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Real-time calculation of total light interception in crop canopy

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Highlights: Daily total PAR interception is divided into three scales: organ, plant and canopy, and the core is organ scale calculation. Calculation of total intercepted PAR could be combined with photosynthetic rate parameter to study the relation between photosynthesis efficiency and production of specified canopy, after that, further analysis of agricultural production decisions may be carried out.

Key words: Total light interception, real-time calculation, sky visible rate

INTRODUCTION

Simulation of distribution of photosynthetically active radiation (PAR) in crop canopy is a key factor of quantitative photosynthesis simulation in precise agricultural model. Most current light interception research focused on simulation algorithms of spatial light distribution within the canopy (Chenu et al, 2008; Wang et al, 2008). The development of computer hardware and 3D scanner now helps to generate more accurate geometric model of crop canopy, which leads to a better geometric basis for light distribution calculation. The calculation is developed into a more accurate surface element scale instead of simple statistical model.

Generally, daily total PAR interception is divided into three scales: organ, plant and canopy, and the core part is organ-scale calculation. Calculation of total intercepted PAR could be combined with photosynthetic rate parameters to investigate the relation between photosynthesis efficiency and production rate of specified canopy, and then further analysis of agricultural production decisions may be carried out.

There are three components of light intercepted into canopies, i.e. direct solar radiation, sky diffuse radiation, multi-reflected and scattered radiation. The third component may be omitted in the estimation of total PAR into canopies (Alados et al, 2002). The speed of light interception calculation has beenone of the bottlenecks of this research. In fact, direct light calculation is much faster and can be calculated in real-time for every time step, however, diffuse light calculation is very time consuming and limits speed from real-time. In this paper, a robust algorithm of real-time calculation of total light interception in crop canopy is proposed to estimate total light interception in different scales along with the time changing.

MATERIALS AND METHODS

The field experiment was carried out at the experimental field of Beijing Academy of Agriculture and Forestry Sciences (39°94'N, 116°29'E), China. Maize (*Zea mays* L. variety 'XY335') canopy architecture and intensity of PAR were measured in sub-plots located in the middle of the canopy on September 23 and September 25 of 2010 respectively. A 5 plants $\times$ 3 rows geometric model containing 195576 facets (Fig.1) was constructed using measured morphology data acquired by 3D digitizer (Xiao et al, 2011). Geometric organs are composed of basic facets, and blades require double-sided facets. It's assumed that the 3D structure of the canopy kept unchanged during the calculating procedure. Continuous intercepted PAR with a

3-second time interval was measured for the ear leaf on the plant in the middle of the canopy using a self-developed light interception device which contains 11 sensors uniformly distributed on the leaf. This measurement process begins at 10:11 and ends at 15:25.

For each facet in the canopy, the sky visible rate (SVR) was calculated through projecting all the facets on a hemisphere which located on the calculating facet (Wang et al, 2005). In this method, proportion of unoccluded area of the hemisphere was calculated to acquire the facet's SVR. For all the facets in the canopy, this calculation is time-consuming. We adopted a multi-resolution subdivision hemisphere method here to calculate SVR of a given canopy, also applied multi-core parallel computing to speed up. A canopy with 150000 facets took 30 minutes to calculate SVR by multi-core parallel computing on an 8-core processor workstation. Since SVR of each facet doesn't change when the geometric canopy is still, this proposed method pre-computed SVR to make total calculation real-time.

Suppose T is the total time of the calculation and it is divided into N sections, i.e. N+1 time node and the length of each time section is *T/N*. Actual external light data including total radiation R_i and the proportion of direct light was measured at each time node *i, i=0,…,N*. Therefore, initial external direct light R_i^{direct} and diffuse light $R_i^{diffuse}$ were calculated at each time node.

Direct light interception within the canopy was calculated by Z-Buffer projection. Diffuse light intercepted on each facet was obtained by multiplying external diffuse light and SVR on the facet. Finally, total light intercepted by an organ in time length *T* is:

$$R = \frac{T}{N}\sum_{i=1}^{N}\sum_{k=1}^{M}(R_i^{direct}\cos\theta + R_i^{diffuse} r_k)s_k$$

Where s_k is the area of facet k, r_k is the SVR of facet k, *M* is the total facet number of a organ or a plant or canopy, $\cos\theta$ indicates the cosine value of the angle between *k*-th facet's normal and the direct light direction. The total intercepted light calculation of an organ in *T* is complete. Because of the direct light distribution is using Z-Buffer projection in real-time, with a finite number of productions and summations, the entire calculation could achieve real-time.

RESULTS AND DISCUSSION

We selected intercepted PAR from the measured data at 20 time points from 10:30to 15:15per 15minutes and meanwhile intercepted PAR on the same blade was simulated on the same 20 time points. Fig.2 shows the relation between the measured data and simulation. These results show that the general trend and data distributed range are almost same between the simulation and measured data. The main reason of the errors can be attributed to 2 factors：(1) Error from artificial digitized geometric model. (2) Breeze leads to instability of the upper leaves in the experiment. Fig.3 provides a visualization result at 12:00.

As a result, the proposed method could calculate the total light interception among a specified period of time at different scales including organ scale, plant scale and canopy scale. Furthermore, this method could be combined with actual field equipments to achieve real-time calculation of situational awareness and also could be used for real-time rendering of the light distribution animation of crop canopy.

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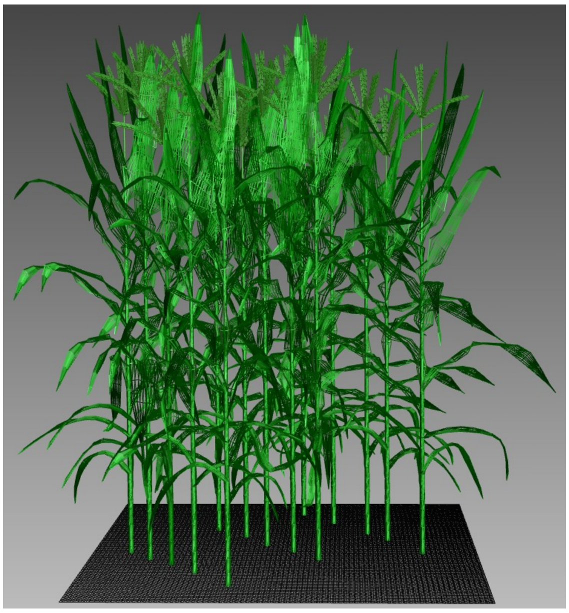

Figure 1: Geometric model of the canopy.

Figure 3: Visualization of the simulated interception at 12:00.

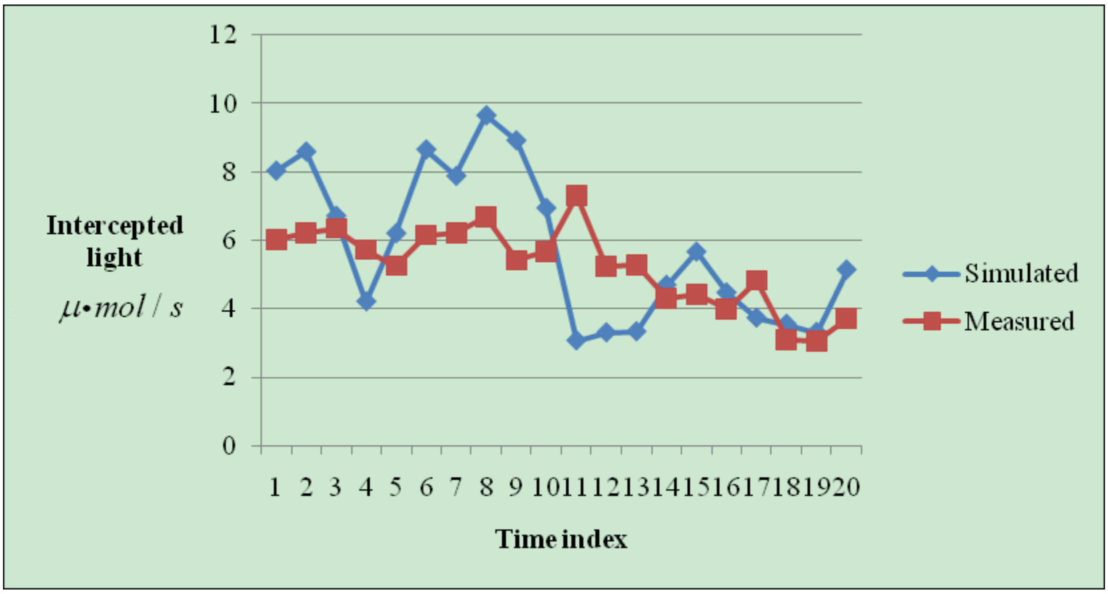

Figure 2: Contrast between simulation and measured data.