RESEARCH BULLETIN FACULTY OF AGRICULTURE

UNIVERSITI PUTRA MALAYSIA

Agro-Search

ISSN 0128-9322

VOLUME 8 NUMBER 1 • JULY 2001

NEW EQUATIONS FOR CANOPY ORIENTATION

C.B.S. TEH[1], L.P. SIMMONDS[2] AND T.R. WHEELER[3]

[1] Department of Land Management, Universiti Putra Malaysia, 43400 UPM Serdang, Selangor, Malaysia

[2] Department of Soil Science, University of Reading, Whiteknights, P.O. Box 233, Reading, RG6 6DW, UK

[3] Department of Agriculture, University of Reading, Earley Gate, P.O. Box 236, Reading, RG6 2AT, UK

INTRODUCTION

Canopy orientation describes how a canopy occupies aerial space, and can be characterized mathematically by density distributions of leaf inclination (leaf angle from vertical) and leaf azimuth (leaf angle from north in a clockwise direction). The density distribution of leaf inclination and azimuth correspond to the probability of finding a leaf in a particular inclination and azimuth range, respectively (Lemeur, 1973a, b). Although there are some equations available for describing canopy orientation (e.g., de Wit, 1965; Lemeur, 1973a; Shell and Lang, 1975, 1976), they are often of limited use, and are either inaccurate, or too simplistic (Teh *et al.*, 2000).

Consequently, this study was mainly to develop two new equations that could characterize a wide range of leaf azimuth and inclination densities more accurately, especially for canopies with irregular orientation distributions. The accuracy of these two new equations would then be tested against two crop species with contrasting canopy types: a heliotropic (solar-tracking) sunflower and a non-heliotropic maize.

THEORY

Equation for leaf azimuth density

The distribution of leaf azimuth density was characterized using a modified von Mises density function (Shell and Lang, 1975, 1976):

$$g(\phi_L)=\frac{1}{2\pi I_O(T_{azi})}\exp\{T_{azi}\cos[S_{azi}(R_{azi}-\phi_L)+d(\phi_L)]\} \rightarrow (1)$$

where $g(\phi_L)$ is leaf azimuth density at azimuth ϕ_L; $I_o(T_{azi})$ is the modified Bessel function of the first kind and order zero; T_{azi} is called the thickness or elongation index (dimensionless); S_{azi} the shape (or number of azimuth preferences) index (dimensionless); R_{azi} the rotation (or general canopy azimuth position) index (degrees or radians); and $d(\phi_L)$ is a distortion distribution, given by: $d(\phi_L) = \cos[S_{azi}(R_{azi}-\phi_L)]$. These parameter names are chosen as they better reflect their purpose and usage in the context of canopy architecture description.

Varying the values of T_{azi}, S_{azi} and R_{azi} will yield various types or distribution shapes of leaf azimuth density (Fig. 1). The thickness index T_{azi} specifies how thick or elongated the distribution will be. Greater values of T_{azi} will increase the distribution stretch or elongation. The S_{azi} index indicates the number of azimuth preferences, and this gives the distribution a distinct shape. When S_{azi} = 0 or 1, for example, the distribution shape is a circle (no azimuth preference); S_{azi} = 2 produces a distribution with two azimuth preferences so the distribution looks like a figure '8' or a stretched circle; and S_{azi} = 3 produces three azimuth preferences so the distribution looks like a triangle. The R_{azi} index indicates the general canopy azimuth position, and varying its value rotates the distribution around the origin, where positive R_{azi} rotates the distribution clockwise. This rotation index is crucial in the characterization of canopy heliotropism because R_{azi} can be used to describe canopy movement (Fig.2). When $S_{azi} = 1$, for example, varying the thickness index T_{azi} can shift the centre of distribution to describe the canopy leaning or pointing toward a specific direction such as towards the sun. Greater values of T_{azi} will shift the canopy even more. The rotation index R_{azi} can then be used to characterize the movement or solar-tracking by the canopy. From preliminary analysis, Eq. (1) is well behaved when values of the indices T_{azi}, S_{azi}, and R_{azi} are restricted to the range of 0.0-2.0, 0.0-3.0, and 0°-300°, respectively.

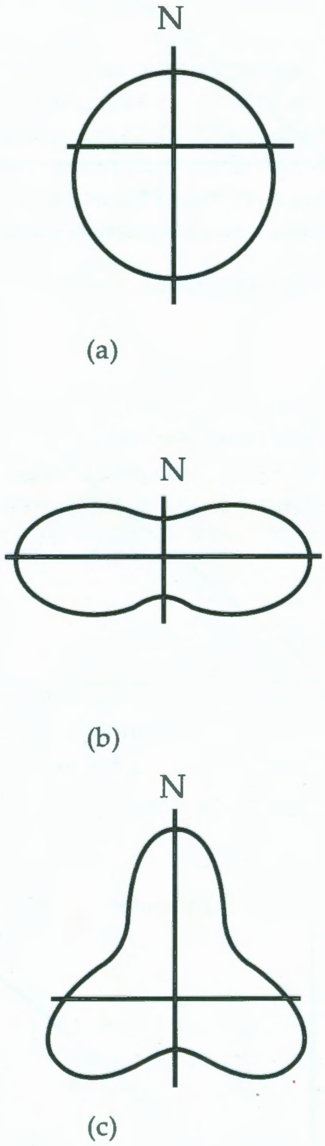

Fig. 1. Polar graphs showing various distributions of leaf azimuth density generated using Eq. (1) with $d(\phi_L)=0$ (N indicates north): (a) $T_{azi}=0.00$, $S_{azi}=1$, $R_{azi}=0°$; (b) $T_{azi}=0.70$, $S_{azi}=2$, $R_{azi}=90°$; (c) $T_{azi}=0.40$, $S_{azi}=3$, $R_{azi}=0°$

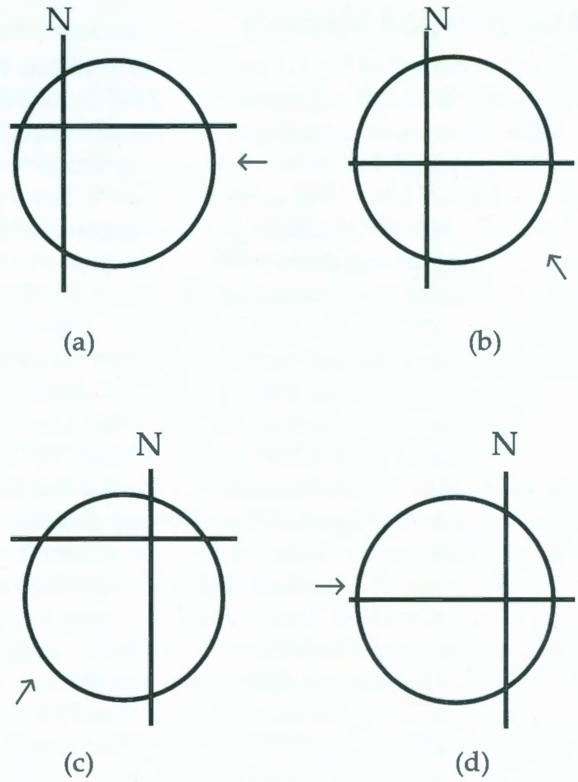

Fig. 2. Simulation of a heliotropic canopy with $T_{azi}=0.55$, $S_{azi}=1$, and $d(\phi_L)=0$. The canopy tracks the sun movement from (a) to (d) (N indicates north; arrow indicates the sun's azimuth): (a) $R_{azi}=90°$ when sun is at east; (b) $R_{azi}=135°$ when sun is at south-east; (c) $R_{azi}=225°$ when sun is at south-west; (d) $R_{azi}=270°$ when sun is at west.

Distribution of leaf inclination density

An equation similar to Eq. (1) was developed to characterise the distribution of leaf inclination density:

$$g(\theta_L)= \frac{2}{2\pi I_0(T_{azi})} \exp\{T_{inc}\cos[S_{inc}(R_{inc}-\phi_L)+d(\theta_L)]\} \rightarrow (2)$$

where $g(\theta_L)$ is leaf azimuth density at inclination θ_L; $I_0(T_{inc})$ is the modified Bessel function of the first kind and order zero; T_{inc} is called the thickness or elongation index (dimensionless); S_{inc} the shape (or number of inclination preferences) index (dimensionless); R_{inc} the rotation (or general canopy inclination position) index (degrees or radians); and $d(\theta_L)$ is a distortion distribution, given by:

$$d(\theta_L)=\cos[S_{inc}(R_{inc}-\phi_L)$$

Materials and Methods

The accuracy of Eq. (1) and (2) was tested on two crops with differing canopy types: sunflower (*Helianthus annuus* L. hybrid Sanluca) and maize (*Zea mays* L. hybrid Hudson). These two crops were planted on 22 May 1998 at Sonning Farm, Reading, UK (51°27′ N; 0°58′ W). Field size was approximately 0.13 ha and planting density for each crop was 60,000 plants ha^{-1}, and row spacing was 0.6 m.

Canopy architecture measurements on maize and sunflower started 66 days after planting (27 July 1998), and continued every week for five weeks. Leaf area was measured using a leaf area machine (LI-COR, Lincoln, Nebraska, USA; Model 3000), and leaf inclination and leaf azimuth densities were determined from measurements of leaf inclination, azimuth and area. The method described by Lemeur (1973b) and Ross (1981) was used. Leaf inclinations were categorised into six classes of 15° intervals: 0 to 15°, 15 to 30° onto 75 to 90°; and leaf azimuths were categorized into eight classes of 45° intervals: 337.5 to 22.5°, 22.5 to 67.5° onto 292.5 to 337.5°. Thus, each leaf was associated with one inclination class and one azimuth class. For each leaf inclination class, the leaf area of all azimuth classes was pooled and vice versa. The pooled leaf area of an inclination class was then divided with the total leaf area for all inclination classes. Finally, division by p/12 yielded the density for a leaf inclination class. The same procedure was used to obtain the density of a leaf azimuth class except that the division was by p/4.

The indexes T, S, and R in Eq. (1) and (2) were fitted to the observed leaf orientation densities by minimizing the error sum of squares between the observed and simulated densities. The absolute mean error (AME) of estimation was calculated as the mean difference between the measured and simulated values.

Results and Discussions

For both maize and sunflower, the canopy orientation equations (1) and (2) fitted the observed leaf orientation densities accurately, where there was a close clustering of points along the 1:1 line of agreement (Fig. 1). The AME of estimation for both equations was also near zero with 95% of the errors (mean error ± two standard deviations) occurring within a narrow range. All of these denoted good fit by both equations in the characterization of the observed canopy orientation of sunflower and maize.

For sunflower, the AME for the leaf azimuth density equation, or Eq. (1), was 0.05 with 95% of the errors between – 0.13 and 0.12. The AME for the leaf inclination density equation, or Eq. was 0.14 with 95% of the errors between - 0.35 and 0.41. Likewise for maize, the AME (with the range of 95% of errors in brackets) for Eq. (1) and were 0.05 (– 0.14 and 0.13) and 0.13 (– 0.36 and 0.39), respectively.

Both equations (1) and (2) fitted the observed canopy orientation of the two crop species with contrasting canopy types-a heliotropic sunflower and a non-heliotropic maize. Consequently, this study introduced two equations that could be used to numerically describe the canopy orientation of a crop accurately.

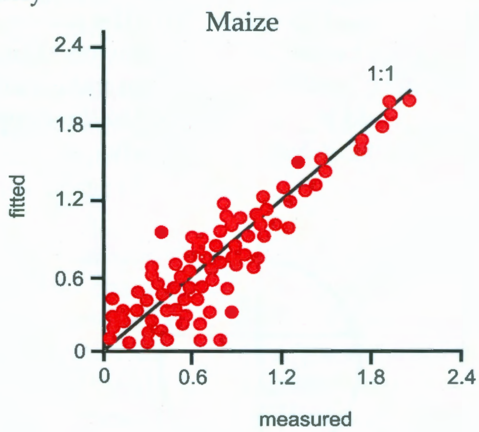

Fig 3(a) Leaf inclination density

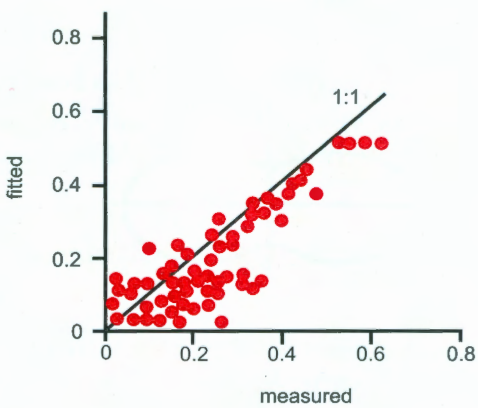

Fig 3 (b) Leaf azimuth density

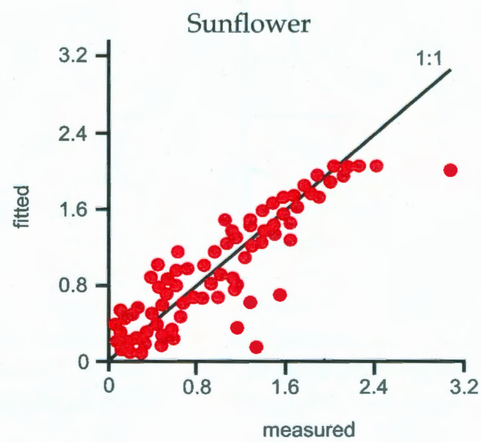

Fig 3(c) Leaf inclination density

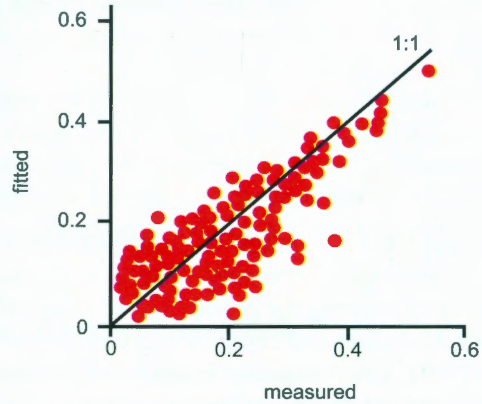

Fig 3(d) Leaf azimuth density

Fig. 3. Comparisons between measured and simulated leaf inclination and azimuth densities

The advantages of having numerical descriptions are that one can more easily compare any changes in azimuth and inclination distribution of a crop species between growing seasons, between crop treatments, or between crop varieties. Without numerical descriptions, comparisons between canopy orientations must be done visually by graphs.

Conclusion

This study introduced two accurate equations to numerically describe the distributions of leaf azimuth and inclination densities. These equations would be useful for the quantitative description of canopy orientation, as well as for quantifying canopy orientation differences.

Further work is planned to determine the possibility of linking the equations' indexes to physical and biological plant factors, and the variability of these indexes in different environments. The equations will also be used in some detailed plant radiation models.

References

DE WIT, C.T. 1965. Photosynthesis of Leaf Canopies. Agricultural Research Reports. No. 663. Pudoc, Wageningen.

LEMEUR, R. 1973a. Effects of spatial leaf distribution on penetration and interception of direct radiation. In Slatyear, R.O. (ed.) Plants Response to Climatic Factors. Proc. Uppsala Symp., 1970 (Ecology and conservation. 5.), UNESCO, Paris, pp. 349-356.

LEMEUR, R. 1973b. A method for simulating the direct solar radiation regime in sunflower, Jerusalem artichoke, corn and soybean canopies using actual stand structure data. Agric. Meteorol. 12: 229-247.

ROSS, J. 1981. The Radiation Regime and Architecture of Plant Stands. Dr W. Junk Publishers, The Netherlands.

SHELL. G.S.G. AND LANG, A.R.G. 1975. Description of leaf orientation and heliotropic response of sunflower using directional statistics. Agric. Meteorol 15: 33-48.

SHELL. G.S.G. AND LANG, A.R.G. 1976. Movements of sunflower leaves over a 24-H period. Agric. Meteorol. 16: 161-170.

TEH, C.B.S., SIMMONDS, L.P. AND WHEELER, T.R. 2000. An equation for Irregular distributions of leaf Azimuth density. Agric.For. Meteorol. 102: 223-234.