SURFACE AREA OF NEEDLES IN *PINUS RADIATA* — VARIATION WITH RESPECT TO AGE AND CROWN POSITION

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ABSTRACT

Needle weight per unit surface-area was determined for **Pinus radiata** D.Don fascicles by coating needles with glass balls suspended in a fluidised bed. Within a tree-crown, weight/area of needles increased with age and declined strongly with increasing shade. In an unthinned canopy the decline from sun- to shade-crown was 31%, while in an open thinned canopy it was 26%. Fascicle position within the crown, therefore, requires recognition when determining foliage surface-area from needle mass by the method described.

INTRODUCTION

It has long been recognised that gas-exchange of plants is best expressed on the basis of foliage surface-area, especially as this opens the way to calculating component resistances in the diffusive pathway between atmosphere and leaf. Transpiration rates, for example, are often used to compute estimations of stomatal diffusive resistance or conductance provided leaf area is known. The assessment of leaf area has been reviewed by Kvet and Marshall (1971). Most techniques are planimetric, and photo-electric developments have greatly simplified leaf-area determination for broad-leaved species with leaves approximating to flat surfaces. There is no simple solution to leaf-area determination of needle-shaped conifer leaves. Projected surface-area can be determined by photo-electric planimeter (e.g., Ludlow and Jarvis, 1971) but total surface-area is commonly calculated from dimensions treating needles as geometric bodies. Kerner *et al.* (1977) computed needle surface-area for *Picea abies* (L.) Karst in a variable geometric model using linear dimensions. They found it necessary to account for sun-shade leaf adaptation since "adaptation of the needles to the changing environment within the crown space is extensive and all their anatomical and morphological characteristics are involved".

Total crown foliage can usually be readily obtained only via the needle dry weight, and where sun/shade differentiation exists a considerable shift in weight/surface-area ratio is to be expected (e.g., Larcher, 1975; Schulze *et al.,* 1977).

In conjunction with field gas-exchange studies using climatised cuvettes (Benecke, 1980) needle surface-area was determined using the method of Thompson and Leyton

(1971). An opportunity arose thereby to sample foliage of different ages from sun and shade positions in the crown of *P. radiata* trees for determination of the weight surface-area ratio.

METHODS AND MATERIAL

Needle fascicles were collected in March 1979 from *P. radiata* trees (*c.* 8 m tall) in trial plots of a 9-year-old forest stand at Eyrewell State Forest in Canterbury (altitude 158 m. 43°24'S, 173°16'E). Trial treatments included thinning from 1600 stems/ha to 800 stems/ha and application of nitrogen fertiliser (400 kg N/ha as ammonium sulphate), both approximately 2 years prior to this investigation (D. Mead, pers. comm.). Thinned plots were open with plenty of light falling through the canopy to the ground between trees. Trees in fertilised plots had slightly denser and darker green crowns. Tree crowns in unthinned plots effectively formed a closed canopy.

Samples of current-year fascicles were collected from three branches per tree in the sunlit part of the crown at an approximate height of 5 m, from three trees per thinned plot. Growth, vigour, branching order, and sun exposure were kept as similar as possible. This material was used to give an indication of tree and branch variability for foliage of similar age, exposure, and crown position.

A second series of fascicle samples was collected from single trees in thinned and unthinned plots. Sampling points were standardised to sun crown at *c.* 5.0 m height facing solar north, and shade crown at *c.* 1.8 m facing south. Samples of fascicles were chosen on the same branch from current, second-year, and third-year growth. Foliage of *P. radiata* at Eyrewell fell mainly into these three age groups and many fourth-year needles were already showing signs of senescence or abscission. There were few fifth-year needles.

Needle fascicles were exercised with a scalpel close to the point of attachment, leaving most of the sheath intact. In the laboratory fascicles were coated with glass balls (grade 14. 0.078-0.06 mm diam.) along full needle length, including the transparent distal part of the sheath up to the point of suspension. The pressure-sensitive glue (Bostik RDB 645/2) was used as a 10% v/v solution in 1-1-1 thrichloroethane (86%) and butanol (4%). After determination of fascicle dry weight the foliage weight/area ratio was calculated as follows:

$$\text{Foliage wt./area} = \frac{\text{DM}}{\Delta\text{W}} \times \text{f}$$

where DM = fascicle dry matter (g)

ΔW = glass-ball coating (g)

f = calibration factor for glass balls (mg/cm^2)

For pine needles the calibration factor was obtained using various lengths of accurately gauged wire (1.685 mm diam.) of cross-sectional area similar to needles. With grade 14 glass balls the factor was 13.39 ± 0.07. Using known areas of wire (for needles) or paper (for flat leaves) linear regressions of glass ball weight/area were produced with coefficients of determination (r^2) of > 0.99. Use of a fluidised bed (Davies and Benecke, in press) greatly simplified the technique for obtaining a uniform coating of glass balls on needle surfaces.

Data were subjected to an analysis of variance.

RESULTS

Differences between trees of the same treatment are not large but are significant (Table 1). Within a tree, fascicles from similar positions on different branches also showed significant though relatively small differences. It also appears that current-year foliage in the sun crown of thinned trees has a slightly and significantly greater weight per unit surface-area in the nitrogen treated plots than in the unfertilised plots.

TABLE 1—Needle fascicle* weight per unit area (mg/cm^2) of 9-year-old **P. radiata** thinned to 800 stems/ha, fertilised (T + F) and unfertilised (T — F). ANOVA confirmed significant differences between fertiliser treatments, between branches from similar crown position within trees ($P < 0.01$), and between trees within fertiliser treatment ($P < 0.05$). (Mean values ($n = 9$) presented with standard error of mean)

Treatment	Tree	Branch 1	Branch 2	Branch 3
T + F	A	8.20 ± 0.15	8.79 ± 0.22	8.39 ± 0.20
	B	8.38 ± 0.13	8.83 ± 0.10	9.39 ± 0.18
	C	8.86 ± 0.19	8.44 ± 0.21	9.78 ± 0.28
T — F	A	7.68 ± 0.14	8.31 ± 0.15	8.63 ± 0.23
	B	8.03 ± 0.25	7.45 ± 0.30	8.49 ± 0.16
	C	7.22 ± 0.21	6.93 ± 0.27	7.50 ± 0.18

* All fascicles current-year from sun crown at 5 m.

Results from the second series of fascicle samples (Table 2) show the strong increase in needle weight/unit area with increasing age in all treatments in both upper and lower crown positions. Highly significant is the large difference in the decline of needle weight within an age group from the sun to the shade crown. This decrease in needle weight within the lower crown accentuated with increasing amount of foliage and crown cover. Thus the decline in fascicle weight per unit area from sun to shade was 31% for unthinned trees and 26% for heavily thinned trees.

TABLE 2—Needle fascicle weight per unit area (mg/cm^2) of two thinned (T) and two unthinned (U) 9-year-old **P. radiata,** fascicles taken from sun crown at 5.0 m and shade crown at 1.8 m for three age-classes. ANOVA confirmed significant differences between sun and shade crown, between each foliage age, and between thinned and unthinned within shade crown ($P < 0.01$). There was no significant difference ($P > 0.05$) between T and U within sun crown. (Mean values ($n = 20$) presented with standard error of mean.)

Fascicle age	Treatment	Crown position: Sun	Crown position: Shade
Current	T	7.74 ± 0.13	5.90 ± 0.09
	U	7.88 ± 0.15	5.45 ± 0.16
Second-year	T	9.01 ± 0.13	7.24 ± 0.07
	U	9.45 ± 0.19	6.31 ± 0.06
Third-year	T	11.50 ± 0.20	7.76 ± 0.14
	U	12.08 ± 0.21	8.51 ± 0.12

DISCUSSION

Trees in the thinned plots of the 9-year-old stand at Eyrewell Forest have been growing in open conditions and crowns are relatively well lit. Nevertheless there is still a very sharp differentiation in the weight per unit surface-area of needles not only with age but also between upper and lower crown. It is thus important to account for fascicle position within the tree crown when sampling for determination of crown surface-area by glass-bead technique.

Beets (1977) was able to give estimates of needle (fascicle) surface-area of *P. radiata* using a geometric model based on fascicle weight, length, and density. The shape coefficient remained nearly constant and density was found to vary with tree and age of needles only, whereas needle position in the tree crown had no influence on density. Should this finding be generally applicable it simplifies the sampling problems for needle area estimation of the whole tree crown. However, it seems useful to confirm whether the constraints of Beets' model are generally met in forest stands. In second-year *P. radiata* fascicles sampled during November on the basis of crown position, density determined by volume displacement declined by $12\% \pm 1\%$ from sunlit to shaded crown.

In the forest of Eyrewell, *P. radiata fascicles* showed strong differentiation between sun and shade needles. The 13 open-grown trees examined by Beets (1977) at Rotorua were of similar height (7-10 m) to, but distinctly younger (6 years) than, the trees studied at Eyrewell. Crown conditions were, therefore, not necessarily the same. In older more mature stands the sun/shade differentiation of *P. radiata* needles within the crown can be expected to increase with increasing canopy closure. In addition. weight/area or density factors will be time-dependent especially in young foliage where changes during the course of the first growing season may be particularly large.

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