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International Plant Genetic Resources Institute

Book of Abstracts

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THE EFFECT OF LEAF SHAPE ON THE INTERCEPTION OF SOLAR RADIATION

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ABSTRACT

The objective of this study was to evaluate the effect of six leaf shapes on both direct and diffused solar radiation interception using computer simulations. Six plant prototypes were generated, where they were all equal to each other in all aspects, differing only that each of them had a different leaf shape. Computer simulations showed that leaf shape had an effect on solar radiation interception, although its effect was to a rather small degree of not more than 11% increase in solar radiation interception. All plant properties being equal, solar radiation interception could be increased by having leaf shapes that are: 1) long and narrow, 2) broader at the apex than at the basal, and 3) supported by leaf petioles. These three conditions increase solar radiation interception by reducing leaf clustering and self-shading especially near the plant stem.

INTRODUCTION

The primary objective of this study was to evaluate the effect of various leaf shapes on both direct and diffused solar radiation interception using a detailed solar radiation model. This study may help to better select crop varieties having the "proper leaf form" for optimum plant production, as well as to better understand plant adaptation mechanisms in response to environmental stresses.

MATERIALS AND METHODS

The canopy space of a plant is divided into a network of 3-D cuboids that is perpendicular to the planting row direction, where for each cuboid in the network, three kinds of information are required: a) leaf area density, b) leaf orientation distribution, or the G-function, and c) mean travelling distance of a solar beam (Sinoquet and Bonhomme, 1992; Thanisawanyangkura *et al.*, 1997). Located at the centre of the 3-D network of cuboids is a computer-generated plant (prototype) where, in this study, its leaf number, leaf azimuth, leaf position, planting distance, and plant height were held constant. Only its leaf shape, area and inclination were varied. Six simple shaped leaves were selected in this study to assess their effect on solar radiation interception: round (RD), square (SQ), triangle (TR), inverted triangle (ITR), ellipse (EL) and lobe (LB) (Figure. **Error! Reference source not found.**). The effect of these leaf shapes on light interception was examined in the following three conditions: a) leaf area index (LAI) 0.5, 1.0 and 3.0; b) leaf inclination 22.5°, 45° and 90°; and c) leaves with and without petioles. The leaves of the plant prototype were described as 3-D polygons so that the Sutherland-Hodgman's 3-D polygon clipping algorithm (Sutherland and Hodgman, 1974) could be used to determine the section of a leaf polygon encompassed by a given cuboid.

RESULTS AND DISCUSSION

The interception of both direct and diffuse solar radiation increased with increasing LAI and leaf inclination (Table **Error! Reference source not found.**). Most importantly, given a leaf inclination and LAI, the mean hourly interception of solar radiation was effected by the leaf shape, albeit to a rather small extent. The differences in solar radiation interception among the six plant prototypes were not more than 11% from each other. Moreover, their differences declined to not more than 5% from each other for full or near canopy cover (*i.e.*, LAI 3.0). At near or full canopy cover, the total fraction of direct or diffuse solar radiation intercepted was at near maximum 1.0; consequently, any further

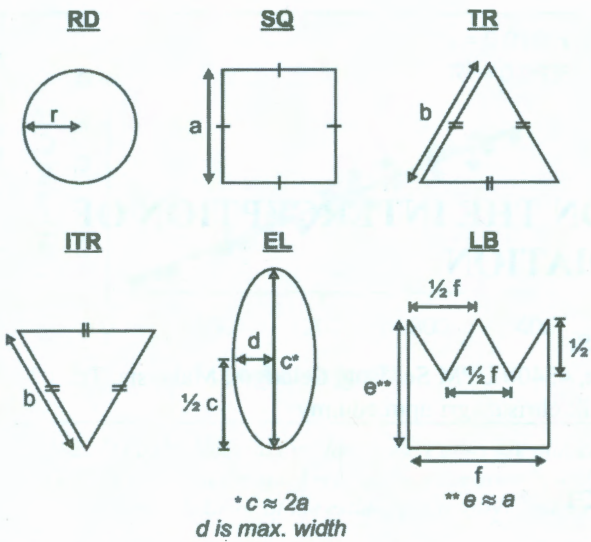

Figure 1. Leaf shapes for the six plant prototypes: round (RD), square (SQ), triangle (TR), inverted triangle (ITR), ellipse (EL) and lobe (LB)

advantages of having a particular leaf shape to increase solar radiation interception at this stage would be small. As shown in Table **Error! Reference source not found.**, the mean hourly interception of both direct and diffuse solar radiation by the plant prototypes can be distinguished into two groups, where solar radiation interception decreased in the following manner: (ITR » EL) > (RD » SQ » TR » LB). Lobed leaves are often thought to alter the plant-radiation regime significantly by producing deeper sunflecks within the canopy (Horn, 1971). However, this study showed no effect of leaf lobbing *per se* (LB prototype) on solar radiation interception. The interception of both direct and diffuse solar radiation for all prototypes could however be further increased by the presence of leaf petioles. Compared to sessile (non-petiole) leaves, leaves with petioles (100 mm in length) further increased the solar radiation interception by not more than 12%, but this increase generally declined for full or near canopy cover. Additionally, the interception of both direct and diffuse solar radiation by ITR and EL petiole leaves was on the average 14% higher than that by RD sessile leaves. The increase in solar radiation interception due to the presence of petioles was generally most pronounced for RD, SQ, TR and LB plant prototypes (an average gain of 7%) as compared to ITR and EL prototypes (an average gain of 3%). This difference is due to the ITR and EL prototypes intercepted most the fraction of direct and diffuse solar radiation as compared to other plant prototypes. Thus, additional advantages of having leaf petioles to further increase solar radiation interception would be small for the EL and ITR prototypes. Interestingly, stretching a leaf longer and narrower while maintaining the same leaf area augmented solar radiation interception. The elliptic, sessile leaves for the EL prototype were stretched longer by 100 mm while maintaining the same leaf area. Compared to the non-modified EL leaves, the longer and narrower EL leaves further increased the interception of both direct and diffuse solar radiation by not more than 14%. This increase in interception, like the previous scenarios, declined for full or near canopy cover.

For every prototype, there was a strong negative correlation coefficient between the mean solar radiation intercepted and the coefficient of variation (c.v.) of leaf area density. Because all plant properties were held constant in this study, a low c.v. value of leaf area density would indicate a more uniform spread or distribution of leaf area in the canopy aerial space. This in turn means lesser self-shading and clumping of leaves. For all plant prototypes, the c.v. values of leaf area density for petiole leaves were lower than that for sessile leaves. This corresponded to the earlier observation that prototypes with petiole leaves intercepted more solar radiation than that by prototypes with sessile leaves. Also observed earlier was that the EL modified leaves (leaves modified to be longer and narrower) intercepted more solar radiation than that of the EL non-modified leaves. This again was consistent to the lower c.v. values for EL modified leaves as compared to the c.v. values for EL non-modified leaves. This study also showed that although TR and ITR prototypes had both triangle leaves, ITR intercepted more solar radiation than TR because of the orientation of ITR where the bulk of the leaf area was away from the plant stem (*i.e.*, leaves broader at their apex than at their basal) which reduced clustering of leaves around the plant stem which in turn lowered the c.v. of leaf area density.

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Table 1. Mean hourly fraction of intercepted solar radiation for all plant prototypes with sessile (non-petiole) leaves.

(a) Direct solar radiation

Proto-	LAI 0.5				LAI 1				LAI 3			
type		45°	90°	Mean	22.5°	45°	90°	Mean	22.5°	45°	90°	Mean
RD	0.258	0.278	0.279	0.272	0.401	0.458	0.472	0.443	0.722	0.812	0.848	0.794
	(0.0)	*(0.0)*	*(0.0)*	*(0.0)*	*(0.0)*	*(0.0)*	*(0.0)*	*(0.0)*	*(0.0)*	*(0.0)*	*(0.0)*	*(0.0)*
SQ	0.267	0.283	0.281	0.277	0.407	0.464	0.473	0.448	0.729	0.816	0.849	0.798
	(3.4)	*(1.9)*	*(0.8)*	*(2.0)*	*(1.6)*	*(1.3)*	*(0.1)*	*(0.9)*	*(0.9)*	*(0.4)*	*(0.1)*	*(0.5)*
TR	0.261	0.280	0.275	0.272	0.415	0.462	0.469	0.449	0.731	0.812	0.842	0.795
	(1.1)	*(0.9)*	*(-1.1)*	*(0.3)*	*(3.6)*	*(1.0)*	*(-0.7)*	*(1.2)*	*(1.3)*	*(0.0)*	*(-0.6)*	*(0.2)*
ITR	0.279	0.306	0.299	0.295	0.440	0.498	0.505	0.481	0.751	0.839	0.876	0.822
	(8.2)	*(10.2)*	*(7.4)*	*(8.6)*	*(9.8)*	*(8.8)*	*(7.0)*	*(8.5)*	*(4.0)*	*(3.3)*	*(3.3)*	*(3.5)*
EL	0.275	0.307	0.305	0.295	0.442	0.496	0.508	0.482	0.750	0.833	0.878	0.820
	(6.3)	*(10.6)*	*(9.3)*	*(8.6)*	*(10.2)*	*(8.4)*	*(7.7)*	*(8.7)*	*(3.9)*	*(2.6)*	*(3.6)*	*(3.3)*
LB	0.264	0.280	0.258	0.267	0.417	0.462	0.456	0.445	0.734	0.812	0.839	0.795
	(2.3)	*(0.8)*	*(-7.4)*	*(-1.5)*	*(4.2)*	*(1.0)*	*(-3.5)*	*(0.4)*	*(1.7)*	*(0.0)*	*(-1.1)*	*(0.1)*

Note: In the same table column, values in the brackets indicate the difference (in percent) from the fraction of solar radiation intercepted by the RD prototype.

( ) Diffuse solar radiation

Proto-	LAI 0.5				LAI 1				LAI 3			
type		45°	90°	Mean	22.5°	45°	90°	Mean	22.5°	45°	90°	Mean
RD	0.283	0.293	0.303	0.293	0.438	0.482	0.509	0.476	0.726	0.813	0.874	0.804
	(0.0)	*(0.0)*	*(0.0)*	*(0.0)*	*(0.0)*	*(0.0)*	*(0.0)*	*(0.0)*	*(0.0)*	*(0.0)*	*(0.0)*	*(0.0)*
SQ	0.291	0.300	0.305	0.299	0.445	0.486	0.511	0.481	0.700	0.814	0.874	0.796
	(3.0)	*(2.5)*	*(0.8)*	*(2.1)*	*(1.7)*	*(0.8)*	*(0.3)*	*(0.9)*	*(-3.7)*	*(0.1)*	*(0.0)*	*(-1.1)*
TR	0.295	0.300	0.298	0.298	0.463	0.491	0.509	0.487	0.739	0.810	0.867	0.805
	(4.5)	*(2.5)*	*(-1.6)*	*(1.7)*	*(5.7)*	*(1.8)*	*(-0.1)*	*(2.3)*	*(1.8)*	*(-0.4)*	*(-0.8)*	*(0.1)*
ITR	0.295	0.324	0.326	0.315	0.472	0.521	0.538	0.510	0.758	0.845	0.907	0.837
	(4.5)	*(10.6)*	*(7.7)*	*(7.6)*	*(7.9)*	*(8.1)*	*(5.7)*	*(7.2)*	*(4.3)*	*(4.0)*	*(3.8)*	*(4.0)*
EL	0.303	0.325	0.331	0.319	0.476	0.520	0.546	0.514	0.753	0.851	0.908	0.838
	(7.3)	*(10.8)*	*(9.1)*	*(9.1)*	*(8.8)*	*(7.8)*	*(7.3)*	*(7.9)*	*(3.7)*	*(4.7)*	*(4.0)*	*(4.2)*
LB	0.294	0.301	0.280	0.292	0.462	0.491	0.493	0.482	0.742	0.813	0.863	0.806
	(4.1)	*(2.9)*	*(-7.5)*	*(-0.3)*	*(5.5)*	*(1.8)*	*(-3.2)*	*(1.2)*	*(2.1)*	*(0.0)*	*(-1.2)*	*(0.2)*