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Digital image analysis of different crown shape of *Platycladus orientalis*☆

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ABSTRACT

Platycladus orientalis (L.) Franco is a beautifully crown-shaped evergreen tree species used for ornamental cultivation. These trees are also important afforestation plants at hill sites containing calcareous parent rocks and exhibit high tolerance to drought and barren sites. However, *Platycladus orientalis* trees with abnormal crowns, such as fusiform and torch-form, have been identified at sites with extreme drought and barren hills in Shandong, China, although the abnormal crowns does not reduce the ornamental value of these trees. In the present study, we used the RGB imaging and geographical statistical analyses through the construction of meteorological indices. The results indicate that variations of abnormal *Platycladus orientalis* crowns are associated with both the internal metabolism of these trees and the external environment. Crown shapes are strongly affected by the local dry, hot and windy meteorological environment, particularly individuals planted at poor hill site conditions. In response to extreme events of drought, high temperature and strong winds, the twigs and scale leaves of *Platycladus orientalis* typically wilt from the lower part to the upper part of the crown. The fusiform and torch-form crowns are formed through the wilting of partial twigs and scale leaves to avoid the entire wilt of the trees, thereby saving the life of the tree at the expense of partial twigs and scale leaves.

1. Introduction

The crown is the most important photosynthetic organ of woody plants. The size and shape of the crown are biological and ecological characteristics (Maguire and Kanaskie, 2002; Liu et al., 2009) directly associated with or indicated the health status (Waring et al., 1980) of the plants and affected by the surrounding environment (Noguchi, 1979; Lawrance, 1939). In the past, the studies investigating the meteorological impaction on the crown shape of trees were not less (Liu et al., 2009; Solberg, 1999; Ma and Wang, 2006; Zierl, 2004). We have recently engaged in the study of the crown shapes of trees after typhoon events (Wang et al., 2008; Wang et al., 2009a) and the asymmetrical crown of some landscape tree species (Wang and Zhang, 2011). While studying the crown shape of *Platycladus orientalis* in Shandong Province, China, we observed special tree crowns in torch and fusi-form shapes, reflecting the withering of partial lower twigs, and the normal tower form resulting from the phototropism of lower twigs. The partial withering of the twigs typically occurs in response to changes in the climate, soil and artificial processes. However, the meteorological extremes, such as strong wind, extremely hot weather and drought, which directly impact the water and energy balance of these trees, are the triggers of the branch wilts from lower to the upper parts, resulting in special crown shapes of different forms. Indeed, withering might be the result of their structural embolism (Fahn, 1990) to save the life of the tree at the expense of partial twigs and scale leaves (Tyree and Zimmermann, 2002)in the extreme drought and barren hill site environments. This extreme environment adaptation might be a key to drought endurance and importantly ecological and physiological information of the *Platycladus orientalis*.

Many approaches have been used to study tree crown shapes, including visual evaluation, direct measurement with scales, detection with special instruments, regression estimation and image analysis (Redfern and Boswell, 2004). Among these methods, image analysis is simple, fast and time and money saving (Wang et al., 2009a). Combined with the construction of special meteorological indices, we analyzed the special crown shapes of *Platycladus orientalis* using the digital image measurement to construct a simple and easily measured index properly responding their health status and site conditions. This technique might be for the management of non-commercial forest of *Platycladus orientalis* in Shandong Province, China.

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2. Materials and methods

2.1. RGB image capture and analysis of Platycladus orientalis tree crowns

The image analysis of crown shape is defined as a sideward study of tree crowns using digital image measurement method. The RGB images obtained in the present study are sideward images of the crown shape, including the entire stem, captured at the ground level with an elevation of less than 10 degrees. In the present study, a Fuji SL305 digital camera was used.

To capture the images, the major target trees were separate individuals located at the southeast, south and southwest slope of the hills, except in the special study concerning the shading slope. The mature trees with diameters of more than 10 cm were the primary targets for image capture, not including the trees under severe intraspecific competition in closed stands with the characteristics of small crowns on top of the tree. The juvenile *Platycladus orientalis* trees with vigorous growth were not imaged in the present study except in the use of special figures, because of their thin and imperfect crowns. Trees with clustered crowns were also excluded, as each individual represents a juvenile body. In addition, dying trees with sparse crowns, small scale leaves and dim leaf colors were also excluded because of the stagnation of crown development in these trees. Moreover, crowns with artificially sheared lower branches and evidence of livestock feeding were also excluded from imaging.

The sample sites, where are provided with wide representation and traffic convenient, were selected beforehand in the Google map system. For example, we have investigated almost all counties containing plantations of *Platycladus orientalis* in Shandong and each selected one or two hill sites near the highway or freeway. The crown images were captured at more than 23 sites in Shandong Province and 2 sites in Jiangsu Province in China. The average number of sampling trees in each site is about 30 individuals or more.

The length tool in ImageTool 3.0 software was used to measure the shape of the crowns in the image analysis (Fig. 1). Subsequently, the crown shape index we invented recently was calculated in pixels by using Eq. (1),

$$CSI = C/H \tag{1}$$

in which, the *CSI* is the crown shape index; *C* is the width at the widest part of the sideward of the crown; and *H* is the height from root collar to the level of the widest part of the crown which respond the moving of the core of crown from low to high. In addition, we have previously demonstrated that no significant difference was found in the process of detecting the *CSI*s of same tree in different distance and the CSI index was not affected by the image capture distance, although all of the images were not scaled.

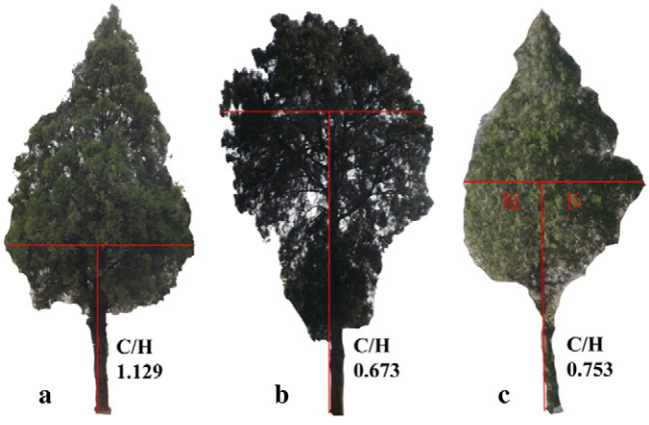

Fig. 1. Typical crown shapes of *Platycladus orientalis* trees; a. tower form; b. torch form; c. fusi form.

After a series of observations, we confirmed that the normal crown shape of the *Platycladus orientalis* is the tower shape (Fig. 1a). Some individuals have exhibited torch (Fig. 1b) or fusi (Fig. 1c) forms in stress environments. In Fig. 1c, the crown shape showed a slight asymmetry, reflecting the impact of persistent prevailing winds (Fig. 1c). Using the crown shape index (CSI), these crown forms were properly determined and analyzed.

In the present study, the color of canopy RGB images has also been analyzed using the RGB analysis method (Wang and Omasa, 2012) accompanying with G/L value calculation (Wang et al., 2009a).

2.2. Construction of Max30twp index, accumulate-arid-index and accumulate-humid-index

In the present study, meteorological analysis was used to confirm the inducer of the abnormal crown shape of *Platycladus orientalis*, in which, the meteorological data were obtained from the China Meteorological Data Service Center. The Max30twp index was calculated using the meteorological data of daily maximum wind speed, daily precipitation and daily maximum temperature in July, August and September within past 61 years (1951–2011) at 31 meteorological observatory stations in Shandong Province and 10 meteorological observatory stations in neighboring provinces. The detail is described in Eq. (2):

$$Max30twp = \sum_{m=7}^{9} N_m \left(\sum_{m=7}^{9} \left(\sum_{n=1}^{30} \max(t_{mn})/30 \right) \right) \Big/ 6 + \sum_{m=7}^{9} \left(\sum_{n=1}^{30} \max(w_{mn})/30 \right) /3 \Big/ \sum_{m=7}^{9} R_m - \sum_{m=7}^{9} P_m/180 \tag{2}$$

in which, Max30twp is the meteorological index, Max() is a function to calculate the maximum value; t_{mn} is the n^{th} daily maximum temperature in m month within the 61 years, in which $n = 1,2,\ldots..30$; $m = 7,8,9$; W_{mn} is the n^{th} daily maximum wind in m month within the 61 years, in which $n = 1,2,\ldots..30$; $m = 7,8,9$; N_m is the average rain-free-day numbers in m month; R_m is the average rainy-day numbers in m month; and Pm is that the mean precipitation in m month. The meteorological relevance of the Max30twp is that the higher the extreme temperature, the wind speeds and the number of mean rain-free days, the higher the index; and the larger the mean precipitation, the lower the index.

To analyze the impact on abnormal crown shape, we calculated the accumulative aridity index of ten days (AD10) and the accumulative humidity index of ten days (HD10) using Eqs. (3) and (4), respectively, for Jinan City in the first half of 2012;

$$AD10_i = \sum_{j=1}^{10} MT_{i+j} \Big/ \sum_{j=1}^{10} PR_{i+j} \tag{3}$$

$$HD10_i = \sum_{j=1}^{10} PR_{i+j} \Big/ \sum_{j=1}^{10} MT_{i+j} \tag{4}$$

in which, $i = 1, 2\ldots 365$ and $i = 1$ January 1st, $J = 1, 2 \ldots 10$, MT is the daily maximum temperature and PR is the daily precipitation.

2.3. Thermo image capture and wind speed measurement

The thermo images, which were used for measuring the image temperature of *Platycladus orientalis* canopy within and without the valley area, were determined through thermography using a NEC H2640 thermal infrared (8–13 μm) camera equipped with a temperature measuring scope ranging from −40 to 500 °C and a minimum sensible temperature of 0.03 °C. Throughout the measurements, the camera