Quantification of Spatial Light Distribution of Field-grown Tobacco Canopy Based on Three-Dimensional Modeling

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Background

Quantification of the interaction of tobacco plant growth with their environmental condition is pivotal since environmental condition has great impacts on yield and quality of tobacco.

The interception of incident radiation of a canopy is significantly affected by plant architecture and this can be characterized by means of modeling.

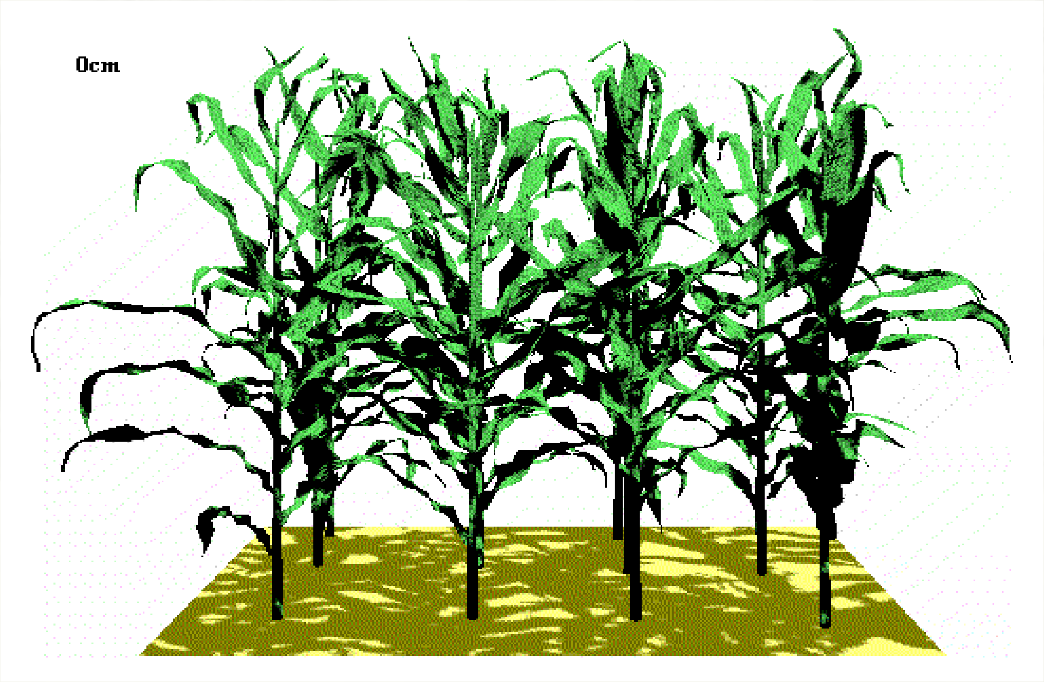
Background

It is difficult to precisely quantify the radiation distribution in a tobacco canopy using traditional models partly due to the complexity of tobacco leaf geometry.

In recent decades, more and more researchers work on three-dimensional (3D) plant modeling. 3D architecture models have been constructed successfully for various crops, e.g. cotton, maize and rice.

Background

Canopy radiation distribution and photosynthesis can be simulated accurately based on 3D plant architecture models.



Background

Three-dimensional digitizing has become the most effective means for collecting the architectural information of individual plants.

3D digitizer (Fastrak, Polhemus, USA)

Background

3D laser scanner
(FastSCAN, Polhemus, USA)

Three-dimensional laser scanning has also been used for collecting the geometrical shape of plant organs accurately.

Objectives

To quantify the spatial radiation distribution of a field-grown tobacco canopy

Plant geometry measurement

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3D canopy architecture model

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Canopy light distribution model basing on Monte Carlo ray tracing

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Model validation.
Simulations of spatial light distribution in canopy

Field experiment

The field experiment was conducted in 2012 at Zhaowei Experimental Station (24° 18′N, 102° 29′E, Altitude: 1642 m), Yuxi, Yunnan, China.

No strong wind significantly disturbed canopy architecture during the measurement.

3D plant digitizing in the field

Four neighbor plants in two adjacent rows (with two plants in each row) in the middle of the experimental field were selected.

3D coordinates of the midrib and both leaf margins of each leaf of the selected plants was measured *in situ* using the Fastrak Stylus (Polhemus, USA) in August 5.

3D laser scanning indoor

- Then these measured plants were transplanted into pots with soil for indoor measurement.
- The geometry of each leaf blade of these plants was scanned using FastSCAN Cobra™.
- To minimize the interference of light on laser scanning :Metal stuffs were cleaned up from the measurement area before scanning. The incoming light was shaded.

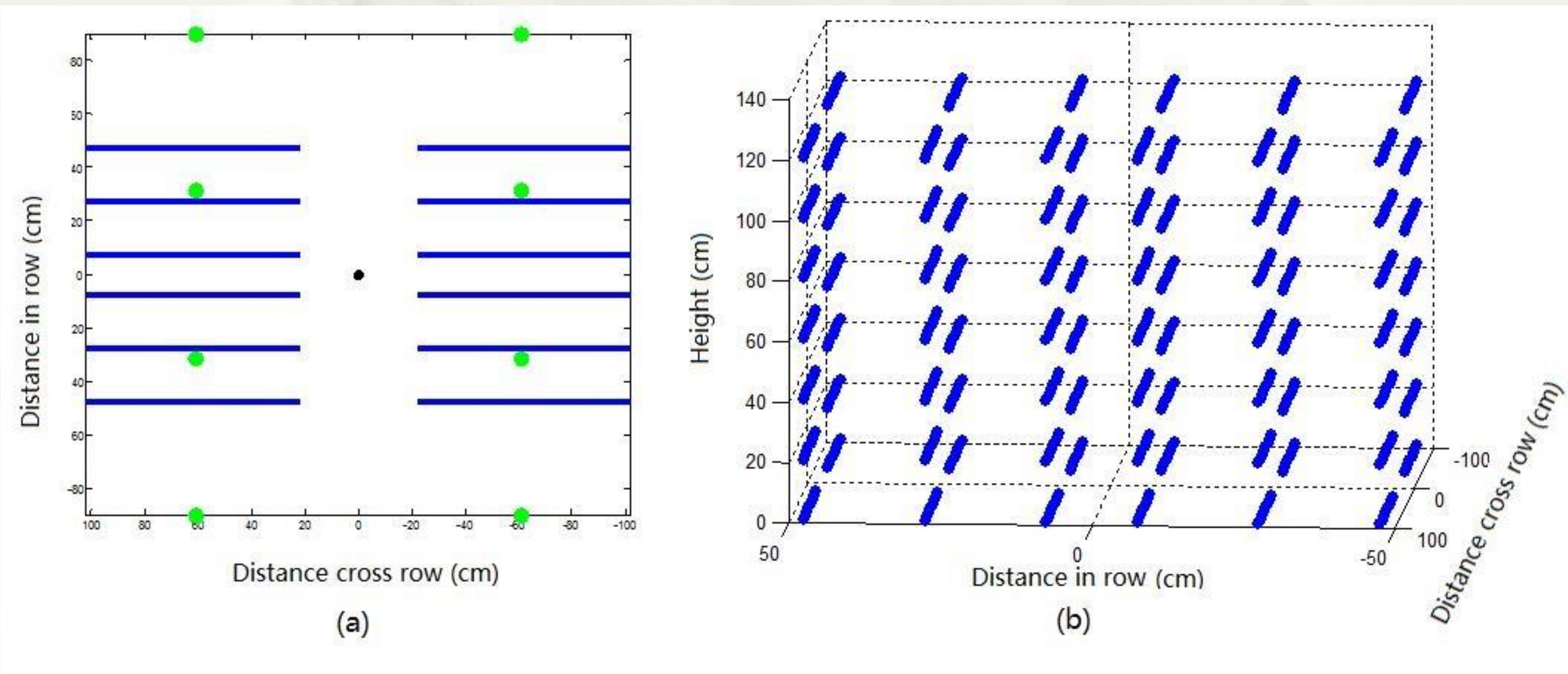
Field measurement of spatial radiation distribution in a tobacco canopy

The 3D radiation distribution of the selected tobacco canopy was measured in the field from 12:00 to 13:00 in August 5 using AccuPAR (LP80, Decagon Devices, USA).

The AccuPAR has a 80-cm probe with 80 sensors arrange evenly and gives averaged output for every 10-cm segment.

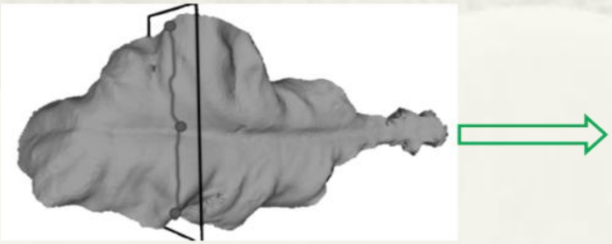
Field measurement of spatial radiation distribution in a tobacco canopy

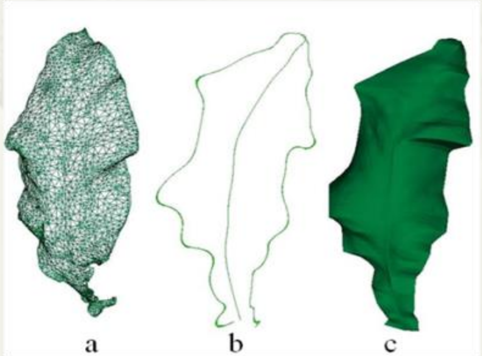
Measurements were taken at 20-cm intervals in heights, and 12 positions in each horizontal plane



Modeling the architecture of a field-grown tobacco canopy

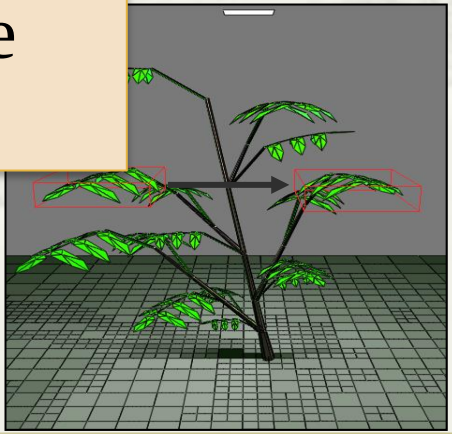
- Realistic geometry of leaf blades were obtained with the scanning data. The geometry of these leaves was then mapped onto the corresponding leaf profiles measured in the field.
- Accordingly, the realistic 3D model of the measured tobacco plot was developed by combining the models of individual measured plants according to the actual row spacing and plant spacing within the row.





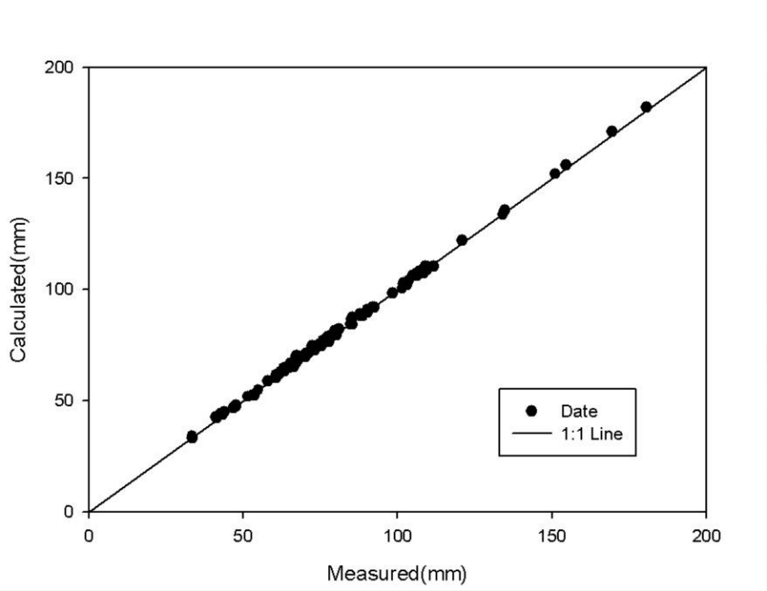
Simulation of 3D radiation distribution in the tobacco canopy

- The spatial light distribution in the measured canopy was simulated using the MCRT model. The simulation was conducted based on the constructed tobacco architectural model for the measurement time.
- Field radiation measurements were compared against simulation results for assessing the models used.



Results:
accuracy of plant geometry

We used FastSCAN Cobra to measure the geometrical shape of tobacco plants. The accuracy of measurement is very high. It shows that all the calculated and measured values were distributed close to 1:1 line with a very good fittness.



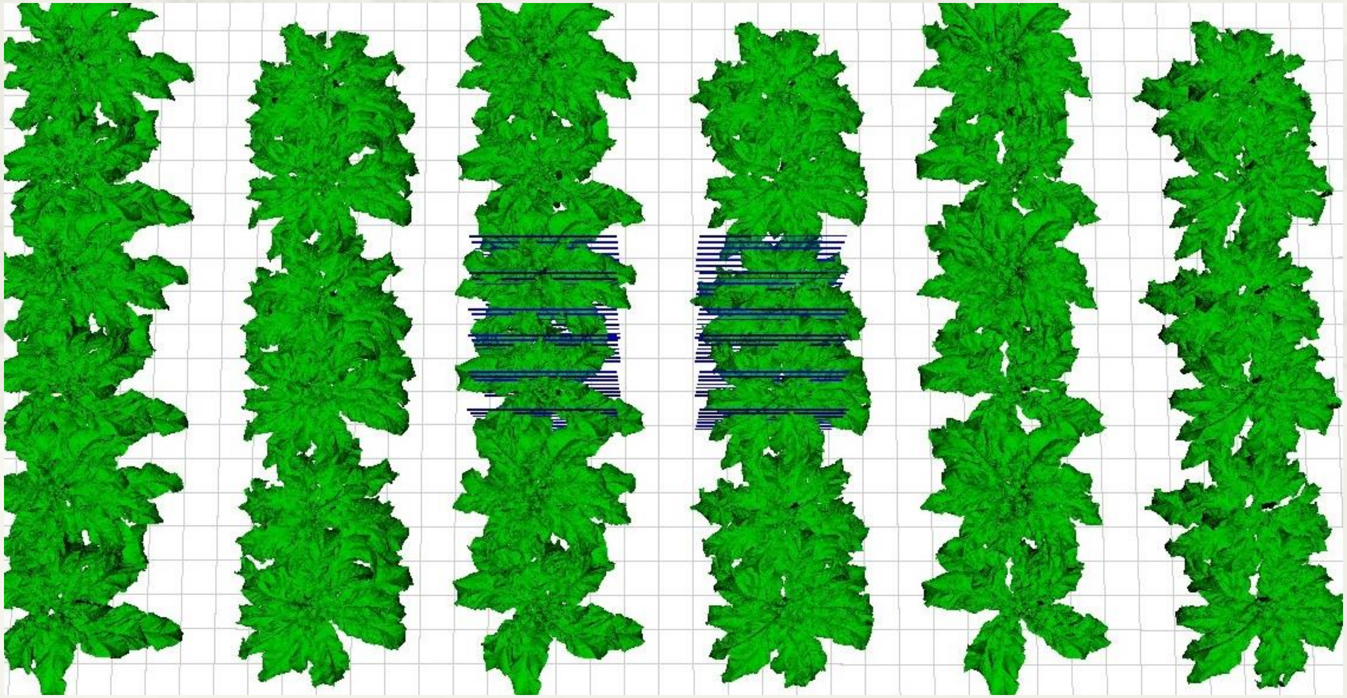
Results: field canopy architectural model

The constructed plant architectural model truthfully characterized the geometry of leaf blades as well as their spatial orientations, and hence described the spatial characteristics of the measured canopy architecture realistically.

Results:
field canopy architectural model

By copying the canopy unit in different directions, a virtual canopy used to mimic the field-grown canopy was built.

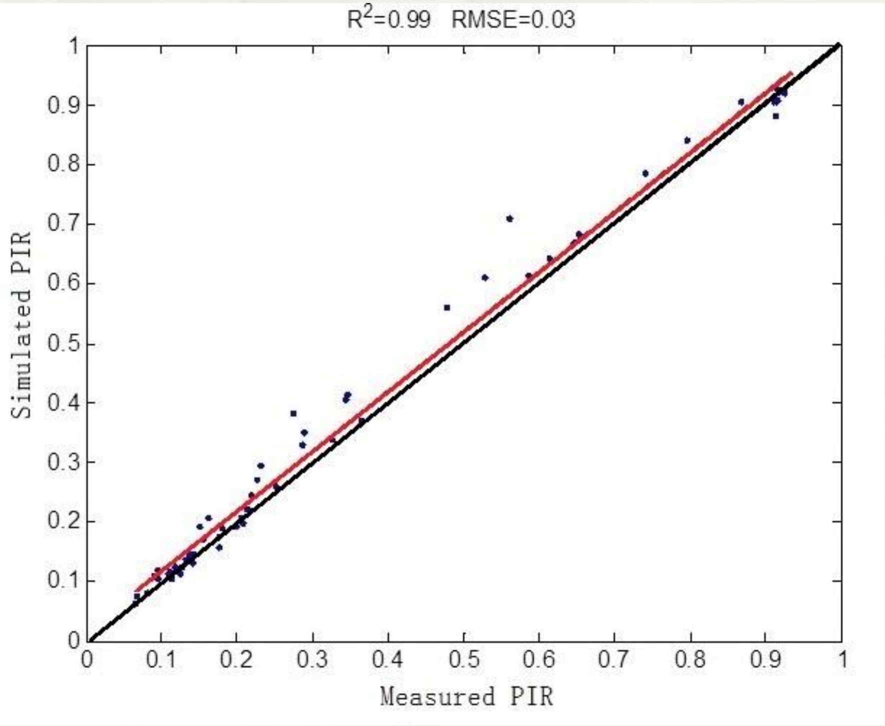
96 virtual AccuPAR sensors were reconstructed and put inside the central unit according to the real positions of AccuPAR in the field radiation measurement.



Results:

Simulation of canopy light distribution and its validation

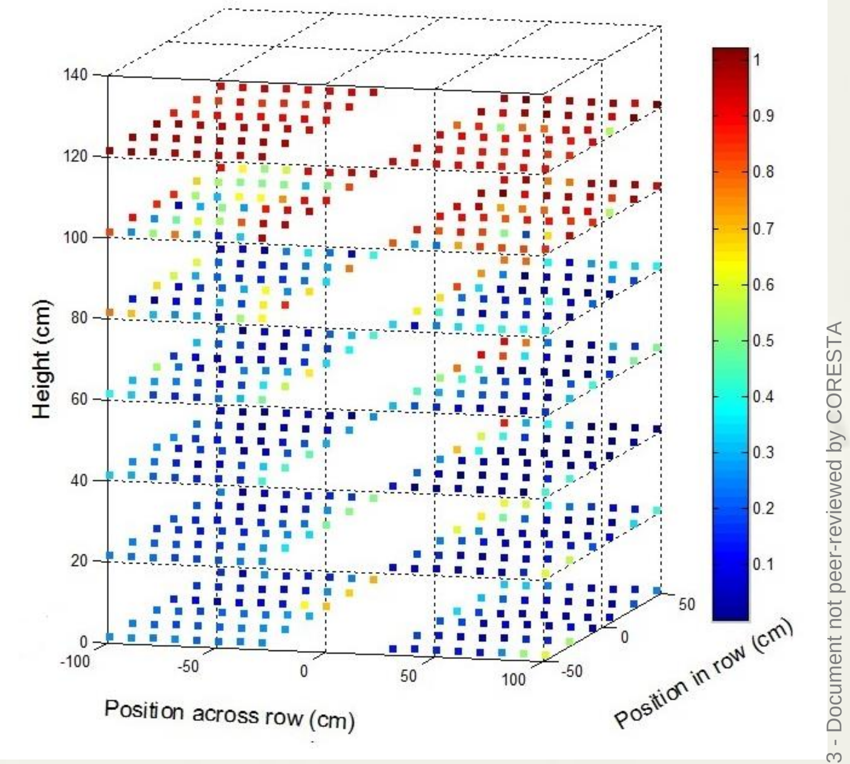
The PIR (PAR interception ratio) over virtual AccuPAR sensors was simulated with the same solar position and sky condition corresponding to the field measurements. Measured and simulated profiles of PIR at different horizontal distances cross row were compared. Correlation between simulations and measurements were strong (R^2=0.99) with no significantly deviated point.



Results:
Simulation of spatial light distribution in the canopy

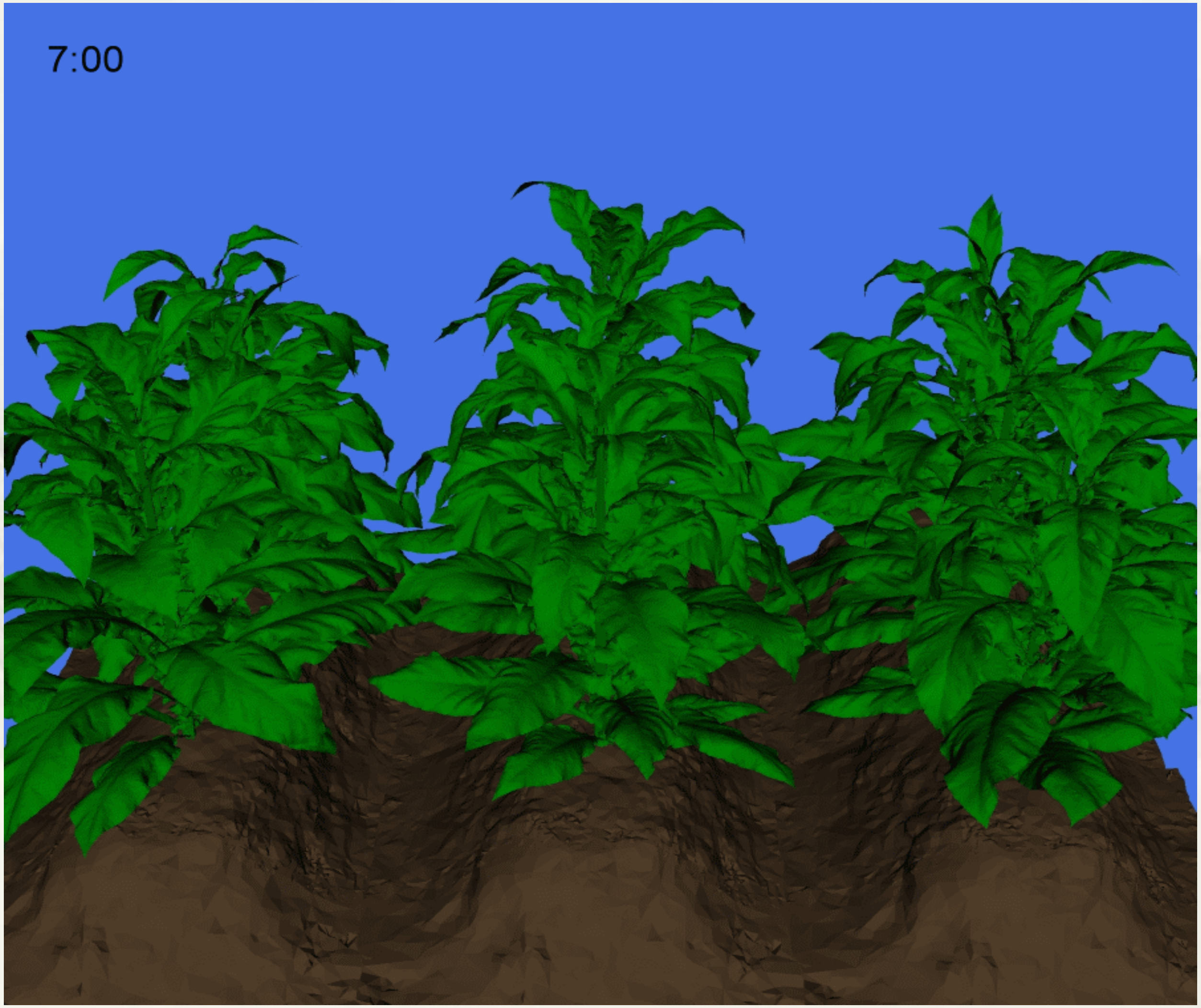
The light distribution over virtual AccuPAR sensors in the canopy at 12:30 on Aug. 5 was simulated. The spatial distribution of PIR in the tobacco canopy was showed in the figure.

It illustrated that the PIR on most points above 1.2 m height was higher than 0.8, then it declined with height decrease. Sharp decline occurred for most points inside the row until the height decreased to 0.8 m, after which the variation tended to be smooth.



Results:

Visualization of simulated diurnal radiation distribution in the tobacco canopy (August 5, 2012)



Conclusions

* The spatial light distribution in the tobacco canopy was accurately simulated based on the constructed 3D canopy architectural model.
* The results showed that the light distribution simulated using the MCRT model had strong correlation with the field measurements. It was confirmed that the MCRT model can meet the need for the simulation of light distribution in field-grown tobacco canopy.
* It also illustrated the great potentials of 3D modeling with high spatial resolution for the study of interactions between plant growth and light environment.

ACKNOWLEDGEMENTS

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Thanks for Your Attention!