Canopy Architecture Quantification and Spatial Direct Light Interception Modeling of Hybrid Rice

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Introduction

Rice is one of the most important crops in the world, and hybrid rice is planted broadly in China which accounts for half of China's rice acreage. Quantification of rice spatial architecture is useful for breeding high yield cultivars, and studies on morphogenesis and development of rice plant structure have been carried out (Watanabe *et al*., 2005). Three-dimensional (3D) digitizing has been a powerful method for the measurement of plant architecture (Sinoquet *et al*., 1998), and 3D light distribution model has been used for the evaluation of different plant architecture (Pearcy and Yang, 1996; Falster and Westoby, 2003; Sinoquet *et al.*, 2007). However, by far, few studies had been carried out on the simulation of spatial light interception of rice canopy grown in the field based on 3D digitized data. In this study, 3D canopies of two hybrid rice cultivars were computer reconstructed based on measurement data obtained with 3D digitizer. Then, characteristics of canopy architecture were analyzed and spatial direct solar radiation interceptions of these two cultivars were simulated with a 3D light distribution model (Wang *et al*., 2006).

Materials and Methods

Field experiment was conducted in 2006 at the experimental farm of China National Hybrid Rice R&D Center, Changsha, China (28˚11′59″N, 113˚04′35″E). Two cultivars of hybrid rice (*Oryza sativa* L.) were planted. One is 'Shanyou63' which has the largest planting area in China. Another is 'Peiai64S/E32' which rice breeders assumed to be a morphological model plant type of super high-yielding rice.

Nine plants (3 rows × 3 columns) were selected at grain filling stage (25 August) and a 3D digitizer (3Space Fastrak, Polhemus, USA) was used to collect the 3D coordinates of plant organs, including midrib of leaves, stems, and main axis of panicles. The length and maximum width of leaf blades, the diameters of stems and panicles were measured after digitizing using a ruler and a micrometer respectively. Then, 3D canopies of this two hybrid rice cultivars were computer reconstructed.

The surface of each leaf blade was divided into facets (Wang *et al*., 2006) which the maximum length of each side was 5 mm. The area of each facet and its inclination angle (zenith angle of the normal to the facet) was calculated according to facet 3D coordinates. The canopies were vertically divided into several layers with 30 cm interval. Then, the distribution of leaf area for each inclination angle with 10° interval at each canopy layer was computed. Leaf area distribution in vertical profile was characterized by leaf area density (LAD, leaf area per unit volume).

The stems and panicles were simplified into planes whose normal azimuths were the same with solar azimuth, and divided into facets like blades. Light interception of each facet in the canopy was computed on measurement date of digitizing (25 August) with a sun elevation increment 5° using a 3D model for direct solar radiation interception within the canopy, which based on parallel projection and Z-buffer algorithms (PPZB, Wang *et al.*, 2005). Light interception density (LID) was used to characterize the vertical profile of light distribution in the canopy which defined as the ratio of direct photosynthetically active radiation (PAR) intercepted by facets per unit volume to the direct PAR at the top of canopy per unit area.

Results

There was a significant difference for the distribution of leaf inclination angle in the vertical profile for the two cultivars (Fig. 1). Peiai64S/E32 had more erect leaf area at the upper canopy with the angle between 70° and 90°. The maximum inclination angle decreased from the top to bottom, with a minimum of 30° to 50° at lower canopy. The inclination angle of Shanyou63 was relatively smaller with the value between 50° and 80° for the upper canopy and its distribution of inclination angle had a small variation in the vertical canopy profile.

The calculated LADs varied with plant height for both cultivars were shown in Fig. 2A. This clearly showed that the maximum value of LAD was at the middle of the canopy (about 65 cm), while LAD of Peiai64S/E32 distributed more evenly than Shanyou63 in the vertical canopy profile.

The simulated results using PPZB model showed that direct solar radiation can penetrate more deeply into the canopy with the sun elevation angle increasing (Fig. 2B). The sunlit area of the canopy can be divided into two parts: Shanyou63 intercepted more direct solar radiation at the upper of the canopy than Peiai64S/E32 with low sun elevation angles (< 32°, e.g. 10° and 30° in Fig. 2B), and this trend reversed at higher sun elevation angles (> 32°, e.g. 50° and 70°, in Fig. 2B).

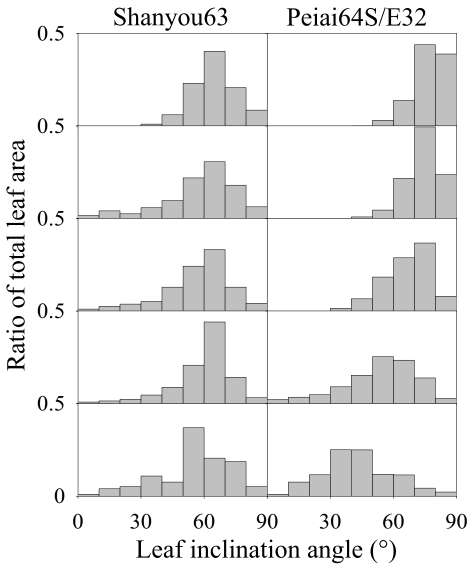


Fig. 1. The ratio of leaf area for each rank of inclination angle to the total leaf area per canopy height layer (30 cm) for Shanyou63 and Peiai64S/E32. Leaf inclination angle was computed as zenith angle of the normal to the facet.

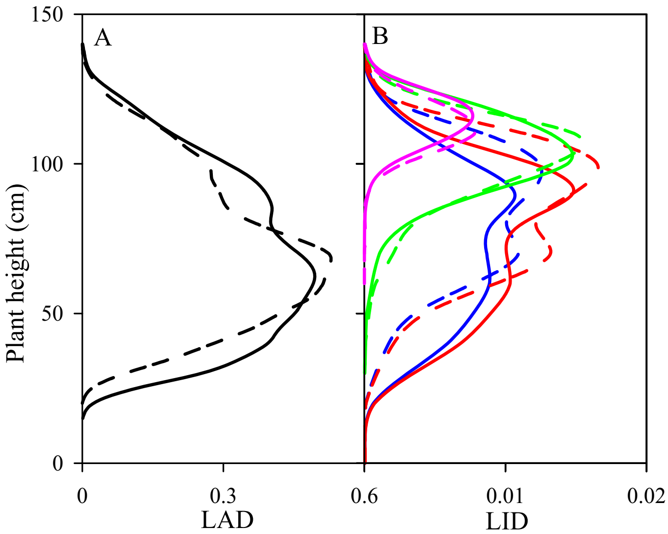
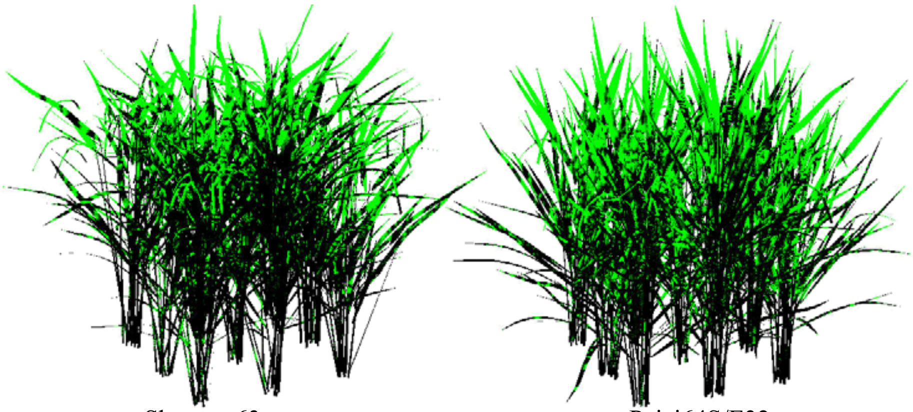


Fig. 2. Leaf area density (LAD, A) and light interception density (LID, B) as a function of plant height for Shanyou63 (dash line) and Peiai64S/E32 (solid line). LID was calculated when the sun elevation was at 10° (pink), 30° (green), 50° (blue) and 70° (red).

Fig. 3 showed the simulation results of the spatial distribution of solar radiation within the canopies for the two hybrid rice when the sun elevation angle was at the maximum sun elevation angle (73°). The canopy of Shanyou63 intercepted up to 92 % of direct solar radiation, which was more than Peiai64S/E32 (89 %). Leaves, panicles and stems contributed 85.8 %, 13.7 % and 0.5 % of light interception respectively for Shanyou63 and 81.9 %, 17.6 % and 0.5 % respectively for Peiai64S/E32. The sunlit leaf area was only 33.6 % and 36.1 % for Shanyou63 and Peiai64S/E32, respectively. The ratio of sunlit leaf area was even smaller with lower sun elevation angle.



Shanyou63 Peiai64S/E32

Fig. 3. The visualization of simulated spatial light distribution of Shanyou63 and Peiai64S/E32 canopies. The sun elevation angle was 73° (25 Aug, 12:30). The green color was for sunflecks, the black for shaded parts.

Conclusions

Leaf area and leaf inclination angle distribution in the vertical canopy profile for two hybrid rice cultivars were analyzed with reconstructed 3D architecture model based on the data collected with a 3D digitizer. The results showed that leaf inclination angle of Peiai64S/E32 was larger than Shanyou63, and leaf area distributed more evenly in the vertical canopy profile than the former one.

Spatial distribution of solar radiation within the canopies during the day of measurement was simulated by using PPZB model. The results showed that plant organs shaded each other dramatically with the sunlit leaf area less than 40 %. Shading effects of panicles in the grain filling stage should not be neglected. Generally speaking, rice cultivars with relatively evenly distributed leaf area in the vertical profile, and steeper leaf angle at the upper canopy and shallower at the lower canopy (e.g. Peiai64S/E32) can intercept more direct solar radiation at higher sun elevation angles, which is beneficial to lower leaves in the canopy for photosynthesis, thus increases crop yield.

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