cherty silt loam that contains a considerable amount of chert. This soil is medium in its ability to supply available water. These soils are low in natural fertility and are strongly acid to very strongly acid. They respond well to additions of fertilizer (True et al., 1968).

Ruston Pine Sandy Loam, 6 to 10 percent slopes:

This soil occupies Coastal Plain Uplands; it is characteristically deep and well drained. Although suited to moderately intensive cultivation, it is mostly in forests consisting of mixed hardwoods and pines. The available moisture capacity is moderate, surface runoff is moderate and the hazard of erosion is moderate to severe (Sherard et al., 1965).

Mine Pits and Dumps:

Numerous mine pits and spoil banks occur in the vicinity of Russellville and Belgreen, Alabama; the result of strip mining for iron ore. The material on the surface is a mixture of the original soil and underlying gravel, and in places limestone. Deep channels, unfilled pits and high, cone-shaped piles remain where seams of iron ore have been removed through strip mining.

In many places revegetation of this land type is difficult because the soil material is steep and unevenly placed. The hazard of erosion is severe, the available moisture capacity is low and the raw soil material is generally unfavorable for plant growth (Sherard et al., 1965).

Slickens:

This land type consists of deposits of fine textured sediments that were separated from iron ore when it was washed. These deposits are in natural basins and in low-lying areas that have been dammed. They are composed of yellowish-brown to dark reddish-brown silt or clay that is 2 to 10 feet deep or more. The surface layer swells on wetting and cracks badly on drying, but the underlying material remains wet during prolonged dry periods (Sherard et al., 1965).

## APPENDIX B

## COMPARISONS OF TEST VALUES FROM THE UNIVERSITY OF TENNESSEE AND NORTH CAROLINA STATE UNIVERSITY

Differences in foliar nutrient levels as determined by the two testing facilities were generally not significant (Table B-1). The University of Tennessee values for phosphorus, potassium, calcium and magnesium were slightly higher than values obtained at North Carolina State, while foliar nitrogen was higher in the North Carolina State test. Although results varied somewhat between the two facilities the trends of all elements were generally the same. Some of the differences were likely due to the analysis of samples collected separately, rather than the subdivision of a single sample.

Differences in soil test results between the two test facilities (Table B-2) can be largely attributed to the use of different extractant methods and a different soil to solution ratio. Rogers (1979) found that the new Mehlich extractant method used by North Carolina State University was slightly less effective than the Tennessee procedure. He further found that as the soil to extracting solution ratio decreased the amount of the nutrient extracted increased. The Tennessee procedure uses a 1:4 soil to extractant ratio while the new Mehlich method uses a 1:10 ratio (Rogers, 1979).

Soil test procedures at most laboratories are designed to measure available nutrients for the growth of agricultural crops and not forest trees. Correlation of soil test values to the growth of forest trees would provide more meaningful results to foresters.

Table B-1. Mean Values of Foliar Nutrient Levels Determined from Two Test Facilities

| Munsell Color | 2.5 GY 6/6 | | 2.5 GY 5/4 | | 2.5 G 3/4 | |
|---|---|---|---|---|---|---|
| Nutrient | → Increasing Greenness → | | | | | |
| | U. T. | (N. C. St.) | | | | |
| | (Percent) | | | | | |
| N | 1.20 | (1.38)* | 1.33 | (1.42) | 1.58 | (1.64) |
| P | 0.15 | (0.14) | 0.14 | (0.14) | 0.17 | (0.14)* |
| K | 0.38 | (0.38) | 0.41 | (0.36)* | 0.44 | (0.41) |
| Ca | 0.31 | (0.27) | 0.27 | (0.18)* | 0.27 | (0.19)* |
| Mg | 0.10 | (0.11) | 0.09 | (0.10) | 0.09 | (0.10) |

*Significantly different at the .05 level.

Table B-2. Mean Values for Soil Nutrient Levels Determined from Two Test Facilities

| Munsell Color | 2.5 GY 6/6 | | 2.5 GY 5/4 | | 2.5 G 3/4 | |
|---|---|---|---|---|---|---|
| Nutrient | → | | Increasing Greenness | | → | |
| | | | lbs/acre (kg/ha) | | | |
| P 0-4" | | | | | | |
| U.T. | 3.3 | (3.7) | 5.3 | (5.9) | 5.3 | (5.9) |
| N.C. St. | 5.1 | (5.7) | 2.8 | (3.1) | 5.8 | (6.5) |
| P 4-8" | | | | | | |
| U.T. | 3.0 | (3.3) | 6.7 | (7.5) | 7.4 | (8.3) |
| N.C. St. | 9.5 | (10.6) | 1.5 | (1.7) | 4.0 | (4.5) |
| K 0-4" | | | | | | |
| U.T. | 138.0 | (154.6) | 167.0 | (187.1) | 177.0 | (198.4) |
| N.C. St. | 178.3 | (199.7) | 200.0 | (224.0) | 196.2 | (219.8) |
| K 4-8" | | | | | | |
| U.T. | 120.0 | (134.5) | 133.0 | (149.0) | 141.0 | (158.0) |
| N.C. St. | 165.4 | (185.3) | 165.0 | (184.8) | 169.1 | (189.4) |

## APPENDIX C

## STATISTICAL ANALYSIS

Table C-1. Analysis of Variance Procedure

| Source | D.F. | S.S. | M.S. | F |
|---|---|---|---|---|
| Foliar-N | | | | |
| Model | 2 | 0.7691 | 0.3846 | 19.54* |
| Error | 32 | 0.6298 | 0.0197 | |
| Corrected Total | 34 | 1.3989 | | |
| Foliar-P | | | | |
| Model | 2 | 0.0039 | 0.0019 | 3.47* |
| Error | 32 | 0.0177 | 0.0006 | |
| Corrected Total | 34 | 0.0215 | | |
| Foliar-K | | | | |
| Model | 2 | 0.0182 | 0.0090 | 4.5* |
| Error | 32 | 0.0701 | 0.0022 | |
| Corrected Total | 34 | 0.0883 | | |
| Foliar-Ca | | | | |
| Model | 2 | 0.0148 | 0.0074 | 0.96 |
| Error | 32 | 0.2464 | 0.0077 | |
| Corrected Total | 34 | 0.2612 | | |
| Foliar-Mg | | | | |
| Model | 2 | 0.0014 | 0.0007 | 1.96 |
| Error | 32 | 0.0116 | 0.0004 | |
| Corrected Total | 34 | 0.0130 | | |
| Soil-P 0-4 inches | | | | |
| Model | 2 | 30.6355 | 15.3178 | 2.70 |
| Error | 32 | 181.5359 | 5.6730 | |
| Corrected Total | 34 | 212.1714 | | |
| Soil-P 4-8 inches | | | | |
| Model | 2 | 129.0022 | 64.5011 | 4.64* |
| Error | 32 | 445.1692 | 13.9115 | |
| Corrected Total | 34 | 574.1714 | 13.9115 | |
| Soil-P (total) | | | | |
| Model | 2 | 283.919 | 141.959 | 4.53* |
| Error | 32 | 1002.767 | 31.336 | |
| Corrected Total | 34 | 1286.686 | | |

Table C-1 (continued)

| Source | D.F. | S.S. | M.S. | F |
|---|---|---|---|---|
| Soil-K 0-4 inches | | | | |
| Model | 2 | 9289.707 | 4644.853 | 1.04 |
| Error | 32 | 143007.436 | 4468.982 | |
| Corrected Total | 34 | 152297.143 | | |
| Soil-K 4-8 inches | | | | |
| Model | 2 | 2507.363 | 1253.681 | 0.51 |
| Error | 32 | 78766.923 | 2461.466 | |
| Corrected Total | 34 | 81274.286 | | |
| Soil-K (total) | | | | |
| Model | 2 | 21335.311 | 10667.656 | 0.88 |
| Error | 32 | 388818.974 | 12150.593 | |
| Corrected Total | 34 | 410154.286 | | |
| Soil-pH 0-4 inches | | | | |
| Model | 2 | 1.670 | 0.835 | 3.65* |
| Error | 32 | 7.325 | 0.229 | |
| Corrected Total | 34 | 8.995 | | |
| Soil-pH 4-8 inches | | | | |
| Model | 2 | 1.606 | 0.803 | 5.92* |
| Error | 32 | 4.341 | 0.136 | |
| Corrected Total | 34 | 5.947 | | |
| Site Index | | | | |
| Model | 2857.853 | 1278.926 | 17.55* | |
| Error | 32 | 2332.147 | 72.879 | |
| Corrected Total | 34 | 4890.000 | | |
| Basal Area (Sq. ft./A.) | | | | |
| Model | 2 | 19882.077 | 9941.038 | 16.53* |
| Error | 26 | 15635.165 | 601.352 | |
| Corrected Total | 28 | 35517.241 | | |

*Probability greater than F less than .05.

Table C-2. Duncan's Multiple Range Test

| Variable | Color | Mean | Grouping |
|---|---|---|---|
| Foliar-N | | | |
| | Green | 1.58 | A |
| | Yellow-Green | 1.33 | B |
| | Yellow | 1.20 | C |
| Foliar-P | | | |
| | Green | 0.17 | A |
| | Yellow | 0.15 | B<br>B |
| | Yellow-Green | 0.14 | B |
| Foliar-K | | | |
| | Green | 0.44 | A<br>A |
| | Yellow-Green | 0.41 | A B<br>B |
| | Yellow | 0.38 | B |
| Foliar-Ca | | | |
| | Yellow | 0.31 | A<br>A |
| | Green | 0.27 | A<br>A |
| | Yellow-Green | 0.27 | A |
| Foliar-Mg | | | |
| | Yellow | 0.10 | A<br>A |
| | Green | 0.09 | A<br>A |
| | Yellow-Green | 0.09 | A |
| Soil-P 0-4 inches | | | |
| | Yellow-Green | 5.31 lbs./A | A<br>A |
| | Green | 5.30 lbs./A | A<br>A |
| | Yellow | 3.33 lbs./A | A |

Table C-2 (continued)

| Variable | Color | Mean | Grouping |
|---|---|---|---|
| Soil-P 4-8 inches | | | |
| | Green | 7.40 lbs./A | A |
| | | | A |
| | Yellow-Green | 6.70 lbs./A | A |
| | Yellow | 3.00 lbs./A | B |
| Soil-P (Total) | | | |
| | Green | 12.70 lbs./A | A |
| | | | A |
| | Yellow-Green | 12.00 lbs./A | A |
| | Yellow | 6.33 lbs./A | B |
| Soil-K 0-4 inches | | | |
| | Green | 177.00 lbs./A | A |
| | | | A |
| | Yellow-Green | 167.70 lbs./A | A |
| | | | A |
| | Yellow | 138.33 lbs./A | A |
| Soil-K 4-8 inches | | | |
| | Green | 141.00 lbs./A | A |
| | | | A |
| | Yellow-Green | 133.10 lbs./A | A |
| | | | A |
| | Yellow | 120.00 lbs./A | A |
| Soil-K (Total) | | | |
| | Green | 318.00 lbs./A | A |
| | | | A |
| | Yellow-Green | 300.80 lbs./A | A |
| | | | A |
| | Yellow | 258.30 lbs./A | A |
| Soil-pH 0-4 inches | | | |
| | Yellow | 5.56 | A |
| | | | A |
| | Green | 5.36 | A B |
| | | | B |
| | Yellow-Green | 5.05 | B |

Table C-2 (continued)

| Variable | Color | Mean | Grouping |
|---|---|---|---|
| Soil-pH 4-8 inches | | | |
| | Yellow | 5.57 | A |
| | | | A |
| | Green | 5.26 | A B |
| | | | B |
| | Yellow-Green | 5.06 | B |
| Site Index | | | |
| | Green | 90 | A |
| | Yellow-Green | 82 | B |
| | Yellow | 68 | C |
| Basal Area | | | |
| | Green | 137 (Sq. ft./A) | A |
| | | | A |
| | Yellow-Green | 131 (Sq. ft./A) | A |
| | Yellow | 77 (Sq. ft./A) | B |

Note: Means with the same letter are not significantly different. Alpha Level = .05.

Table C-3. R-Square Values

| Variable | R-Square |
|---|---|
| Foliar-N | 0.55 |
| Foliar-P | 0.18 |
| Foliar-K | 0.21 |
| Foliar-Ca | 0.06 |
| Foliar-Mg | 0.11 |
| Soil-P 0-4 inches | 0.14 |
| Soil-P 4-8 inches | 0.22 |
| Soil-P (Total) | 0.22 |
| Soil-K 0-4 inches | 0.06 |
| Soil-K 4-8 inches | 0.03 |
| Soil-K (Total) | 0.05) |
| pH 0-4 inches | 0.19 |
| pH 0-8 inches | 0.27 |
| Site Index | 0.52 |
| Basal Area | 0.56 |

Alpha Level = .05.

VITA

Alan D. Lyons was born in Mobile, Alabama, on April 16, 1956. His family moved to Hendersonville, Tennessee, in 1962 where he attended elementary schools, and was graduated from Hendersonville High School in June 1974. The following September he entered Volunteer State Community College, Gallatin, Tennessee. He dropped out of school in December of 1975 and worked as a garbage collected for the next eight months. In August of 1976, he transferred to Western Kentucky University, Bowling Green, and the following March of 1977 he transferred to The University of Tennessee, Knoxville, where he received a Bachelor of Science Degree in Forest Resource Management in June of 1979. During the summer of 1979, he was employed as a student intern with Champion Timberlands, Waynesboro, Tennessee. In September of 1979, he accepted a research assistantship in the Department of Forestry, Wildlife, and Fisheries, and entered The University of Tennessee, Knoxville, Graduate School.