Scientia Horticulturae 164 (2013) 610–615

Contents lists available at ScienceDirect

Scientia Horticulturae

journal homepage: www.elsevier.com/locate/scihorti

Canopy leaf area index for apple tree using hemispherical photography in arid region

Chunwei Liu[a,b], Shaozhong Kang[b,*], Fusheng Li[c], Sien Li[b], Taisheng Du[b]

[a] Jiangsu Provincial Key Laboratory of Agricultural Meteorology, College of Applied Meteorology, Nanjing University of Information Science and Technology, Nanjing 210044, China
[b] Center for Agricultural Water Research in China, China Agricultural University, Beijing 100083, China
[c] College of Agriculture, Guangxi University, Nanning, Guangxi 530005, China

ARTICLE INFO

Article history:
Received 16 July 2013
Received in revised form
28 September 2013
Accepted 4 October 2013

Keywords:
Analysis software
Apple orchard
Canopy structure
Gap fraction
Hemispherical image
Leaf area index

ABSTRACT

The hemispherical images of apple orchard were collected using fisheye lens in 2010 and then respectively analyzed by the methods of Bonhom, 2000, 2000G, sphere, ellipse, LAI 2000-3 rings, LAI 2000-4 rings and Miller to obtain leaf area index (LAI), plant area index (PAI), gap fraction, leaf inclination angle and clumping index in an arid region of northwest China. Results show that during DOY (day of year) 202–237 (at flourish stage), the estimated LAI by logarithmic ellipse method and PAI by LAI 2000-4 rings method were 1.96 and 1.95 $m^2\ m^{-2}$, respectively, which were close to the direct LAI (1.85 $m^2\ m^{-2}$). However, the direct LAI was higher than the estimated LAI from ellipse method of Hemiview (1.59 $m^2\ m^{-2}$) and lower than the estimated PAI from gap fraction analysis method of Photoshop (2.67 $m^2\ m^{-2}$). Thus the methods of logarithmic ellipse and the LAI 2000-4 rings were used to estimate the LAI (PAI) from hemispherical images. And the estimated LAI by the methods of logarithmic ellipse and the LAI 2000-4 rings were used to analyze seasonal variations of canopy parameters. LAI increased rapidly at leaf expanding stage and then maintained at high level from the vigorous to harvest stage. Canopy gap fraction in the south side was similar to that in the north side. The leaf inclination angle tended horizontally to receive more radiation with the development of apple growth. In addition, the estimated LAI from hemispherical images using the methods of logarithmic ellipse and LAI 2000-4 rings was accurate even without calibrating clumping index. Thus the estimated canopy parameters from hemispherical images using the methods of logarithmic ellipse and LAI 2000-4 rings can be used for the modeling of evapotranspiration.

1. Introduction

Canopy parameters, such as leaf area index (LAI), leaf inclination angle and gap fraction, are used to describe radiation distribution in the canopy and estimate the evapotranspiration in the orchard. LAI is the one-side area of leaves per unit ground area without considering the shape of the leaves (Bréda, 2003; Chen and Black, 1992; Lang, 1991; Smith et al., 2008) and it is crucial to calculate orchard evapotranspiration using Shuttleworth–Wallace model (Shuttleworth and Wallace, 1985). Because canopy parameters cannot distinguish the woody area from the direct LAI, Leblanc et al. (2005) suggested that plant area index (PAI) may be useful. References such as LAI, PAI and gap fraction has been monitoring to reflect evergreen or deciduous forest canopies that are the main gateways regulating the exchange of carbon and water vapour between terrestrial ecosystems and the atmosphere (Clark and Murphy, 2011; Seidel et al., 2011) and to calculate the evapotranspiration in arid orchard where needs precise water management during the growing season (Marsal et al., 2014; Testi et al., 2004). Mean leaf inclination angle is one of important parameters in canopy structure that stands the angle between the normal and vertical directions of the leaf, reflecting mean horizontal condition of the leaves, which determines the radiation intercepted by the forest or orchard canopy (Stuckens et al., 2011; Wang et al., 2007).

Direct and indirect methods can be applied to measure LAI in fruit trees. The direct method to measure LAI is more precise than the indirect method, but it is usually destructive to the trees, and labor- or time-consuming. Thus, some indirect methods on the basis of optical principle are used to improve the drawbacks of direct methods, and they can obtain other canopy parameters such as leaf inclination angle and gap fraction as well (Chen et al., 1997; Lang et al., 2010; Jonckheere et al., 2004). Hemispherical photography is one of the indirect methods and it is convenient to operate, collect photography limitlessly and assess photography simultaneously. Hemispherical photography is collected using fisheye lens and analyzed using the threshold value of the gap

* Corresponding author. Tel.: +86 10 62737611; fax: +86 10 62737611.
E-mail addresses: kangsz@cau.edu.cn, kangshaozhong@tom.com (S. Kang).

0304-4238/$ – see front matter © 2013 Published by Elsevier B.V.
http://dx.doi.org/10.1016/j.scienta.2013.10.009

Table 1
Parameters of experimental trees in the orchard. Truck diameters of 34 trees were measured in the orchard, and trunk diameters of 150–200 mm and 200–250 mm occupy 24% and 71% of total trees, respectively.

Tree no.	A1	A2	A3	A4	A5	A6
Trunk diameter (mm)	178	203	214	227	217	235

fractions obtained from digital RGB (red, green and blue) images with a sky background (Sandmann et al., 2013). However, many authors suggested that clumping index leads to lower estimated LAI by hemispherical photography than the direct LAI (Chen et al., 1997; Chen and Cihlar, 1995; Leblanc et al., 2005; Macfarlane et al., 2007a). And canopy density determined by exposure time of hemispherical image is crucial to precisely estimate LAI (Zhang et al., 2005).

A series of software packages, such as Hemiview (Delta-T Device), Winscanopy (Rich et al., 1993) and Caneye (Weiss et al., 2004), have been developed for analyzing hemispherical images, and each has several calculation methods to obtain the results for different sites. However, the applicability of different methods in analyzing hemispherical images needs to be further investigated in the arid apple orchard. This study collected hemispherical images using fisheye lens over the whole season of apple tree in arid region of northwest China in 2010 and estimated canopy parameters using different software packages. The indirect LAI values from gap fraction inversions were validated by the direct LAI values. So the objectives of this study were to obtain suitable software packages in analyzing canopy hemispherical images in apple orchard and analyze seasonal variations of canopy parameters using the selected software packages, so as to provide reliable canopy parameters for the evapotranspiration model.

2. Materials and methods

2.1. Experimental outline

Field experiment was conducted in 2010 at Shiyanghe Experimental Station for Water-saving in Agriculture and Ecology of China Agricultural University (N37°52′, E102°51′, altitude 1581 m), located in Wuwei city, Gansu province of northwest China. The site is a typical continental temperate climate zone with a mean annual sunshine duration of more than 3000 h, mean annual temperature of 8 °C, annual accumulated temperature (>0 °C) of more than 3550 °C, mean annual precipitation of 164.4 mm, mean annual evaporation from a free water surface of 2000 mm and free frost days of 150 days. The groundwater table is below 40–50 m. Experimental soil is irrigated desert soil (Siltigic-Orthic Anthrosols) and soil texture is sandy loam, with a mean dry bulk density of 1.46 g cm^{-3} and mean volumetric water content at field capacity of 0.30 cm^3 cm^{-3}.

Apple trees (*Malus domestica Borkh*. cv Golden Delicious) were planted with an east-west row orientation in 1981, with row spacing of 6 m and plant spacing of 4 m. Irrigation amount was calculated by mean evapotranspiration over the growing stage for nearly 5 years, and irrigation date was determined by actual orchard management and environmental condition, and irrigation method was border-irrigation in the plot (4 m × 6 m). Irrigation amount for each tree was controlled by a water meter. The trees were fertilized with N, P_2O_5 and K_2O of 800, 200 and 150 kg h m^{-2}, respectively, and received similar pest and weed control and pruning in the orchard. And the trunk diameters of the randomly selected apple trees are shown in Table 1.

2.2. Measurements

2.2.1. Leaf area index by direct method

Direct LAI measurements were taken during 20th July to 30th August when apple canopies were well developed and the LAI was steady. Since it was time-consuming to measure each leaf area of mature apple trees, Macfarlane et al. (2007a,b) measured total LAI by dividing and weighing tree's branches into three groups. The following equation was used to estimate LAI of three apple trees in our study:

$$\mathrm{LAI} = \frac{nA_n}{S} \quad (1)$$

where LAI is direct leaf area index, n is the number of total effective leaves defined as leaves with larger leaf area and thicker leaf stem or two or three small area leaves as an effective leaf; A_n is mean leaf area of the trees measured randomly for 300 leaves by AM300 portable leaf area meter (ADC Ltd. UK); S is canopy area calculated by canopy diameter of four directions with steel measuring ruler (5 m) and stem base diameter with vernier caliper (50 cm).

2.2.2. Hemispherical photography

Hemispherical images were obtained using a Nikon FC-E8 fisheye lens attached to a Nikon Coolpix 8400 digital camera supported by a tripod approximately 0.5 m tall in six apple trees (Table 1). The camera was leveled using a bubble level placed in the flash slot, and the north direction was indicated automatically by the Winscanopy (Winscanopy 2006a, Regent, Quebec, Canada) analysis system. The camera was set to auto and manual model in the same position to get images of different exposure time. Since the manual exposure cannot distinguish the leaves from the branches of the apple tree, Zhang et al. (2005) suggested that the manual model of the camera contributes to the difference between canopy and sky, and the process is to (1) use the same camera with the same fish-eye lens in a very large opening with no obstructions and the preferred aperture is F5.3 or similar; (2) determine the in-stand exposure by increasing the shutter speed by two stops with the aperture unchanged at F5.3 for manual exposure and automatic shutter speed for automatic exposure in the experiment of apple orchard. Hemispherical images were taken at sunset every 5 days.

2.2.2.1. Number of pixels to calculate canopy references. Hemispherical images were analyzed using Adobe Photoshop CS4-11.0.1 as follows: large gaps between tree crowns of each photograph were selected using the 'wand' tool and the total number of pixels contained large gaps (g_L) recorded from the Image Histogram; all gaps were then selected using the Select Similar menu item and the total number of pixels in gaps (g_T) recorded from the Image Histogram. The fractions of foliage cover (f_f) and crown cover (f_c) were calculated as (Macfarlane et al., 2007c):

$$f_f = 1 - \frac{g_T}{Q} \quad (2)$$

$$f_c = 1 - \frac{g_L}{Q} \quad (3)$$

where Q is the total pixels of the hemispherical image. Crown porosity (ϕ) is calculated from

$$\phi = 1 - \frac{f_f}{f_c} \quad (4)$$

The PAI was estimated using a modified version of the Beer–Lambert law as follows,

$$\mathrm{PAI} = f_c \frac{\ln(\phi)}{\kappa} \quad (5)$$

where κ is the extinction coefficient.