Simulation Study On The Influence of Roof Inclination On The Light Environment Of Solar Greenhouse

Wenxiong Yang1*
1 Beijing Vocational College of Agriculture, 102442, China
*wenxiongyang@bvca.edu.cn

Abstract. With the help of the first solar greenhouse light environment simulation software, the influence of different roof inclination on the light environment of solar greenhouse with the same ridge height is simulated. The results show that when the ridge height of greenhouse is constant and the inclination angle of roof changes, all the evaluation indexes in greenhouse change to different degrees. When the roof angle increases from 28 ° to 32 °, the cumulative light input on the floor and the total energy of light radiation in the greenhouse decrease by 22.4% and 11.7% respectively, and the uneven of light intensifies, which is not conducive to the growth of greenhouse crops. Therefore, it is not recommended to increase the inclination of the roof when the ridge height of the greenhouse is constant.

1. Introduction
The inclination angle of the roof has an important influence on the indoor lighting environment of the solar greenhouse. Many scholars have carried out relevant research for this purpose: Xuan built and analyzed the mathematical model of daylighting roof curve of solar greenhouse [1]. Wang et al. made a comparison on the daylighting performance and the mechanical properties of the arch frame of the front roof of four kinds of curved solar greenhouses [2]. Li et al. compared the light environment of several kinds of solar greenhouses with common roof shape and inclination angle, the results showed that the roof shape had little influence on the light environment characteristics of the solar greenhouses. Double circle and straight line plus arc are are two kinds of roofs which are easy to be made, and the lighting performance also meets the requirements. The inclination angle of the roof has a significant influence on the solar radiation amount of the solar greenhouses penetrating into the room, 24 ° ~ 32 °, every 2% increase The sum of accumulated light radiation energy of each surface per unit greenhouse length increases by 4.6% on average, among which the average increase on the wall surface is 10.9%. Increasing the roof angle is helpful to improve the indoor temperature environment [3]. Cheng et al. carried out the design and analysis of the roof curve of the solar greenhouse under the constraints of the basic shape conditions. For the roof with double circle combination, straight arc combination and non-circular curve shape, studied the reasonable design steps of the roof curve, and obtained the mathematical expression form and parameters of the curve [4]. Zhou et al. analyzed the improvement and innovation process of the roof structure of China's solar greenhouse from the changes of the geometric dimensions of the front and rear roofs of the solar greenhouse and summarized some innovative technologies of the front and rear roofs of the solar greenhouse, including the characteristics of the variable roof angle solar greenhouse. [5].

In this paper, the effects of different roof inclination angles (26 °, 28 °, 30 °, 32 °) on indoor light environment of solar greenhouse are studied. Because there are many influencing factors of sunlight environment in solar greenhouse, in order to facilitate the research, some other influencing factors...
need to be fixed, such as greenhouse orientation, roof shape, covering materials, etc., but the change of roof inclination will inevitably cause the change of greenhouse span and roof ridge height.

Therefore, to study the influence of different roof inclination on the indoor light environment of solar greenhouse, we need to discuss it in two cases. The first is the constant span of greenhouse, the change of roof height caused by the change of roof inclination, and the light condition in the solar greenhouse. The second is the constant height of the roof ridge, the change of the greenhouse span caused by the change of the roof angle, and the light condition in the solar greenhouse. In the first case, Yang et al. Have carried out research. The results show that when the span of the solar greenhouse is fixed, all of them are 8m, and the roof inclination angle increases from 26 ° to 32 °, the average absolute value of the front roof transmittance increases by 0.5%[6] .

This paper mainly studies the second case that the height of roof ridge is constant and the change of greenhouse span is caused by the change of roof inclination and the light condition in the solar greenhouse.

2. Materials & Methods

2.1. Material

In this paper, the simulation software of sunlight environment in solar greenhouse, which is initiated by the Key Laboratory of Ministry of agriculture of China Agricultural University, integrates all kinds of models and simulation methods, creatively puts forward the method of light reverse tracing and the assumption of sky equiluminance for the first time, constructs the sunlight radiation environment model of solar greenhouse, making the model more systematic, complete, accurate and close to the reality[7].

The core of the model is to give the irradiance formula of any point P in the solar greenhouse:

\[ I_p = I_{sp} + I_{sp} \]

Unit: W·m⁻².

\( I_{sp} \) is the direct irradiance of any point P in the greenhouse, and the formula is:

\[ I_{sp} = \frac{(1 - P^w)I_0}{2(1 - 1.4 \ln P)} \sin h \cos ^2 \frac{\omega}{2} \cdot (1 - CC/10) \cdot \tau_{s} \cdot (1 - Haze) \]  

Where \( I_0 \) is the normal solar irradiance at the outer boundary of the atmosphere; \( P \) is the transparency of the atmosphere. It is related to geographical location and weather conditions; \( m \) is atmospheric quality; \( H \) is solar altitude angle; \( \omega \) is angle between calculation plane and horizontal plane; \( CC \) is cloud amount; \( Haze \) is haze; \( \tau_{s} \) is the light transmittance of covering material to direct radiation.

\( I_{sp} \) is the scattering radiation illuminance of any point P in the greenhouse, the formula is:

\[ I_{sp} = \frac{\lambda_v}{180} \cdot \tau_s \cdot \left[ I_0 \left( \frac{(1 - P^w)}{2(1 - 1.4 \ln P)} \sin h \cos ^2 \frac{\omega}{2} + P^w \cos \phi \right) \right] \cdot CCF \cdot \frac{I_{sp}}{\tau_{s}(1 - Haze)} + \frac{Haze}{1 - Haze} \cdot I_{sp} \]

Where \( \lambda_v \) is the visible angle of view; \( \tau_s \) is the transmissivity of the new dry and clean covering material to the scattered radiation; \( \phi \) is the angle between the sun light and the normal of the calculation plane; \( CCF \) is cloud cover coefficient; other parameters are the same as above.

2.2. Condition setting

In this paper, the solar greenhouse, except for different roof inclination and different greenhouse span caused by different roof inclination, other building parameters and external environment parameters are the same. The specific settings are as follows: greenhouse orientation: 40 ° north latitude, 120 ° longitude; greenhouse roof shape is double circle composite roof curve; greenhouse ridge height is
3.94 m; covering material PVC, the light transmittance of new dry and clean materials is 85%, the light loss rate caused by structural material shading is 10%, the light loss rate caused by aging degree of covering materials is 8%, and the pollution degree of covering materials causes The light loss rate is 8%, and the haze of the covering material (the scattering effect of the transparent covering material on the direct light) is 10%. Specific time period: 9:00-15:00, true sun time on December 22. The sky was clear and cloudiness was 1.

The change of greenhouse span: when the ridge height of greenhouse is constant and the roof inclination is 26 °, 28 °, 30 ° and 32 °, the greenhouse span is 8.87m, 8.22m, 7.65m and 7.15m respectively.

2.3. Evaluation method
There are five evaluation indexes for the light environment of the solar greenhouse, which are: the average transmittance of the front roof (%), the average irradiance of each surface of the greenhouse in the specified time period (w / m²), the accumulated light radiation energy of each surface in the unit greenhouse length (MJ), the accumulated total light radiation energy in the unit greenhouse length (the accumulated light radiation energy of the ground, the wall and the rear roof in the unit greenhouse length The sum of the quantities in MJ) and the direct astigmatism ratio (%).

3. Result

3.1. Average transmittance of front roof

As shown in Figure 1, the average transmittance of the front roof changes with the inclination of the roof. It can be seen from the figure that when the ridge height of the greenhouse is constant, the average transmittance of the front roof increases with the increase of the inclination of the roof. This shows that the increase of the roof angle is conducive to the increase of the overall light transmittance of the front roof. The reason is that the increase of the roof angle and the decrease of the incidence angle of solar radiation lead to the increase of the overall light transmittance of the front roof. However, the increase range is limited, especially when the roof angle increases from 28 ° to 30 °, the overall transmittance of the front roof hardly changes, so it is very difficult to improve the transmittance of the roof by increasing the roof angle when the height of the greenhouse ridge is unchanged.
3.2. Average irradiance of each surface of greenhouse in a specified time period

As shown in Figure 2, the average irradiance of each surface of the greenhouse changes with the height of the roof ridge in the specified time period (9:00-15:00 on December 22, true sun time). It can be seen from the figure that when the height of the roof ridge is unchanged, and the roof inclination increases, the average irradiance of each surface of the greenhouse changes to different degrees. The average irradiance of greenhouse floor decreased slowly, and the average irradiance of greenhouse floor and rear roof increased slightly. When the roof angle increases from 28° to 32°, the change of the average irradiance of the greenhouse floor, wall and back roof is: -5.8w/m², 6.2w/m² and 1.5w/m² respectively, with the increase rate of: -3.7%, 2.1% and 3.1% respectively. The reason is analyzed: the average irradiance of the greenhouse floor decreases, which is mainly restricted by the shortening of the greenhouse span; while the average irradiance of the greenhouse wall and back roof is slightly increased The increase is essentially affected by the increase of roof inclination and light transmittance.

3.3. Accumulated light radiation energy of each surface in unit greenhouse length

As shown in Figure 3, the accumulated light radiation energy of each surface of the greenhouse in a specified period of time varies with the inclination of the roof. It can be seen from the figure that under the same roof inclination, the accumulated light radiation energy of the greenhouse floor is the largest, that of the wall is the second, and that of the rear roof is the smallest. When the roof angle increases, the accumulative radiant energy of greenhouse floor decreases obviously, while the accumulative radiant energy of greenhouse wall and back roof increases slightly. When the roof angle increases from 28° to 32°, the cumulative light radiation energy of the ground, wall and back roof of the greenhouse changes by -6.68 MJ, 0.44 MJ and 0.05 MJ respectively, with the change rates of: -22.4%, 2.0% and 3.1% respectively.
Analysis of the reasons: when the roof angle increases, although the average radiant illuminance of the greenhouse floor changes little, the span of the greenhouse floor significantly decreases, resulting in a significant reduction in the amount of light entering the ground, that is, the greenhouse span is the main factor for the change of the accumulated radiant energy of the greenhouse floor; the accumulated radiant energy of the greenhouse wall and the rear roof slightly increases, which is due to the increase of the roof angle. The influence of large and slightly increased light transmittance, that is, the roof inclination is the main factor of the accumulated light radiation energy of the greenhouse wall and rear roof.

3.4. Total accumulated light radiation energy per unit greenhouse length

As shown in Figure 4, the total energy of light radiation accumulated in a given period of time within a unit greenhouse length varies with the inclination of the roof. It can be seen from the figure that the total radiant energy of greenhouse is linearly and negatively related to the inclination of roof. When the roof angle increases from 28° to 32°, the total energy of light radiation in the greenhouse decreases by 6.19mj, the decrease percentage is 11.7%. The essential reason is that the reduction of greenhouse span plays a leading role in the reduction of total energy of light radiation in the greenhouse. This shows that when the ridge height of greenhouse is constant, the accumulation of total incoming light decreases with the increase of roof inclination.

3.5. Direct astigmatism ratio

| Roof inclination angle | 26°  | 28°  | 30°  | 32°  |
|------------------------|------|------|------|------|
| Direct astigmatism ratio | 74.0/26.0 | 74.5/25.5 | 75.0/25.0 | 75.4/24.6 |
| Ratio                  | 2.85:1 | 2.92:1 | 3.00:1 | 3.07:1 |

Table 1 above shows the change of the direct astigmatism ratio with the inclination of the roof. It can be seen from the table that with the increase of the roof angle, the direct scatter ratio shows a significant increase trend, which indicates that the increase of the roof angle is not conducive to the increase of the proportion of scattered light in the greenhouse, that is, when the height of the greenhouse ridge is constant, the increase of the roof angle will aggravate the uneven light in the greenhouse.

4. Conclusion & Discussion

When the ridge height of the greenhouse is constant and the roof angle changes, all the evaluation indexes in the greenhouse change to different degrees: The average light transmittance of the front roof, the average radiation illuminance and the accumulated light intake of the greenhouse wall and the back roof have little change, but slightly increase, which is mainly restricted by the inclination of the roof; the accumulated light intake of the greenhouse floor and the accumulated total light radiation...
energy in the greenhouse have significant change, which is negatively related to the inclination of the roof. When the roof angle is increased from 28° to 32°, the cumulative light input to the ground and the total light input to the greenhouse are reduced by 22.4% and 11.7% respectively. At the same time, the proportion of the scattered light in the greenhouse is reduced. This shows that when the height of the greenhouse ridge is constant, the total light input to the greenhouse is reduced and the light heterogeneity is increased, which is not conducive to the growth of greenhouse crops. Therefore, it is not recommended to increase the inclination of the roof when the ridge height of the greenhouse is constant.

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