OPTIMIZATION OF POSITION OF REFLECTIVE BOARDS FOR INCREASING LIGHT INTENSITY INSIDE CHINESE LEAN-TO GREENHOUSES

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Abstract: Equations were derived based on the principles of light reflection to optimize the height and angle parameters of the reflective board in real time and location. The optimized parameters were applied to enhance the light intensity inside the lean-to greenhouses in China. The calculated results were significantly correlated to the actual measurements. Therefore, the equations developed in this study can be used to optimize the design parameters for the reflective board in practice. Additionally, based on the derived calculation equations, the optimized ranges of height and angle parameters were calculated for setting reflective board from autumn to winter and spring at latitude 32-42º in China.

Key words: position optimization, reflective board, sunlight intensity, Chinese lean-to greenhouse

1. INTRODUCTION

Installing reflective materials inside a greenhouse, especially a lean-to greenhouse, is one of the most effective and economical solutions to improve light intensity(Li et al, 1998; Cai, 1994; Kong, 2004). Previous research reported that hanging reflective screen under the ridge of lean-to greenhouses has more light enhancement than that on the back wall(Li et al, 1998). But the technical challenge in adopting this measure is to determine the optimal installation position of the reflective board with a width of about 1 m, the popular size of commercial products. If the position is too low, it is very inconvenient for operational and management activities. Tall plants may also block some of the light from reaching the reflective surface. On the other hand, if the board is installed too high, its light enhancing effect will be reduced (unpublished data). As to the angle between the reflective board and ground level, some researchers reported that it should be in the range of 75-85º (Jia, 2000). In fact, the optimal height and angle of reflective board should change with the time and location of the specific greenhouse(Pucar, 2002). In this study, mathematical equations were developed and tested to enhance light intensity by optimizing the parameters of height and angle of reflective board inside lean-to greenhouses in various time and locations.

2. OPTIMIZATION THEORY

2.1 Optimization Consideration

A few assumptions were made as follows to simplify the calculations. (1) Light enhancement of the reflective board depends mainly on the reflection of direct light. (2) Sunbeam light does not change its initial direction when passing through the greenhouse cover until it reaches the reflective board. (3) When the direct light travels inside greenhouse, light intensity attenuation effect is negligible.

With the above assumptions, the optimal objectives of reflective board location were described as follows: (1) To adjust height of the reflective board to make its bottom edge as far away from the top of crop canopy as possible. (2) At the optimal height, to determine the inclination of the reflective board to cast a minimal shading area on the back-wall and to produce a maximal light enhancement in the cultivation area from 1 m away from reflective board to northward, where is normally associated with the greatest light enhancement by reflective board(Cai, 1994; Kong, 2004).

2.2 Optimization Calculation

Suppose that there is a point A, from which the vertical distance to the vertically installed reflective board is R (m), the azimuth angle of the greenhouse is θ^*, the vertical distance from the top of the crop canopy to the bottom edge of the reflective board is H (m) (Fig. 1), and the height of the reflective board is L (m).

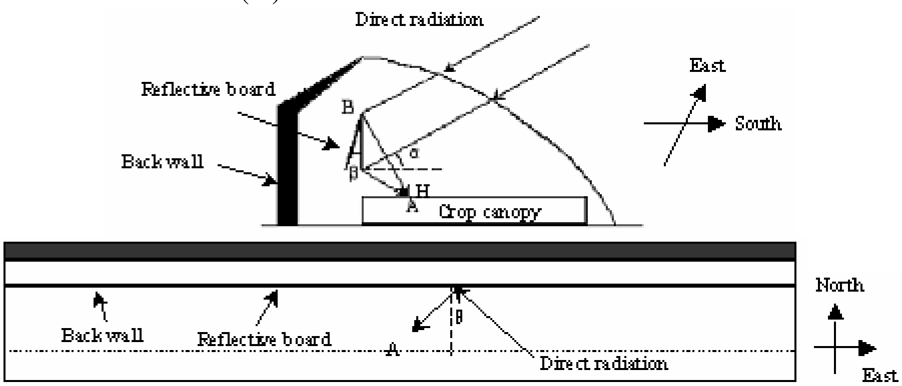

Figure 8. Schematic diagrams of cross-section(upper) and planform(lower) of the greenhouse with reflective board

In order to achieve a maximal light enhancement in the area from point A to the northward aspect, the area must always be in the range of the reflected direct sunlight. For objective (1), the optimized height of the reflective board at a given time should be the maximum value of H. H_{max} at a given time can be calculated using the following equation:

$$H_{max} = \frac{R\ tg\alpha}{\cos(\theta + 2\theta^*)} \qquad (1)$$

Where , α: solar altitude (degree); θ: azimuth angle of the sun (degree);θ^*: azimuth angle of the greenhouse, when the south roof faces to south, $\theta^* = 0$, negative values for east aspect, and positive values for west aspect; and, R: vertical distance of point A to the vertically installed reflective board.

Let the bottom edge of the reflective board at its optimized height move northward around its top edge, point B (Fig. 1). Suppose that the rotation angle of reflective board is β (Fig. 1). In order to make the point A and its northward area be in the range of the reflected sunlight, the reflective board can be rotated at a angle ranging from 0 to $\beta_{max.}$ For objective (2), β_{max}, can be regarded as the optimized angle. From the rules of geometry and the laws of light reflection, we can derive

$$tg(\alpha + 2\beta_{max}) = \frac{H_{max} + L}{R/\cos(\theta + 2\theta^*)}$$

i.e.

$$\beta_{max} = \frac{1}{2}[arc\ tg \frac{H_{max} + L}{R/\cos(\theta + 2\theta^*)} - \alpha]$$

Substituting equation (1) into the above equation we obtain the following:

$$\beta_{max} = \frac{1}{2}\left\{ arc\, tg[tg\alpha + \frac{L\cos(\theta + 2\theta^{*})}{R}] - \alpha \right\} \qquad (2)$$

According to equations (1) and (2), in order to calculate the optimized height and angle at a given time, the critical parameters need to determine are the solar altitude (α) and azimuth angle of the sun (θ) at a given time, with L and R are known. The two parameters at a given time can be calculated from several well known equations, with the local longitude and latitude are known(Zhou, 2003).

3. EXPERIMENTAL VALIDATION

A compact experiment was conducted inside a Chinese type lean-to greenhouse with an azimuth angle of -4º on December 12th, 2004, when the sky was clear. The reflective board with a width of 0.98 m was hung vertically under the ridge of the greenhouse with different height (H) of 0 m, 0.2 m, 0.4 m, 0.6 m, 0.8 m and 1 m. When the reflective board was fixed at the height of 0.5 m, its bottom edge rotated northward around its top edge by angles of 0º, 15º, 30º, 45º and 60º. A calibrated light sensor (Li-COR, Nebraska, USA), which was positioned on the top of crop canopy at a 1-m vertical distance from the reflective board southward, was used to measure the PPFD (Photosynthetic Photon Flux Density) at different time of that day from 8:00 to 16:00 at an interval of one hour.

As shown in Fig.2, the PPFD decrease slowly from 0 m to a certain height and rapidly at higher positions. The critical height varied with time, with about 0.3 m to 0.5 m during 9:00-14:00. The critical heights from experiments and from the calculation of optimized height of the reflective board matched very well during 9:00-14:00 as shown in Table 1. As shown in Fig.3, like the critical height described previously, there was also a critical angle. The PPFD decreased rapidly when the rotation angle increased beyond the critical angle. As can be observed from Fig.3, the critical angle ranged from 15º to 30º, which was consistent with the calculated value of the optimal angle shown in Table 1.

Table 1. Calculated results for optimizing the installing height and rotation angle of reflective board in the experimental greenhouse on December 12, 2004

Time (hh:mm)		8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00
Calculated parameters	α (°)	6.5	14.9	21.4	25.6	26.8	25.0	20.4	13.5	4.9
	θ(°)	-52.2	-41.1	-28.3	-13.9	1.4	16.6	30.7	43.1	54.1
Calculated results	Hmax (m)	0.23	0.41	0.49	0.52	0.51	0.47	0.40	0.29	0.1
	βmax (°)	11.6	13.3	13.9	14.2	14.5	15.1	15.9	16.6	16.7

β'max (°)	18.6	16.6	15.2	14.4	14.5	15.4	17.2	19.7	22.7

Note : β'_{max} is the optimal rotation angle when the installation height of reflective board was 0.5 m throughout the whole day.

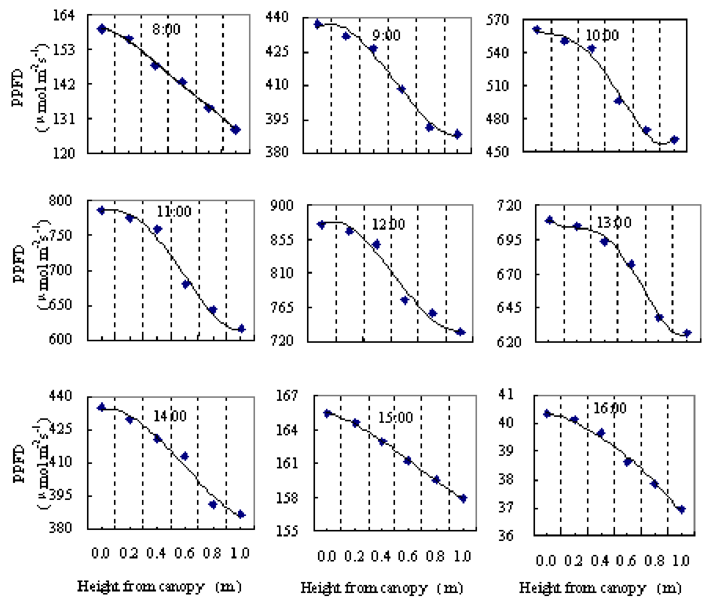

Figure 2. Effects of reflective board at different height on the photosynthetic photon flux density (PPFD) inside greenhouse

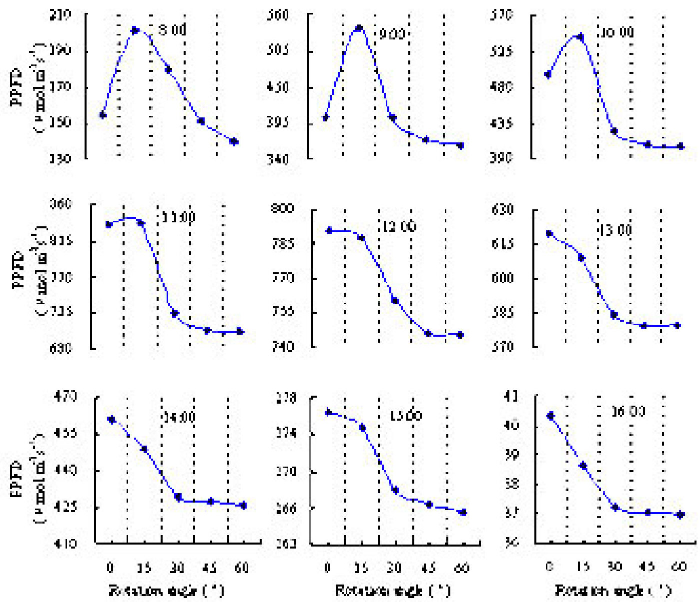

Figure 3. Effects of reflective board at different rotation angle on the photosynthetic photon flux density (PPFD) inside greenhouse

4. DISCUSSION

In summary, the calculated results of the critical height and angle for reflective board installation in a greenhouse agreed well with the experimental data. The derived equations in this study can be used for the optimization of reflective board installation inside the lean-to greenhouses in China. If the algorithm was accomplished with a computer program, the optimal height and angle of reflective board can be automatically adjusted in real time during a day.

However, taking into account the level of the economical development in rural areas in China, an approximate optimal height ranging from 0.5 to 2.4 m, and optimal angle ranging from 3º to 15º can be calculated for a given day during autumn, winter and spring in the region of latitude 31º~42 º in China. The calculated optimal angle was in agreement with other studies that indicated that the inclination of reflective board should be in the range of from 75º to 85º(Jia, 2000).

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