Estimation of leaf area of Loblolly pine needles by new rapid method

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Abstract

The methods developed to determine total needle surface area of pine trees are time-consuming, require expensive laboratory instrumentation, and cumbersome under field conditions. Needle surface area and leaf area index of Loblolly pines (*Pinus taeda* L.) were investigated using three approaches namely the Photo-Electronic method, Johnson's method and the Shivaj's method. The Photo-Electronic method was generally not effective for determining needle surface area. Johnson's method and the Shivaji's rapid method produced needle surface area values closer to the actual values than the Photo-Electronic method. There was a highly significant correlation ($r^2 = 0.99$) between the Johnson and Shivaji methods. Although the Shivaji's method produced slightly lower leaf area values than Johnson's method, there were no significant differences observed between the two methods. The simplicity of the proposed (Shivaji's rapid) method suggests that it has great promise for predicting needle surface area, and consequently the leaf area index of pine trees.

1 Introduction

Research on the efficiency of intercepted solar radiation and utilization by vegetative canopies, requires frequent measurements of leaf area and leaf area index are important biophysical descriptor of crop canopies, and are important parameters used routinely in forest ecology and tree physiology (Johnson 1984). Because accurate measurements of leaf area are laborious and time consuming, numerous direct and indirect methods of measuring leaf area for various crops have been developed (Hatfield et al. 1978, Marshall 1968, Johnson 1984). Kvet and Marshall (1971) characterized the methods into two broad categories: estimation methods that employ a mathematical relationship between leaf characteristics, and leaf area planimetric methods including photo-electric techniques. The glass bead technique described by Thompson and Leyton (1971) is another approach of surface area estimation. These methods vary greatly in their accuracy, precision, bias and ease of measurements.

The method proposed by Johnson (1984) hereinafter referred to as Johnson's method, requires a very high degree of precision in measurements. Hence, it is potentially vulnerable to serious errors basically due to two major problems: (i) the volume measurements of displaced water at 20 °C has to be very precise, to the hundredth of a cm^3, and (ii) the measurement of cumulative lengths of all needles has to be very precise, to the hundredth of a mm. Therefore, this method requires some special skills in measuring the volumes and the cumulative lengths to avoid serious errors. Also, additional problems may arise when the needles are not tied loosely before measurement. In such cases, the sample needle-bundles may trap a considerable amount of air bubbles which will increase the volume measurement readings considerably compared to the true measurements. These result in serious efforts, and Johnson (1984) cautioned against these flaws. The temperature of water for measuring the volume displacement is critical; it has to be maintained at 20 °C. In conditions where maintenance of this constant temperature is not possible, it adds significant efforts in volume readings.

The method proposed in this study for pine needle surface area determination is based on the concept that there is a definite and constant relationship between density and the volume for all pine needles. Johnson's method was based on the assumption that a pine needle can be represented by a segment of a cylinder. His assumption was primarily derived from the findings reported by Madgwick (1964) for red pine fascicle shape where most of them taper in the terminal few millimeters of the needle, for radiata pine (Wood 1971), and Scottish pine (Rutter 1957). However, while making approximations (i.e. assuming a cylindrical shape of the pine fascicle), Madgwick (1964) noted that most of the taper occurred in the terminal few millimeters of the needle circumference, 2 mm from the tip and averaged 77 % of the mid-length. From this, it is obvious that at least for 23 % of the cases, the results were false. The needle geometry is also a function of climatic effects and the genetic make-up of pine species, and hence the species variations also cannot be left unaccounted for. Johnson's and other methods which produce results based on these assumptions can be erroneaous, and will produce under or over estimation. They may also fail to reveal the accurate needle surface areas. Previously proposed methods (Johnson 1984, Beets 1977) also rely heavily upon the use of the volume of water (at 20 °C) displacement by pine needles. This usually is a prime source of potential error because of the fresh needle volume which changes its character depending upon its water content, species variations, and other seasonal as well as regional variations.

The methods developed so far to determine total needle surface area of pine trees are time-consuming and require expensive laboratory instrumentation, and are cumbersome under field conditions. The objectives of this research were: (i) to estimate the total needle surface area of Loblolly Pine (*Pinus taeda* L.) by two approaches and a new procedure using growth parameters and (ii) to examine relationships between the proposed and the existing procedures for estimating total needle surface area.

2 Materials and methods

The study was conducted in young pine plantations (3 to 5 year old) located at 32.5°N and 85.5°W, during mid-June, 1987 and 1988, at the USDA-Southern Forest Research Station, Auburn University, Auburn, Alabama. The pine trees from each observation site were cut and the needles were separated. Ten percent of the needles of each tree were used to determine the leaf area using an area meter, and a video screen monitor for measurement displays.

The calculation of total needle surface area according to Johnson's method required the determination of the cumulative needle length of all needles in the sample, volume of water displaced by the needles, and the number of needles per fascicle. Needle length was measured from top of the basal sheath to the tip. The needles were cut at the basal sheath prior to determining the volume. Individual needle lengths were summed to give the cumulative length of needles in each sample. These three observations were used to compute the total needle surface area using the following formula given by Johnson (1984):

$$A = 2L\,(1 + p/n)\,(Vn / p\,L)^{0.5}$$

The above equation provides the total surface area. In this equation, **A** is the total surface area (cm^2), **L** is the total cumulative length (cm), **n** is the number of needles per fascicle, and V is the volume of water (cm^3, at 20 °C) displaced by needles. This is similar to the model developed by Beets (1977) to estimate total leaf area of whole fascicle of Radiata Pine needles. However, it required sub-sampling (20–30 fascicles per tree) for fascicle volume, dry weight and length, mean shape coefficient for needles, and number of fascicles on tree of interest. In the photo-electronic method, the fascicles were separated from the individual pine trees and 10 % of the total fascicles were used each time for leaf area measurement. The separated fascicles (needles) were placed on a transparent plastic conveyor belt and the cumulative area (cm^2) of all the needles were measured electronically by LI-COR LI 3000 surface area meter.

The "Shivaji's proposed" method requires the determination of the cumulative length of all the fascicles in the sample, the oven dried weight of the fascicle sample, and the number of needles per fascicle. This procedure is similar to Johnson's method except that it requires the dry weight of needles instead of volume of water displaced. The pine constant (**Pc**) is a constant derived from ratioing volume to the oven dried weight of needles of the sample for which the total surface area determination is desired.

Due to the geometric similarities in the pine needle geometry, this constant should be similar for different pine varieties. Hence, the constant (1.537) may be used for all pine varieties as far as the needle geometry is concerned. This constant for pine geometric configuration is not influenced by age, size of needle, plant varieties or any other non-geometrical parameters of the pine needles. The "Shivaji's proposed model" is derived by replacing '**V**' in equation (1) by '**NDW**', and by including **Pc**. The proposed model for needle surface area is expressed as:

$$A = 2L\,Pc(1 + p/n)\,(NDWn/p\,L)^{0.5}$$

where **A** is the total surface area (cm^2), **L** is the total cumulative length (cm), **n** is the number of needles per fascicle, **NDW** oven dried weight of needles (g), and **Pc** is the pine constant which is a ratio of volume of needles (cm^2) to its oven dried weight (g). The data were analyzed using REG procedure in the Statistical Analysis System (SAS) software (SAS Institute, 1985) to determine relationships between predicted and measured surface areas of Loblolly Pine needles.

3 Results and discussion

The surface areas of needles obtained from the photo-electronic planimetric procedure were frequently higher compared to Johnson's or the proposed method, and the results are presented in Table 1. This method consistently gave more needle surface area than the Johnson or proposed methods. Overall, needle surface area was higher by 32.2 % and 32.1 % compared to the Johnson's and "Shivaji's proposed" methods, respectively.

The calculated total surface area of the sample needles as calculated using Johnson's model are presented in Table 1. This method gave 32.2 % lower needle surface area than did the photo-electronic planimetric method. The reasons for this discrepancy may be due to the overlap of pine needles while passing through the screen on the plastic conveyor belt. In addition, the shadowing and the reflections due to needle geometry might contribute to over estimation of needle surface area as compared to the actual area values measured by the photo-electronic procedure. Therefore, Johnson's procedure should result in calculated surface area values closer to the actual surface area compared to the photo-electronic planimetric method. However, the accuracy of Johnson's method largely depends on the degree of needle taper and the ability to determine and measure the representative needle parameters.

Table 1. Pine needle surface area determination by different methods for the different study sites.

		Pine Needle			Methods of Leaf Area Determination		
Tree Number	Cumul. Length (cm)	Volume of Displaced Water (cm^3)	Dry Weight (g)	Pine Constant	Photo-Electronic (m^2)	Johnson's (m^2)	Shivaji's Proposed (m^2)
Site – I NA 1							
1	222.09	1200	502.0	1.540	3.04	2.06	2.05
2	223.32	1080	451.0	1.550	2.82	1.96	1.95
3	87.46	410	169.0	1.560	1.048	0.76	0.75
4	209.32	1400	643.0	1.480	3.76	2.16	2.25
5	128.76	500	211.0	1.530	1.38	1.01	1.01
6	192.58	2680	1295.0	1.430	6.6	2.87	3.07
7	116.32	630	219.0	1.690	1.17	1.08	0.98
8	366.62	1850	958.0	1.390	4.29	3.29	3.64
9	144.84	630	283.0	1.490	1.26	1.21	1.24
Site – II NA 2							
1	70.89	340	132.0	1.600	0.86	0.62	0.59
2	106.37	540	224.0	1.550	1.33	0.95	0.94
3	24.97	110	42.2	1.590	0.26	0.21	0.20
4	72.15	280	139.0	1.420	1.04	0.56	0.61
5	1.76	50	28.7	1.310	0.21	0.03	0.04
6	10.03	40	20.6	1.380	0.08	0.08	0.08
7	14.89	80	25.5	1.750	0.17	0.13	0.12
8	8.1	30	10.7	1.650	0.06	0.06	0.05
9	59.24	150	148.0	1.010	0.85	0.37	0.57
Site – III / Highway 54							
1	31.94	200	60.0	1.820	0.49	0.32	0.27
2	89.72	445	184.0	1.510	1.15	0.79	0.79
3	102.27	510	215.0	1.540	1.31	0.91	0.91
4	43.49	160	68.7	1.520	0.45	0.33	0.33
5	133.84	540	248.0	1.47.0	1.56	1.07	1.12
6	21.91	120	30.0	2.000	0.22	0.20	0.15
7	62.12	310	118.0	1.620	0.82	0.55	0.52
8	170.59	910	414.0	1.480	2.28	1.57	1.63
9	151.61	810	320.1	1.590	2.12	1.40	1.35
Site – IV / Pill Baptist							
1	54.34	230	98.0	1.530	0.66	0.44	0.45
2	18.03	60	42.6	1.180	0.16	0.13	0.17
3	6.35	20	11.2	1.350	0.04	0.04	0.05
4	9.91	40	16.7	1.530	0.09	0.08	0.08
5	9.35	40	15.5	1.580	0.08	0.07	0.07
6	32.78	170	62.4	1.650	0.44	0.29	0.27
7	42.6	180	73.2	1.570	0.43	0.35	0.34
8	38.6	170	64.0	1.630	0.21	0.32	0.30
9	11.2	80	23.7	1.820	0.18	0.12	0.10

The relationship of needle dry weights vs. the corresponding volume of water displaced, and needle dry weights vs. needle cumulative lengths are presented in Figures 1 and 2.

These results show a linear relationship and high correlations with r^2 of 0.98 and 0.95, respectively as follow.

Needle Dry Weight (Y) vs. Volume of Displaced Water (X):

$$Y = 0.4644\ X,\ r^2 = 0.985$$

Needle Dry Weight (Y) vs. Needle Cumulative Length (X):

$$Y = 2.314\ X,\ r^2 = 0.952$$

There was also a linear relationship between the volume of water displaced by the sample needles and the needle cumulative lengths (Fig. 3) which was highly correlated (r^2 = 0.965).

Volume of Displaced Water (Y) vs. Needle Cumulative Length (X):

$$Y = 5.0899\ X,\ r^2 = 0.965$$

There was a high correlation between the volume of water displaced (VDW) and the needle dried weight (NDW) of each sample. Due to the high correlation between VDW and NDW, VDW/NDW values for each observation were calculated and their square roots for all four study sites were averaged (Table 1) as the pine constant (**Pc**). The average of the resulting pine constant based on observations (1.537) was used as input to the proposed model.

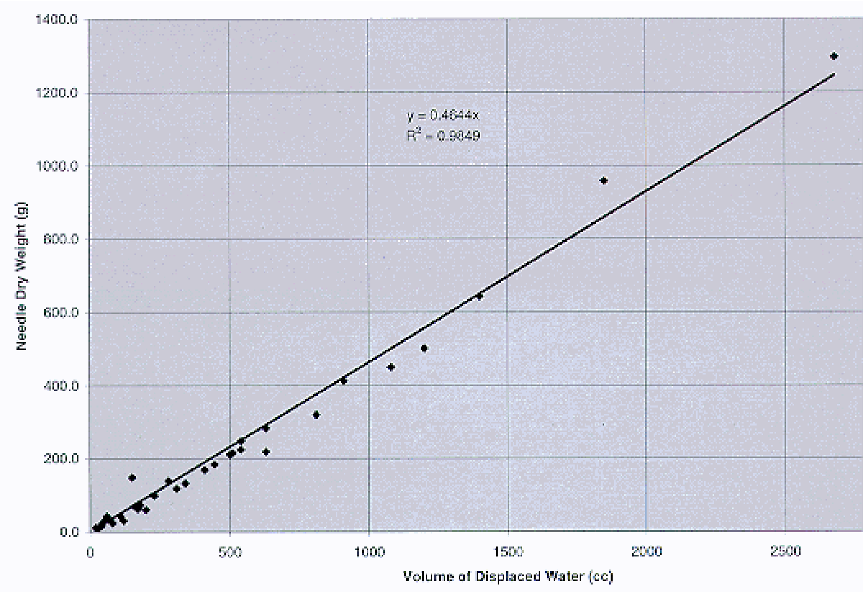

Figure 1. Relationship between needle dry weight and the volume of displaced water.

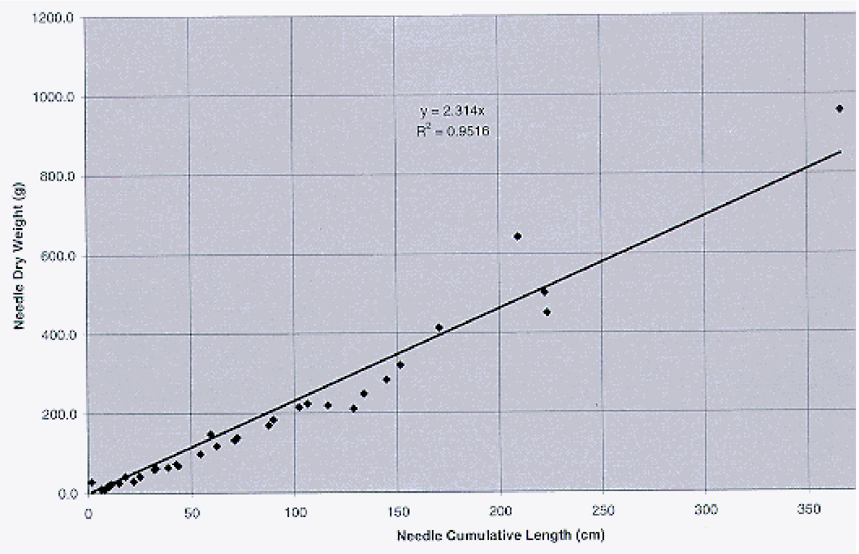

Figure 2. Relationship between needle cumulative length and needle dry weight.

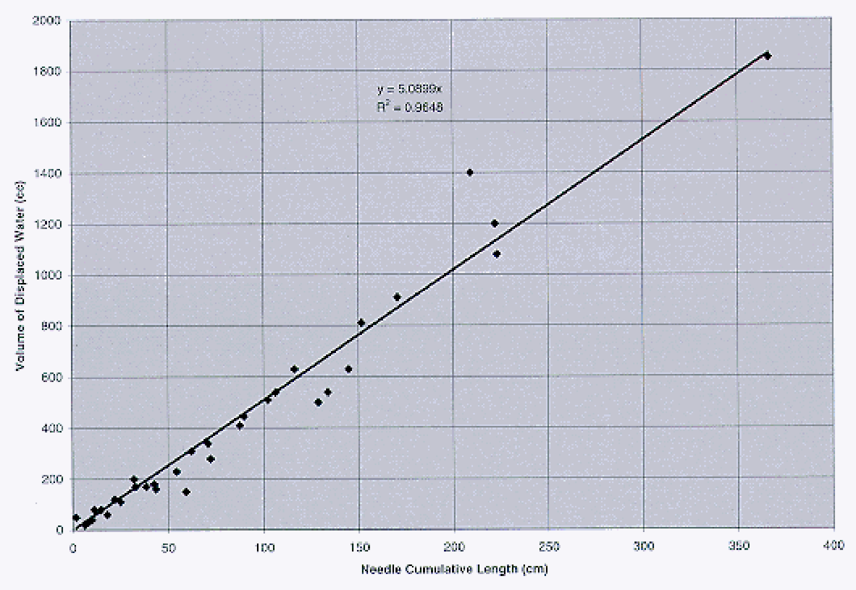

Figure 3. Relationship between needle cumulative length and volume of displaced water.

A comparison of the total surface area of the sample needles resulting from the was performed. The resulting relationship "Shivaji's proposed" and Johnson models is shown graphically in Figure 4.

There was a very high correlation between the two methods with correlation coefficients (r^2) of 0.995, 0.955, 0.999, and 0.985, for sites NA-1, NA-2, High Way-54, and Pill-Baptist, respectively. Figure 4 shows the relationship of data for all the four sites combined. The regression equation is as follow:

Shivaji's Method (Y) vs. Johnson's Method (X):

$$Y = 1.0587\,X - 0.0283,\ r^2 = 0.994$$

The highly significant correlation ($r^2 = 0.994$) between these two models clearly indicated that the results obtained are not significantly different from each other at 0.01 level of probability.

The advantage of the "Shivaji's proposed" method over Johnson's and other methods is that the individual needles or the sample needle volumes are not required for the calculation of the needle surface area. Instead, the oven dry matter, which is the most commonly recorded and easily measured variable, can be reliably used. The only measurement required is the cumulative length of the needle which could be measured while the needle fascicles are intact. The oven dry weight required by the proposed method which is inherently more accurate, easily determined and involve only the use of a simple weighing balance without any spe-

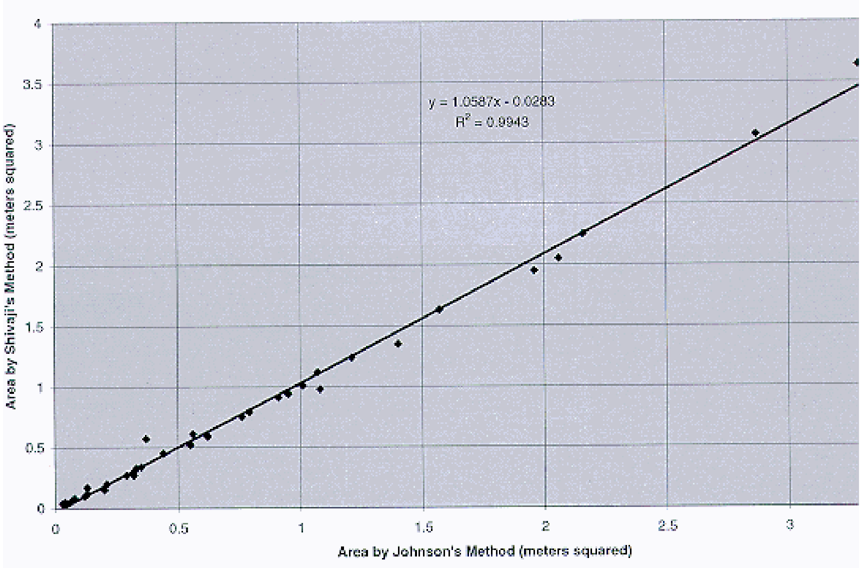

Figure 4. Relationship between needle area calculated by Johnson's method and by Shivaji's proposed method.

cial skills, training, techniques or additional equipment. This eliminates the chances of inherent errors in measurements associated with Johnson or photo-electronic methods. The "Shivaji's proposed" method is much simpler to use than Johnson's procedure for pine needle surface area determinations. Johnson (1984) clearly pointed out that the accuracy of his method would largely depend on the degree of needle taper and the ability of the investigator to determine and measure representative needle parameters. Because of this, the "Shivaji's proposed" method is inherently more accurate and would tend to be more reliable. Further, the environmental conditions, and hence the needle geometry do not influence **Pc**, hence, **Pc** may be useful for different species of pine growing in different environments and locations. The pine constant used in the "Shivaji's proposed" model, theoretically, should be applicable to all pine species (short-needle and other common species), and thus very useful for needle surface area determinations.

The " Shivaji's proposed" method is based on the easily measured and more stable parameter such as the oven dry weight of needles. Unlike Johnson's and many other methods, it does not depend upon needle volume which is quite variable as the prime parameter. In the "proposed" method, these variations and potential sources of error have been further reduced through the use of a factor called pine constant, which makes the "proposed" model much more versatile and reliable.

4 Summary

The determination of Loblolly Pine needle surface area was carried out using two established methods and a modified method. The photo-electronic method was generally not very effective in determining pine needle surface area. Johnson's method and the " Shivaji's proposed" method generated needle surface area values which were much closer to each other than the other method. There was a highly significant correlation ($r^2 = 0.99$) between the Johnson method and the "proposed" method. Although the " Shivaji's proposed" method produced slightly lower values than Johnson's method, there were no significant differences observed between the two methods at a 0.01 level of probability. The relative simplicity of the " Shivaji's proposed" model to the other methods suggests that it may be better for predicting needle surface area, and consequently the leaf area index of pine trees.

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