# Methodology Comparison for Effective LAI Retrieving Based on Digital Hemispherical Photograph in Rice Canopy

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**Abstract.** The paper investigates methodology comparisons for retrieving effective leaf area index (LAI) using digital hemispherical photograph(DHP) in rice canopy. A set of self-making DHP instrument equipped with a fish-eye Len is utilized to acquire DHP in rice canopy, and some self-developing DHP processing procedures are utilized to pre-process DHP and extract effective LAI from DHP ($LAI_{DHP}$) rapidly. Based on Beer-Lambert's law and gap fraction that computed from DHP, four methods of single zenith angle (SZA), Lang, Mill formula(Mf) and iterative formula(IF) are used to derive $LAI_{DHP}$(effective LAI from them are called $LAI_{SZA}$, $LAI_{Lang}$ $LAI_{Mf}$ and $LAI_{IF}$ ,respectively). $LAI_{SZA}$, $LAI_{Lang}$, $LAI_{Mf}$ and $LAI_{IF}$ are inter-compared and are also compared with from AccuPAR LP-80($LAI_{APAR}$) and direct manual method ($LAI_{direct}$). It is found that, in general, $LAI_{SZA}$, $LAI_{Lang}$ $LAI_{Mf}$ and $LAI_{IF}$ are similar to $LAI_{APAR}$, but slightly lower than LAIdirect. During their intercomparsion, $LAI_{Lang}$ is more similar to LAIAPAR than other three and $LAI_{Mf}$ is more similar to $LAI_{direct}$, while $LAI_{SZA}$ and $LAI_{Lang}$ are almost the same. It is implied that Lang method outperformed the other three when compared with AccuPAR LP-80 and Mill formula method outperformed the other three when compared with direct manual measure.

**Keywords:** Rice Canopy; Digital Hemispherical Photograph; Effective LAI; Methodology Comparison

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## 1. Introduction

Rice is one of the uppermost crops in China, and are increasingly important worldwide-both to China and to South Asian countries, and there is an obvious need to obtain accurate estimates of its leaf area index (LAI). LAI is an essential input into many models of rice growth and yield estimation as well as being an essential component of comparative studies of many canopy-level attributes such as carbon cycle, transpiration and water use efficiency and understory synthetic photon flux density (PPFD) capture [1].So LAI is a dimensionless quantity characterizing the canopy of an ecosystem and a key component of biogeochemical cycles in ecosystems. Also managers (farmers and foresters), ecologists, site and global modelers, request information about canopy leaf area index. Unfortunately, this interface between ecosystem and atmosphere is very difficult to quantify, due to its spatial (horizontal and vertical) and temporal variability: annual cycles and interannual variability interact with the crop structure, stratification and heterogeneity [2].

Leaf area index can be measured directly by destructive harvest or allometric approaches [3, 4].Direct measurement may be practical with short canopies such as those of many arable crops, but is usually laborious and timely consuming. Indirect methods for determining LAI are now commonly used to overcome this problem [5,6] and have an additional advantage of being non-destructive. These methods include direct measurement of intercepted radiation using line quantum sensors [7] or radiometers, inclined point quadrant [8], gap fraction techniques [3,5] and capacitance sensors [9]. Of these techniques, it is the group based on gap fraction data that is now the most widely applied.

Digital hemispherical photographs (DHPs) have been widely used to measure canopy structure with the recent rapidly advancement in digital cameras and may have brought us a needed tool at a reasonable cost to estimate LAI. Digital hemispherical photography system(DHPS) made with a fisheye lens allow the acquisition of DHPs without the need of scanners to digitize images and can be quickly inspected on the camera's viewer, or on laptop screen and in a timely fashion in the field. Moreover, for a given camera, the hemispherical images are of consistent size and position on the digital array. This retrieval can be done in a consistent manner at many zenith angles [10, 11, 12] .

The model commonly used with indirect methods (including DHPS) to determine the LAI is the Poisson law. It assumes that leaves are uniformly and randomly distributed, which may be valid for homogeneous canopies[13],but does not hold for canopies with aggregative patterns [14,15].To allow the use of the Poisson law, the concept of effective LAI is proposed[16,17,18] as a result of the contribution of woody elements to the total plant cover, which results in overestimation of LAI, and clumping of foliage, which results in underestimation of LAI. So, in this paper, a set of self-made DHPS is applied to acquire DHPs of rice canopy, and some self-developing DHP processing procedures are utilized to process DHP and to compute gap fraction rapidly from them. Then four methods, single zenith angle (SZA), Lang, Mill formula(Mf) and iterative formula(IF),are utilized to derive effective LAI based on those gap fractions(effective LAI from those four are called $LAI_{SZA}$, $LAI_{Lang}$, $LAI_{Mf}$ and $LAI_{IF}$ , respectively). At last methodology comparison will be investigated in detail.

# 2 Materials and methods

## 2.1 DHPS

In this paper, a DHPS based a set of self-made digital photography sensor with a fisheye lens is utilized to capture fisheye photographs from rice canopy, which contents of fisheye lens, filters changer, CMOS camera and laptop computer, as shown in Figure1.

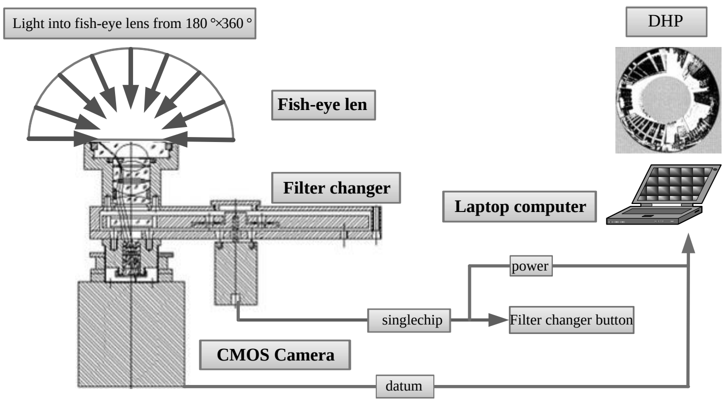



**Fig. 1.** Digital hemispherical photography system (DHPS) for rice canopy

In Figure 1, the optical component of DHPS is the fisheye lens with a view zenith angle of 180° mounted on the CMOS camera, which can acquire visible band DHP of rice canopy. These DHPs are stored in format of JPG on the laptop computer hard disk.

### 1.2 Site description and experiment design

The study area is located in China National Rice Research Institute (CNRRI), Fuyang city of Zhejiang province. DHPs are acquired began in Sept., 2009, 30 days after early rice seedling being transplanted, and once per week in cloudy day till rice tassels. Four sampling plots are set up in the selected paddy field, and AccuPAR LP-80, DHPS and directly manual measure are carried out sequentially in each sampling plot.

X parameter of AccuPAR LP-80 is initialized to 1.0 and detector is set up along two directions: obeying to rice seedling row and 45° clockwise. Mean value of two LAI-readings from two directions respectively is taken as the effect LAI by AccuPAR LP-80,which is called $LAI_{APAR}$.

The DHPS is set levelly in the center of each sampling plot, and inside rice canopy with its fisheye lens oriented upward to 0.5m beneath rice canopy top, or above rice canopy with fisheye Len downwards to 0.5m away from top of rice canopy. Gap fraction is computed from DHPs as the input of calculating LAI. During direct manual measure, five rice seedlings or sixty pieces of rice leaves are picked out. Length (L)and width(W) of each leaf are measured by ruler, and leaf area(LA) is calculated by $LA=L\times W\times 0.83$[8]。Effect LAI from direct manual measure ($LAI_{direct}$) is equal to all rice LAI in a sampling plot divided by its area.

## 2 Methodologies

### 2.1 Working flow

The working flow for extracting effect LAI from DHPs of rice canopy is shown as Figure 2.

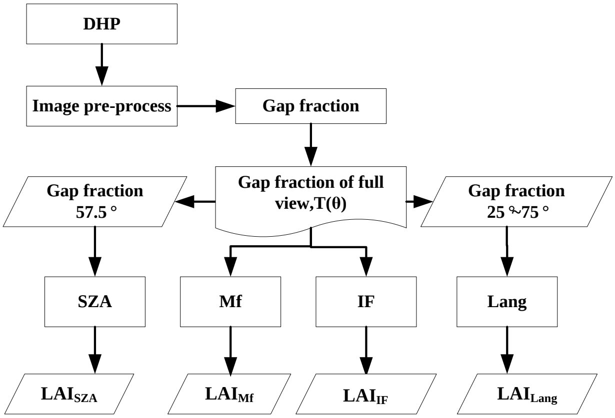



Fig. 2. The flow sheet

Where SZA is single zenith angle, Mf is Mill formula, IF is Iterative formula.

## 2.2 Digital image pretreatment

In DHPS method, effect LAI is derived from gap fraction which computed from binary image of rice canopy. So a series of image pretreatment steps must be carried out to transfer original color photo to gray and to binary consisting of two types of pixels: leaves and background (non-leaves).

In color DHP from fisheye lens upward, rice leaves and background (sky) can be distinguished more clearly in the blue band than in other two. As we know, in visible band, rice leaves absorb more blue than red and green ray, transmission and reflection of blue is the least in rice canopy. So the blue band of DHP is selected as original data for binary classification.

On the other hand, in color DHP from fisheye lens downwards, rice leaves and background can be learn more clearly in the green band than in other two. In this situation, fisheye lens of DHPS is setup downwards above rice leaves, the green gray is reflected mostly by rice leaves, which is acquired by fisheye lens, and absorbed by non-leaves. So the green band of DHP is selected as original data for binary classification.

After color DHP being grayed, a typical two-peak image can be obtained: pixels of foliage making for one and the background make for another in the histogram, and there is little pixel which gray value is between the two peak values, which leads to the valley between two peaks. So the valley value can be applied as the threshold to classify foliage and background pixels clearly and reasonably. In this paper, in gray image from fisheye lens upward, pixels with gray value being lower than the threshold are classified as foliage and higher as background(sky or non-foliage),and in fisheye lens downward, the higher as foliage and lower as background(sky or non-foliage)[19].

## 2.3 Detection of gap fraction

Gap fraction was estimated using an overlay defining *n* annuli covering the hemispherical image with their positions determined by a range of zenith angles, such as *n* is 9 and zenith angles ranging from 5° to 85° with a step of 10. The location of the midpoint of each annulus can be fixed so that annuli are positioned with equal zenith angles. Gap fractions are determined for each annulus using image analysis and computed by Eq. (1):

$$P(\theta) = \frac{P_0(\theta)}{P_0(\theta) + P_1(\theta)} \tag{1}$$

Where $P(\theta)$ is gap fraction at zenith angle $\theta$,$P_1(\theta)$ the fraction of foliage and $P_0(\theta)$ background (none-foliage).

## 2.4 Methodology

### 2.4.1 Theory Basis.

In DHP method effect LAI ($LAI_{eff}$) is computed from the gap fraction $P(\theta)$ following the Poisson law [20,21]:

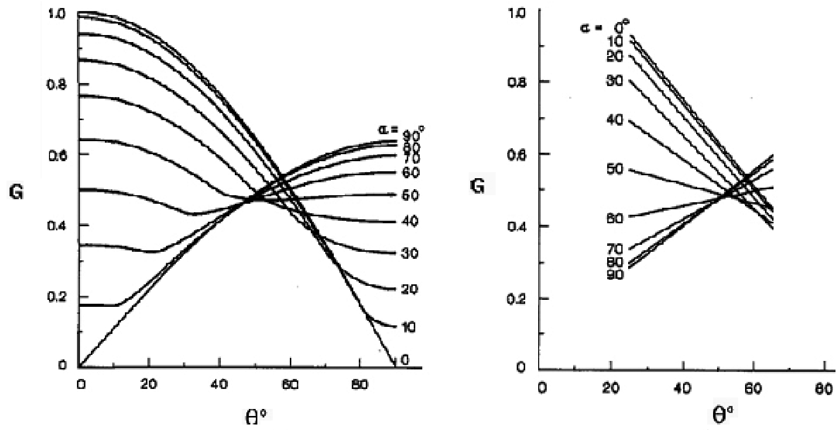
$$LAI_{eff} = \frac{-\ln P(\theta).\cos\theta}{G(\theta)} \tag{2}$$

Where $LAI_{eff}$ is effect LAI, P(θ) is gap fraction at zenith angle θ, G(θ) is the mean projection of a leaf area unit in a plane perpendicular to direction θ which is directly dependent of the leaf angle distribution.

There are two distinct characters about G function [22, 23]:

① at a view angle of 57.5°, G(θ) can be considered as almost independent of leaf inclination, e.g. θ≈57.5 , G(θ) ≈0.5,as shown in Fig.3(a);

② for a uniform leaf azimuth distribution and a constant leaf normal angle, G(θ) can be approximated as a linear function of θ in the 25-65° range. The slope of the regression (∂G(θ)/∂θ) was then related to the average leaf inclination angle(ALIA) by polynomial fitting, as shown in Fig.3(b) which is cut from Fig.3(a) by θ between 25-65°.It can be considered that a linear function may fit G function well in Figure 3(b).




(a) (b)

**Fig. 3.** The projection function G[18]

### 2.4.2 Single zenith angle.

As described in 2.4, at zenith angle 57.5°, G(θ) ≈0.5, effect LAI can be derived independently on the leaf inclination following Eq.(3):

$$LAI_{SZA} = \frac{-\ln T(57.5°).\cos(57.5°)}{0.5} \quad (3)$$

Where T(57.5°) is gap fraction computed within 55-60° zenith angles. For this particular direction, G(θ) is almost independent of leaf inclination simplifying the LAI retrieval process [24].

**2.4.3 Lang model.**

On the assumption that a uniform leaf azimuth distribution and a constant leaf normal angle, G(θ) can be approximated as a linear function of zenith angle θ in the 25-65◦ range. The slope of the regression (∂G(θv)/∂θv) is then related to the ALIA by polynomial fitting. Using an initial estimate of LAI based on gap fraction measurements at a 55° (close to 57.5°) zenith angle, the slope ∂G(θ)/∂θ can be estimated and then ALIA can be derived following Eq.(4):

$$\bar{\alpha} = 56.63 + 2.52\times10^{3} S - 141.47\times10^{-3} S^2 - 15.59\times10^{-6} S^3 + 4.18\times10^{-9} S^4 + 442.83\times10^{-9} S^5 \quad \textbf{(4)}$$

$$x = -3 + (\bar{a} \div 9.65)^{-0.6061} \quad \textbf{(5)}$$

$$\begin{cases} G(\theta) = \dfrac{(x^2+\tan^2\theta)^{1/2}\cos\theta}{x+(\sin^{-1}\varepsilon_1)/\varepsilon_1}, & \varepsilon_1 = (1-x^2)^{1/2},\ x \le 1 \\[2ex] G(\theta) = \dfrac{(x^2+\tan^2\theta)^{1/2}\cos\theta}{x+\dfrac{1}{2\varepsilon_2 x}\ln[(1+\varepsilon_2)/(1-\varepsilon_2)]}, & \varepsilon_2 = (1-x^{-2})^{1/2},\ x > 1 \end{cases} \quad \textbf{(6)}$$

Where $\bar{a}$ is ALIA,S is the slope ∂G(θ)/∂θ[21,23].

So the route for Lang method is followed as: detecting gap fraction P(25°) - P(75°) from DHP with zenith angle ranging from 25° to 75°; ②retrieving effect LAI by SZA; ③computing G(25°) - G(75°) by introducing gap fractions obtained in ① and LAIs in ② into Eq.(2);④the ALIA $\bar{a}$ is calculate by Eq.(4) and then filled in Eq.(5) in order to obtain *x*; ⑤*x* then is utilized in Eq.(6) and assuming θ is 57.5°,a new G(57.5°) is worked out and then filled in Eq.(3) to calculate a new LAI by SZA.

Therefore, the LAI estimates can be refined, and the process is iterated several times until convergence.

### 2.4.4 Miller formula.

Chen and Black[16] derived LAI from the gap fraction measured in all directions using the formula of Miller[25], which assumes that gap fraction depends only on the view zenith angle θ:

$$LAI = 2\int_0^{\pi/2} -\ln(T(\theta))\cos\theta\sin\theta d\theta \quad \textbf{(7)}$$

A practical method was proposed to compute the integral of Eq. (7) from gap fraction measurements in several directions[21]:

$$LAI \approx 2\sum_i^n -\ln(T(\theta_i))\cos\theta_i\sin\theta_i\Delta\theta \quad \textbf{(8)}$$

Where n is denotation of using an overlay defining n annuli covering the hemispherical image with their positions determined by a range of zenith angles, $T(\theta_i)$ is gap fraction in the *i*th zenith angle ring, Δθ is the zenith resolution of annulus expressed by radian.

One of the main limitations with this technique is the necessity to sample the entire directional range of gap fraction variation, which might prove difficult for larger zenith angles.

### 2.4.5 Iterative formula.

In this method, a gap fraction model contents of LAI and average leaf inclination angle(ALIA) simultaneity is built by inputting Eq. (5) to Eq.(6) then to Eq.(2). Then the gap fraction model is inversed by using an iterative optimization technique [26]. The Poisson model is used and the leaf angle inclination is assumed to be azimuthally isotropic with an ellipsoidal zenith angle distribution. Starting with a series of initially given LAI and ALIA, the gap fraction model is run in the forward direction to simulate the gap fraction. The variables LAI and ALIA are then iteratively changed, using the simplex algorithm [27], until a good agreement is met between the simulated and measured gap fraction values.

# 3 Results and discussion

## 3.1 Variety of gap fraction with zenith angle

The trend of gap fraction varies with zenith angle θ is illustrated in Figure 4,where there are five curves created by gap fractions from fisheye lens upward(labeled as “LenUp”) and one for downward (labeled as “LenDown”) ,*n* is the number of concentric annulus.

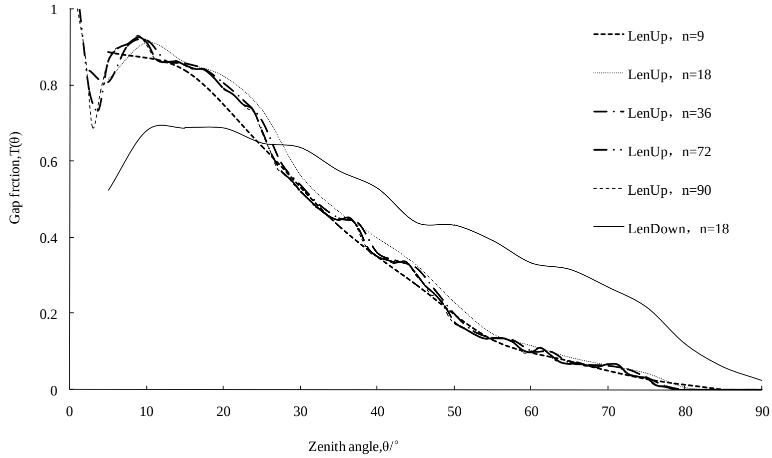



**Fig. 4.** Gap fractions vary with the view angles

As shown in Fig.4,gap fractions decrease while zenith angle θ increasing, which might be caused by that rice leaves captured by fisheye lens of DHPS increase while θ increasing.

### 3.1.1 Impact of fisheye lens orientation on gap fraction.

①Gap fractions from fisheye lens downward is averagely higher than upward. It might be that the reflection of leaves underlaying rice canopy cannot reach to fisheye lens of DHPS because of being sheltered from the topper when lens of DHPS is downward, which leads to the shadowed leaves being misclassified as background in DHP to increase gap fraction.

②Gap fractions from fisheye lens downward is lower than upward when zenith angle is up to the zenith(zenith angle is close to 0°).It could be the sky inverted reflections in water, captured when fish eye lens downward, are misclassified as “leaves” because of almost the same gray value as rice leaves, which result decrease of gap fractions.

③Gap fraction from fisheye lens upward decrease more quickly than upward while zenith angle increasing. It is may be because of the shape of rice leaf: rice leaf is gladiate and its tip is captured in DHP in a greater probability when fisheye lens downward, which leads to gap fraction decreasing. And it is on the contrary when fisheye lens of DHPS is oriented upward.

**3.1.2 Impact of zenith angle resolution on gap fraction.**

There involve all gap fraction information from full view of zenith angle from 0° to 90° in DHP. In this paper DHP is divided into *n* annuli, and *n* gap fractions are detected respectively. When *n* grows view zenith resolution reaches more higher which leads to more detail gap fraction being detected and curves undulates more sharply ,especially in zenith angle of $0<\theta<10°$,as shown on Fig.4. As we know, there are few pixels contented by a single zenith annulus in a relatively small zenith angle such as $0<\theta<10°$,so a little changing of background pixels number might bring a biggish changing of gap fraction .

In this paper, gap fraction is estimated using an overlay defining $n$ ($n$ = 9,18,27,36,45,54,63,72,81 and 90) annuli covering the hemispherical image, and 10 zenith resolutions are reached. There are only 5 gap fraction curves of fisheye lens upward where $n$ = 9,18,27,36, 72, 90 and 1 downward of $n$=18 are picked out as representative zenith resolutions. For these curves of fisheye lens upward, there is little overlapping among the curve of $n$=9 and the others which are closed to each other. There exists almost the same trend while fisheye lens is oriented upward.

## 3.2 LAI retrieving

**3.2.1 Comparison of four methods.**

In this paper $LAI_{SZA}$ is calculated based on gap fraction detected from the annulus of 55°~60°. $LAI_{SZA}$ from four sampling plots are 2.52, 2.53, 2.49 and 2.50 while fisheye lens is oriented upward and 2.33, 2.35, 2.30 and 2.33 while downward. They are close to $LAI_{Lang}$ which is 2.5 when lens downward and 2.31 when upward. But actually G(θ) is derived by $LAI_{SZA}$ in Lang way, which means that Lang way is built upon SZA.LAI from other three approaches are illustrated by Fig.5,in which, $LAI_{Mf}$ is the minimum and $LAI_{Lang}$ is as much as $LAI_{IF}$.

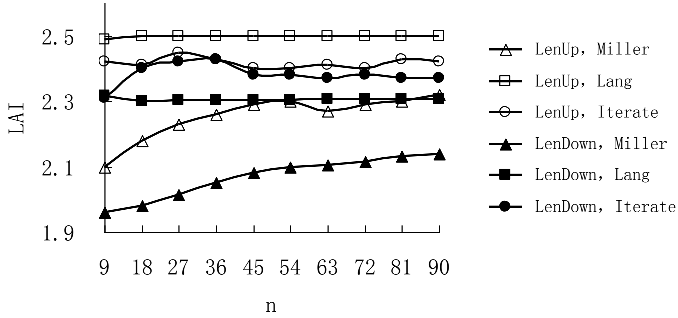



**Fig. 5.** LAIs from different lens direction, zenith angle resolution and method

**3.2.2 Impact of fisheye lens orientation on effect LAI.**

LAIs from fisheye lens upward are always higher than downward. As mentioned in 3.1.1 that shadow of rice leaf is misclassified as background to increase gap fraction in DHP from fisheye lens downward. And a higher gap fraction may leads to a relatively lower LAI according to Eq.2.

**3.2.3 Impact of zenith angle resolution on effect LAI.**

Miller formula is integral, so increasing zenith resolution may do a great deal of good to improve its retrieving precision of LAI. As demonstrated by Fig.5, LAIsMf from two Len orientations keep on increasing while *n* increases until convergence. $LAI_{Lang}$ vary little with variety of zenith resolution except for *n*=9, which indicates that Lang method is a relatively stable one. $LAI_{IF}$ will fluctuate around a value when zenith resolution reaches to a certain level, which means that Iterative formula method is a sensitive one.

So, in the following text, zenith resolution of n=90 is applied in Miller formula and n=18 in the others.

### 3.3 Comparisons among DHP and AccuPAR and direct manual measure

$LAI_{DHP}$ from two lens orientations and four methods varying from 2.14 to 2.50 are lower than 2.75 of $LAI_{direct}$ and close to $LAI_{APAR}$ from AccuPAR LP-80,as shown in Table 1.

**Table 1.** Comparisons of LAIs from DHP and AccuPAR and direct method

| | Methods | LAI |
|---|---|---|
| DHP Fisheye Len Upward | Single zenith angle(SZA) | 2.49 |
| | Miller formula | 2.32 |
| | Lang | 2.50 |
| | Iterative formula | 2.42 |
| DHP Fisheye Len Downward | Single zenith angle(SZA) | 2.31 |
| | Miller formula | 2.14 |
| | Lang | 2.31 |
| | Iterative formula | 2.37 |
| Direct manual measure | | 2.75 |
| AccuPAR LP-80 | | 2.32 |

LAIs from DHPS and AccuPAR PL-80 are both lower than from direct measure. It may be that DHP and AccuPAR PL-80 are both based on the Poisson law which assumes that leaves are uniformly and randomly distributed, which may be valid for homogeneous canopies [13] but does not hold for crops with aggregative patterns such as rice [14,15].The heterogeneousness and aggregation of rice canopy must be taken into account if measuring a LAI with more higher precision than now.

## 4 Conclusions

In this paper it is investigated that effect LAIs of rice canopy are calculated based on gap fractions detected from DHPs taken by a set of self-made DHPS with fisheye lens and comparisons are carried out among LAIs from DHP and AccuPAR PL-80 and direct manual measure. It is found that LAIs from DHPs are lower than from direct manual measure and close to from AccuPAR.

In this paper the precision of LAI from DHP is not as well as from direct manual measure, but DHP is a quick, nondestructive and simple way to obtain LAI in situ. In addition, more parameters of rice canopy structure will be detected simultaneously from DHP if more models are applied in DHP pretreatment. So it is believed that DHP will be a widely utilized way to measure rice canopy structure parameters rapidly.

In the next study for detecting rice canopy structure parameters it is argued that: gap fractions will vary with rice leaves shape during calculating because of relatively lower rice canopy;② The heterogeneousness and aggregation of rice foliage will impact on the precision of extracting LAI.

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