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Modeling Cucumber leaf orientation as growing in heterogeneous canopy

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Highlights: The change of leaf azimuth during cucumber growth was analyzed. Five plant density treatments were conducted to analyze the relationship between light environment and leaf azimuth. There is significant evidence shown in the results that leaf distribution frequency changed as the influence of heterogeneous light conditions.

Key words: LAI, Leaf azimuth, Sunlit greenhouse, Cucumber, Heterogeneity

INTRODUCTION

In cucumber canopy, it can be observed that cucumber leaves adjust the orientation into the direction of the incoming radiation to improve light interception (Kahlen *et al.* 2008). The study of Chen *et al.* (1994) shows that leaf orientation has much greater effects on canopy photosynthesis than spatial distribution of leaf area density. Leaf azimuth should be explicitly described as it has a big impact both on light distribution and photosynthesis (Sarlikioti 2011). Kahlen *et al.* (2008) have done some remarkable research on leaf phototropism in a cucumber canopy. A model was developed by considering leaf reorientation as triggered by the gradient in the R: FR ratio between left and right half of one leaf. Some of our early results show that cucumber leaves in a sunlit greenhouse usually reoriented their azimuth, especially, the leaves oriented to north as influenced by the north wall of the greenhouse which blocks most of the light. The leaf orientation was affected by not only the shade caused by leaf blocked but also the environment heterogeneous in sunlit greenhouse. The objective of this work is to analyze the changes of leaf azimuth during cucumber growth and describe the relationship between light environment and leaf azimuth character using a simplified model.

MATERIALS AND METHODS

Experiments

Four experiments were conducted in autumn 2012 in experimental sunlit greenhouse at Beijing Academy of Agriculture and Forestry Sciences (39º26′ N, 116 º 19′ E). The experiments had 5 density treatments, the planting spacing of treatments (row × plant) were: 30×40cm, 35×40cm, 40×40cm, 45×40cm, 50×40cm. Every two rows in one ridge, the distance between ridges was 70cm. Eight neighboring plants per treatment were selected to measure leaf azimuth, leaf length and leaf width at 2012-10-11, 2012-10-18, 2012-10-29 and 2012-11-8, respectively, as cucumber growing.

Leaf distribution statistics

Leaf distribution in canopy was separated into 8 orientation class. The frequency of leaf distribution in each class and in each canopy was counted. The data of leaf distribution frequency in 30×40cm, 40×40cm, 50×40cm canopies of four experiments were used to analyze the changes of leaf azimuth during cucumber growth and describe the relationship between light environment and leaf azimuth character. The data of 35×40cm and 45×40cm treatments were used to evaluate the accuracy of the model.

Due to the heterogeneous characteristics of light distribution in sunlit greenhouse, light environment is difficult to measure directly. Following the Beer-lambert law, light intensity in the canopy is directly impacted by LAI. Therefore, we use LAI to indicate the light condition in the canopy based on the theory that as LAI increased the light transmittance decreased. In order to study the leaf distribution in detailed, the leaf azimuth distribution range from 0º to 359º in a clockwise direction was separated into 8 orientation classes named in capital letters respectively (from I to VIII) and each class contains 45º angle ranges.

RESULTS

The data of leaf distribution frequency in each class as cucumber growing are shown in figure 1. Leaf distribution was uniform at an early stage in which the leaf number per plant was 8, but it became non-uniform at late stage in which the leaf number per plant was more than 18. The azimuth of most leaves at late stage reoriented to south. Leaf frequency in class I and VIII decreased from nearly 12.5% to 5% while leaf frequency in leaf azimuth distribution classes IV and V increased from nearly 12.5% to 20%, and leaf frequency in II, III, VI and VII fluctuated during cucumber growing in different planting density treatments.

The LAI increased with the increase of leaf number and leaf area; at the same time, planting density also changes leaf area index. With the aim to simplify the relationship between leaf orientation and LAI, the orientation class was integrated into 4 classes which were north (316º-45º), east (46º-135º), south (136º-225º) and west (226º-315º). The leaf distribution frequency changing was different between 4 classes (Fig. 2). A linear function was used to describe the relationship between LAI and leaf distribution frequency in different classes. The regression function and determination coefficient are showed in table 1. The leaf distribution frequency in 316º-45º decreased as LAI increased while the opposite situation was found in the southern direction (136º-225º). There was no significant increase or decrease of frequency in east and west range. The regression functions also show that at the beginning of cucumber growth, the leaf distribution in 4 ranges is uniform (nearly 25%) which match the result in Fig. 1(A) very well.

The function accuracy was tested using data measured in 35×40cm and 45×40cm treatments. The data are shown in Fig. 3, and the RMSE is 6.46.

DISCUSSION

The aim of this study was to analyze the changes in leaf azimuth during cucumber growth and describe the relationship between the light environment and leaf azimuth character using the regression functions (Table 1). There was a significant change in leaf orientation distribution during cucumber growth. The results shown in Fig.1 B exhibited a great fluctuation between different orientation classes and we considered that it might be because of insufficient data. The determination coefficient for LAI dependent leaf distribution changes was low in the eastern and western azimuth classes. We considered that even the slope of the regression functions of this two distribution ranges was very small which means that the leaf distribution frequency changed little with LAI increased, but the frequency of leaf distribution was not constant, since the orientation of most leaves deviated from initial direction were restricted by maximum rotation angle, so some leaves re-orientated the direction from north to east or west. We considered that the frequency in eastern and western classes was affected by the two other ranges. The accuracy of the regression function of north and south distributions was higher than east and west. In the future we need more detailed experiments to refine the relationship between leaf distribution and LAI. The leaf distribution character will be used as parameter in cucumber canopy structural modeling which will be used in light interception calculation, so we also need to evaluate the accuracy of leaf distribution character using canopy light interception results.

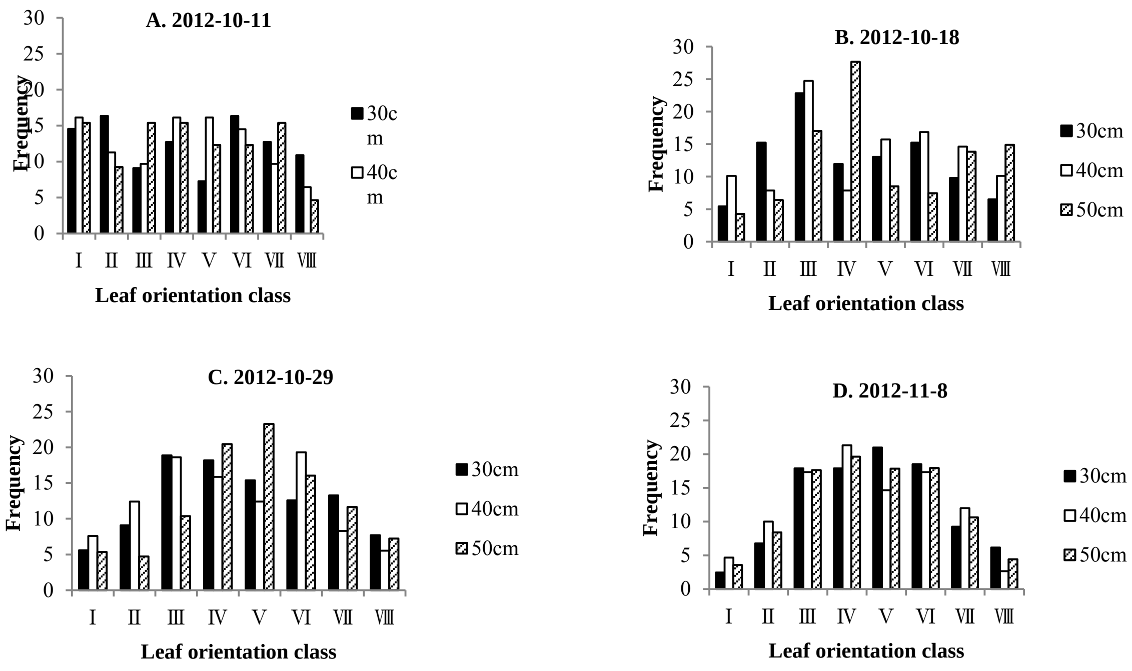

Fig. 1 leaf distribution frequency in each class of 3 treatments (30×40cm, 40×40cm, 50×40cm canopy density) at 4 times. Eight neighboring plants per treatment were selected and average leaf numbers per plant of 4 times were 8, 12, 18, 22, respectively.

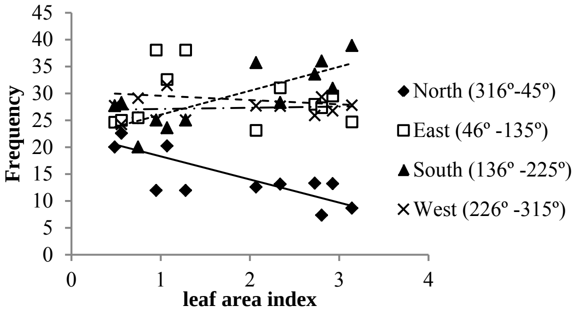

Fig. 2 Leaf distribution as LAI changes.

Table 1. Regression function and determination coefficient (R^2) for LAI dependent leaf distribution changes

Distribution	Regression function	R^2
316º-45º	y = -4.3061*L AI+ 22.598	0.5878
46º -135º	y = -0.7943*L AI + 30.341	0.0246
136º -225º	y = 4.461*L AI + 21.565	0.6187
226º -315º	y = 0.227*L AI + 26.885	0.012

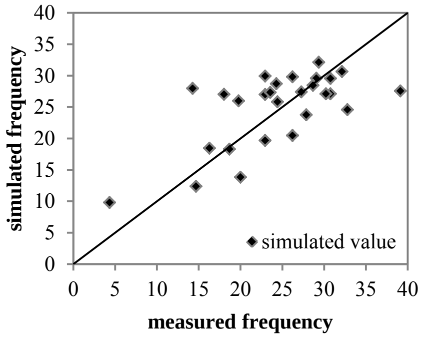

Fig. 3. Comparison between the simulated and measured leaf distribution frequency

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