Ecological Informatics 12 (2012) 16–22

Contents lists available at SciVerse ScienceDirect

Ecological Informatics

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

Image measurements of leaf scorches on landscape trees subjected to extreme meteorological events ☆

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ARTICLE INFO

Article history:
Received 11 June 2012
Received in revised form 24 July 2012
Accepted 25 July 2012
Available online 29 July 2012

Keywords:
Landscape trees
Leaf scorch
Extreme meteorological events
Internal angle

ABSTRACT

Trees grow in changing environments and are usually injured by many external factors including both abiotic and biotic. Leaf scorch is a main symptom for many landscape trees when they are stricken by meteorological extreme events, such as summer drought, strong typhoon and winter freezing and so on. In the study, the internal angle of injured area (IAIA) was defined in relation to vein lines and measured non-destructively for some landscape tree species. Meanwhile, the leaf scorch area percent (LSAP) and percent of scorched central vein (PSCV) were also determined from RGB images. Positive relationships between IAIA and LSAP and between PSCV and LSAP were found. The larger IAIA values for scorched leaves and smaller IAIA values for spot/anthracnose diseased leaves of the studied trees indicated that IAIA may be used as a diagnosing index of leaf scorch symptoms.

1. Introduction

Extreme meteorological events, such as strong typhoons and summer droughts, in addition to root disease often induce tip and/or margin scorches on trees (Günthardt-Goerg and Vollenweider, 2007; Kozlowski, 1976; Vollenweider and Günthardt-Goerg, 2006; Wang et al., 2009a, 2009b; Yapp, 1912) due to severe dehydration. A variety of dieback and decline diseases of trees are favored by abiotic stresses, such as drought, flooding, extreme heat, mineral deficiency and air pollution. These diseases usually become severe after environmental stresses render trees susceptible to organisms of secondary action (Kozlowski, 1985; Omasa et al., 2002; Schoeneweiss, 1981). Moreover, myxomycetes often confine their attacks to the same regions of a leaf (Yapp, 1912). Leaf scorches often showed systematic symptoms when the trees are subjected to severe water stresses. Similar symptoms may also be induced by several biotic agents, viruses and insects (Hammerschlag et al., 1986). However, pathogen-triggered injuries generally cause unsystematic necrosis in a localized pattern and on partial crowns of trees and shrubs. Leaf scorch symptoms originating from extreme environmental events often appear in an inward spreading pattern. A type of inward leaf scorch symptom on dogwood trees has been found in Yamaguchi, Japan, which was hit by a summer drought in 2007 (SD2007) (Wang et al., 2009b). To identify the difference between abiotic leaf scorch and biotic damage, the parameters of internal angle of injured area (IAIA) and percent of scorched central vein (PSCV) were defined. The IAIA is a central angle corresponding to the scorched leaf margin, and the PSCV is a length rate between the scorched part and the total length of the central vein in accord with the percent of scorched leaf tip. They respond the scorch symptoms with respect to their spreading from both radian and length.

Image analysis have increasingly become important tools to holistically study the characteristics of plants or trees (Adamsen et al., 1999, 2000; Jones, 2004; Omasa, 1990; Omasa et al., 2002, 2007; Richardson et al., 2001; Wang et al., 2008a, 2008b). RGB image analysis has been recognized as a useful tool to determine the leaf scorch area percent (Wang et al., 2009c; Zhao et al., 2012), and it has also been used to directly measure the heterogeneousness of leaf living parts and dead parts (Wang et al., 2009b). The common parameters of image analysis, such as distance, angle and area measurement, are useful parameters to describe the morphology of plants and trees (Bai et al., 2005; Bréda, 2003). In this study, it is aimed at objectively responding the ecological information from some landscape trees and finding an easy and low cost way to diagnose the leaf scorches that suffered extreme meteorological events by using the digital image analysis. Another goal is focused on the proper parameter or index to describe the scorch symptoms. As a result, the IAIA value for leaf scorching, spot/anthracnose diseases and wind mechanical damage as well as the PSCV for scorched dogwood leaves etc. was determined by using the software of UTHSCSA Image Tool 3.00 to investigate the difference among the symptoms caused by abiotic stress, biotic attack

☆ Supported by the National Natural Science Funds of China. ID number: 301170671.
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http://dx.doi.org/10.1016/j.ecoinf.2012.07.005

and mechanical damage. The positive result suggests that leaf scorch of these tree species is a systematic symptom which may be potentially diagnosed by using RGB image measurement.

2. Materials and methods

2.1. The studied position and tree species

This study was mainly carried out at Yamaguchi, Japan. The target landscape trees and shrubs included the following species: kousa dogwood (*Cornus kousa* Buerg.), which suffered severe SD2007 at Yamaguchi Central Park; Japanese blue oak (*Quercus glauca* Thunb.) and camphor tree (*Cinnamomum camphora* (L.) J. Presl.), which were struck by the strong dry typhoon 0613 (T0613); trident maple (*Acer buergerianum* Miq.) and zelkova (*Zelkova serrata* Murr.), which were hit by strong spring wind at Yamaguchi University; and Japanese spindle (*Euonymus japonicus* Thunb.), winter creeper (*Euonymus fortunei* (Turcz.) Hand.-Maz.), Glossy Privet (*Ligustrum lucidum* Ait.) and red leaf photinia (*Photinia glabra* (Thunb.) Maxim.) supplement shrubs in several hedges, which suffered winter injury at the Shandong Forestry Research Academy in Jinan, China, and so on.

2.2. Preconditions and methods of image taking

Leaves were monitored before and after the symptom appearance of leaf partial withering, disease and wind mechanical damage to confirm the origin of the symptoms. Leaf scorch events were recorded soon after the symptoms appearance, when the leaf lesion color still had the same color as the living part. During study of the partial freezing dehydration process of some broad evergreen tree species such as Japanese spindle, Glossy Privet and so on; the freezing and thawing process of their leaves were monitored.

The leaves were sampled from sampling trees and took photos with a CCD camera (Canon IXY 6.0) or scanned with a flat bed scanner (Canon d125u2). Images were stored in the form of Tiff format. There is no special constraint for the photograph taking in manual measurement of IAIA, PSCV and LSAP except the blurry images of leaf partial withering symptom for most tree species. Images will be increased luminance by using the adjust tool in Photoshop software if the object leaf is too dim to be seen clearly. The number of sampled leaves for each tree species is shown in the bracket following their names in the figure captions (From Figs. 3 to 6).

In order to increase the sample numbers of diseased and scorched leaves and to check multiple tree species, a large number of photographs from books and publishing papers have also been measured.

2.3. The definition and calculation of IAIA and PSCV values

The internal angle of injured area (IAIA) is a central angle when considering the farthest point that the injury has reached on the central vein (or in the injured area if the injured area is beyond the central vein) as tip point of the angle and considering the two lines from this point to the farthest points that the injury reached on both sides of leaf edge as the two borders of this angle (Fig. 1b and c). The IAIA was directly measured using the angle analysis tool in the software of UTHSCSA Image Tool 3.00.

The PSCV was measured by using the distance tool in the software of UTHSCSA Image Tool 3.00 and calculated using Eq. (1) as follows:

$$PSCV\% = (CV/TV) \times 100 \quad (1)$$

in which *PSCV* is the percent of scorched central vein, *CV* (from C to V in Fig. 1a) is the pixel number of scorched part and *TV* (from T to V in Fig. 1a) is the pixel number of total length of the central vein.

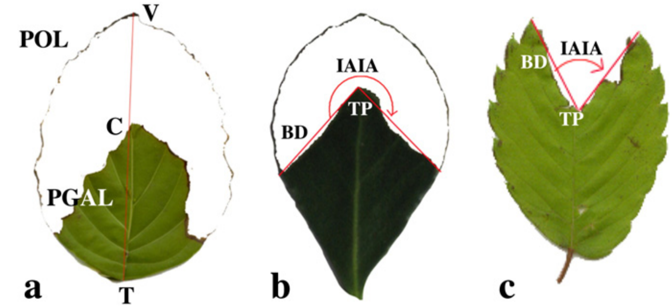

Fig. 1. Diagrams to show the internal angle of injured area (IAIA) and leaf scorch area percent (LSAP). (a) A typical scorched kousa dogwood leaf with the non-scorched green area (PGAL) and entire leaf area (POL) marked. (b) A scorched Japanese spindle leaf with a typically obtuse IAIA. (c) A zelcova leaf mechanically damaged by wind with a significant acute IAIA. The IAIA was measured by the tip point (TP) and side borders (BD).

2.4. Process and method to determine the LSAP

The target kousa dogwood trees were approximately 7 years old and 3 to 4 m high, and these trees were planted around the Yamaguchi Central Park. The number of sampled trees totaled 60. In this study, the leaf scorch area percent (LSAP) values of the sampled leaves were determined by image analysis. All of these trees were monitored and analyzed by image measurement during the years of 2007, 2008 and 2009. In this study, 560 leaves were scanned with a flat bed scanner (Canon d125u2). Photoshop CS 12.0 software was used to remove all objects except the leaves from the images. The scorched area and overall leaf area was measured by using area tool in the UTHSCSA Image Tool 3.00 software or directly read the pixels from Photoshop. The LSAP was then calculated using Eq. (2) as follows:

$$LASP\% = 100-(100 \times PGAL/POL) \quad (2)$$

where PGAL is the number of pixels in the green area of the leaf, and POL is the number of pixels in the overall leaf (Fig. 1a).

A multivariate normality test has been carried out for the data of IAIA, LSAP and PSCV, they are all consistent with the normal distribution with the U checking value less than 1.96 and $P > 0.05$.

2.5. Meteorological data and related parameter

The precipitation data were obtained from the Automated Meteorological Data Acquisition System (AMeDAS) in Japan. The three month accumulated precipitation (*TMP*) was calculated with Eq. (3) to compare the seasonal difference in precipitation among the years 2007, 2008 and 2009 as follows:

$$TMP_{\mathrm{i}} = \sum_{\mathrm{j}=0}^{2} MPR_{\mathrm{i+j}} \quad (3)$$

where $\mathrm{i} = 1, 2 \ldots 10$ and $\mathrm{i} = 1$ in January; $\mathrm{j} = 0$, 1 and 2; and $MPR_{\mathrm{i+j}}$ is the monthly precipitation value in the month of $\mathrm{i} + \mathrm{j}$.

2.6. Leaf venation, water-trail and red-color-trail observations

Leaf venation of target tree species have been studied by using both methods of micro-distance photography and chemical treatment. In which, most of tree species with transparent leaflets was directly observed by using micro-distance photograph, while the tree species with thick and nontransparent leaflets were first treated with NaOH solution to obtain the clear venation images.

By monitoring the leaflet of some evergreen arbor/shrub species, the water-trail, a phenomenon of partial leaflet temporary water deficit with significant visible trace during the process of occasional winter frozen, was studied. Then, the red-color-trail has been observed at the same area where water-trail has been found. They are all similar to the permanent damage symptoms of leaf scorches after extreme winter dehydration. Therefore, the “IAIA” of them were measured with similar method to prove that they also result from the water metabolism and imbalance of water system.

3. Results and analysis

3.1. Extreme meteorological events in 2007, 2008 and 2009 and responses of several kousa dogwood trees in Yamaguchi

In the presence of meteorological changes in the world, the climate in Yamaguchi, Japan fluctuated among the years 2007, 2008 and 2009. The fluctuations were mainly reflected in the three month precipitation values during these years (Fig. 2a). The meteorological environment in 2007 in Yamaguchi, Japan was characterized by drought in almost all of the first eleven months and by high temperatures in February, August, September and October. The annual precipitation was 71.6% of the normal precipitation of this area, and the precipitation for the first nine months was only 60.1% of the normal precipitation. From August 7th to August 18th in 2007, more than 15 days of continual anticyclone weather occurred. During these days, the average and minimum temperatures were higher than normal (1971–2000), and no rainfall occurred. Meanwhile, the relative humidity values represented a U-shaped curve. Although the precipitation during the first half of the year in 2008 was similar to normal years, the annual deviation of mean temperature in the summer was 0.5 °C higher than normal, and the precipitation was less than 80% of the normal precipitation at Yamaguchi. During the hottest days from July 22nd to August 14th in 2008, only 11 mm of precipitation was recorded at the Yamaguchi Observatory. The maximum daily temperature during this period was higher than 33 °C. The characteristic precipitation in 2009 presented a different tendency compared to the years 2007 and 2008, especially in the summer. The prolonged Japanese rainy season and historical record created heavy rainfall in July caused local flooding in Yamaguchi. More than 750 mm of monthly precipitation led to a peak in the TMP as shown in Fig. 2a. After this period, less rainfall in September resulted in a record of the third least monthly rainfall in Yamaguchi meteorological history.

This strongly contrasting climate induced different responses from landscape trees in Yamaguchi, especially for the kousa dogwood trees planted in the Yamaguchi Central Park (Fig. 2b). According to the LSAP values of the 60 fixed sampling trees, more than 40% of the leaf area was reduced by partial withering in 2007. The leaf scorch area of 13% in 2008 for the same sampling trees may be a result of the normal precipitation in the first half of the year (Fig. 2a). In 2009, the LSAP was only 0.3%, which implied that almost no leaf scorch occurred. According to the variation analysis, LSAP values varied significantly among 2007, 2008 and 2009 with an F-value equal to 62.6 ($P<0.01$). There was a consistency between the leaf scorch area percent and precipitation during the summer days, especially in July, August and September. The LSAP indirectly indicated that the heavy rain in the summer of 2009 counteracted the summer heat wave and caused almost no leaf scorch occurrence on the kousa dogwood trees planted in Yamaguchi Central Park. Similarly, the largest IAIA value for kousa dogwood leaves was obtained in 2007, followed by the IAIA values in 2008 and 2009. A significant difference in the IAIA values

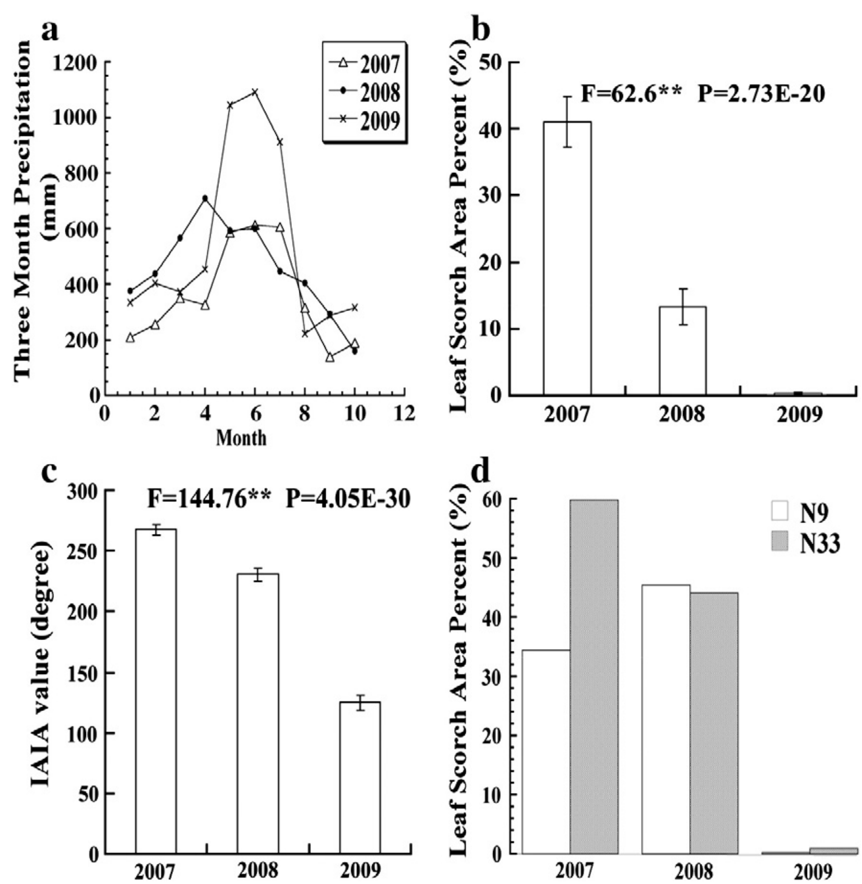

Fig. 2. Precipitation characteristics and responses of several kousa dogwood trees in Yamaguchi in 2007, 2008 and 2009. (a) Three month precipitation (TMP) during 2007 (△), 2008(●) and 2009( ); (b) Leaf scorch area percent (LSAP); (c) internal angle of injured area (IAIA) for 60 kousa dogwood sample trees planted around the Yamaguchi Central Park; (d) Leaf scorch area percent values in 2007, 2008 and 2009 for two kousa dogwood sample trees (number 9 and number 33) with leaf scorch present in all of the three years.

was measured among the years with an F-value of 144.76 ($P<0.01$) (Fig. 2c).

There was almost no appearance of leaf scorch symptoms by August 28th in 2009, which was the date of investigation in all three years of the study period. Leaf scorch symptoms among the kousa dogwood sample trees did not occur until the end of September in 2009, which may have been attributed to the lower incidence of rainfall in September of 2009. According to the investigation, only two individual trees had leaf scorch symptoms on September 20th after prolonged lack of rain and high temperatures. By comparison, the LSAP of these two individual trees (N9 and N33) in 2009 was far lower than that in 2007 and 2008 and could be considered nonoccurrence as compared to 2007 and 2008 (Fig. 2d). Moreover, this result may provide further evidence that the leaf scorch of kousa dogwood trees in Yamaguchi Central Park is associated with the water stress induced by less rain and high temperatures during summer.

3.2. The LSAP, IAIA and PSCV of scorched kousa dogwood leaves

Careful observation of kousa dogwood leaves reveals that leaf veins are thinner from the base to the tip and from the central vein to the margin. Similarly, leaf scorch caused by extreme meteorological events usually starts from the leaf tip and margin of kousa dogwood leaves. This phenomenon to some extent also appeared in this study by measuring the IAIA and PSCV, which reflect the radian and length of the scorched area, respectively, of kousa dogwood leaf images. Thus, as the IAIA and PSCV values increased, the tip and margin scorches became more severe.

According to the measurement of these two parameters, a tendency of the IAIA to increase as the LSAP increased (or a significantly positive exponent relationship) was found (Fig. 3a), with an R^2 value of 0.556 ($P<0.01$). Moreover, a statistically significant and positive exponent relationship existed between the PSCV and LSAP values (Fig. 3b), with an R^2 of 0.841 ($P<0.01$). Thus, as the percent of scorched leaf area increased, a larger area of the leaf tip and margin died of meteorological injury. Therefore, the kousa dogwood leaves showed leaf scorch symptoms starting from the tip and margin of the leaf.

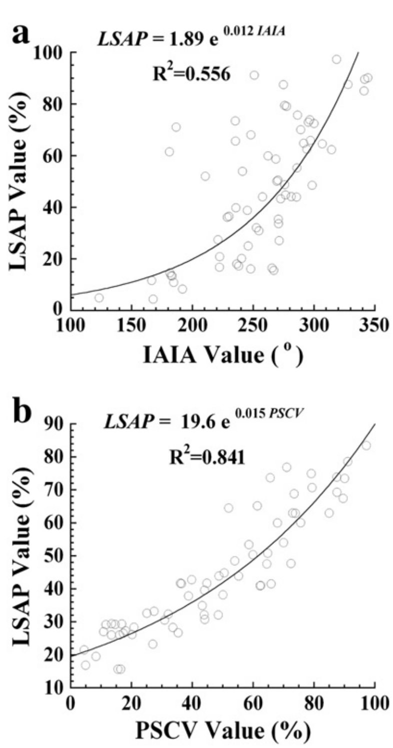

Fig. 3. Relative curves of (a) leaf scorch area percent (LSAP) versus internal angle of injured area (IAIA) and of (b) LSAP versus percent of scorched central vein (PSCV) (n = 65).

3.3. The "IAIA" value of frozen dehydrated leaves with water-trail and red-color-trail

Persistent winter frozen dehydration induced similar symptoms to leaf scorches, such as water-trail (Fig. 4a-1, a-2, a-3 and a-4) and red-color-trail (Fig. 4a-5, a-6) on leaves of some landscape trees with larger "IAIA" values (Fig. 4b-1, b-2, b-3, b-4, b-5 and b-6) of more than 250°. The water-trail is usually restorable and disappeared after thaw of the frozen leaves. Permanent leaf scorch often occurred at the same area as the frozen dehydration persisted for a longer time (Fig. 4a-2, tip), during severe drought or at the extreme stressed environment. For example, in the winter from 2011 to 2012 only a few Japanese spindles around the yard of Shandong Forestry Research Academy in Jinan, China appeared permanent symptoms of leaf scorch starting from tip and margin. In which, some of them were newly transplanted seedlings with imperfect root system; some of them grew on new branches sprouting from an old root stock. Whatever, there has been a significant positive relation between water-trail area rate (w-rate) during frozen dehydration and the green area rate (G-rate) of these leaves after permanent scorch (Fig. 4c). It suggests that the water and energy imbalance become the trigger of permanent scorch, the water-trail and red-color-trail symptoms, which start from the leaf tip and margin.

3.4. Comparison of multiple leaf partial injuries of several landscape trees

Direct image measurement of leaf wind break was seldom found. In 2009, strong windy weather accompanied by heavy rainfall occurred twice in Yamaguchi, in late spring and early summer (on April 20th and May 21st). The maximum gust wind speeds reached 26.2 and 19.9 m/s on April 20th and May 21st, respectively. Due to the strong wind on April 20th, severe mechanical damage was found on the juvenile leaves of zelcova, Japanese blue oak and trident maple trees, and the severity of the damage was also attributed to the early leaf stage and leaf textures. One month later, however, the same intensity of strong wind had no influence on the leaves of these tree species because the leaves were more developed and stronger, which allowed them to endure the strong wind. The wind break damage to the leaves occurred mainly on juvenile leaves and seldom on mature leaves. The injured juvenile leaves usually had smaller IAIA values (Fig. 5a-3, a-4, a-5, b-3, b-4 and b-5) similar to the anthracnose-diseased dogwood leaves (Fig. 5a-1, a-2, b-1 and b-2). However, the strong and hot wind during the summer drought period in August of 2007 triggered leaf scorch symptoms in most of the kousa dogwood trees planted around Yamaguchi Central Park. The IAIA values of kousa dogwood leaves after the summer drought period in 2007 were greater than 250° (Fig. 5a-7 and b-7). In 2006, many landscape trees had leaf scorch on the windward side of their crowns after being hit by strong wind caused by T0613 accompanied with less rainfall. Some camphor trees and Japanese blue oaks were exceptional examples with large IAIA values (Fig. 5a-6, a-8, b-6 and b-8). A similar mechanism was not found simultaneously for both mechanical damage on younger leaves and leaf scorch caused by extreme meteorological events. Interestingly, during the winter injury process, with the average monthly temperature from November 2009 to March 2010 being 1.4 °C lower than normal, some evergreen shrub species planted in Jinan City, China presented similar symptoms to those hit by extreme meteorological events during SD2007 and T0613 in Yamaguchi, Japan with larger IAIA values (Fig. 5a-9, a-10, a-11, b-9, b-10 and b-11). Therefore, the symptoms may be related to water stress as evidenced by the similar symptoms after suffering from the extreme meteorological events of SD2007 and T0613. Winter injury has ever been considered to be the result of a frozen dehydration process (Pearce, 2001), especially in areas where

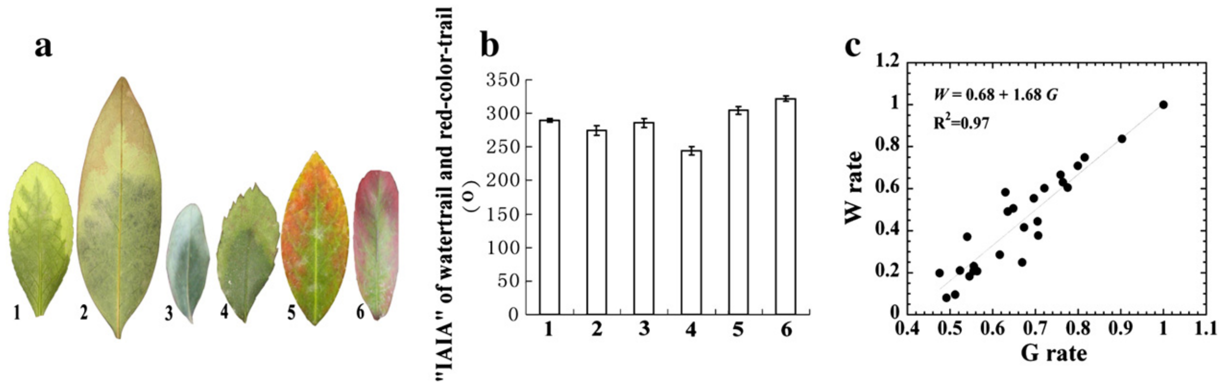

Fig. 4. The images of leaf water-trail (a, 1–4) and red-color-trail (a, 5–6), and the "IAIA" value (b) of some landscape tree species and the relation between water-trail area rate (W-rate) of frozen dehydrated leaves and green area rate (G-rate) of permanently partial withered leaves of Japanese spindles (c) during or after the process of frozen dehydration. In which, 1 is the Japanese spindle (n = 63), 2 the Glossy Privet (n = 26), 3 the Purpus Privet (n = 36), 4 the Wichura Rose (Rosa *wichuraiana* Crep.) (n = 11), 5 the winter creeper (n = 13) and 6 the red leaf photinia (n = 18).

there is a strong winter wind (Pirone, 1978). The IAIA values of these evergreen tree species were similar to the IAIA values of leaf scorch on the kousa dogwood trees caused by summer drought. Thus, these results suggested that the frozen dehydration process has similar mechanism to desiccation or strong, dry typhoon strikes.

Theoretically speaking, the limitation value of the internal angle of the leaf spot disease should be the limitation of the circumferential angle of a circle (or 180°), which is equal to half of the limitation of the central angles of a circle (360°). Therefore, it can be deduced that the IAIA value of an angular leaf spot disease of dogwood is less than 180°.

3.5. Quantitatively measuring results of leaf scorch from historical reports

The IAIA of leaf images measured from the past reports is an easiest way to study the leaf scorch symptoms. By measuring the typically scorched leaves from the reports of Yapp (1912), the larger IAIA of all leaves tally with this conclusion even the linear leaf of Buckhorn Plantain (*Plantago lanceolata* L.) (Fig. 6A; IAIA = 205.9). The IAIA of the typically sampling leaves for the tree species of Common Oak (*Quercus robur* L.), Europea Beech (*Fagus sylvatica* L.), European-haw (*Crataegus oxyacantha*), Poplar (*Populous* spp.) and Rose (*Rosa* spp.) exposed to strong wind was even more than 300° (Fig. 6B, C, D, E and F). Similarly, all leaves from America Linden (*Tilia* spp.), Buckeye (*Aesculus carnea*), Kousa dogwood (*C. kousa* Buerg.) and American elm (*Ulmus Americana* L.) suffered environmental stresses, with partial withering symptoms from the report of Schoeneweiss (1981) also showed larger IAIA more than 300° (Fig. 6G, H) except the American elm leaf suffered bacteria leaf scorch (Fig. 6K, IAIA = 76.9).

According to the measurement of three groups of leaf spot disease and anthracnose disease from some plant disease books consisting of 16, 53 and 57 cases (CAAS, 1965; Ito and Aino, 1976; Pirone, 1978), the average IAIA values respectively equal to 119.7 ± 22.8° (Fig. 6-YT), 142.0 ± 9.8° (Fig. 6-ZG) and 106.9 ± 8.3° (Fig. 6-BD). These results were in accordance with the disease or mechanical damage samplings shown in Fig. 6. They were far less than the mean IAIA values of leaf scorch symptoms caused by SD2007, T0613 and prolonged winter injury with average IAIA values ranging from 250 to 320° with significant statistical differences due to the F value of 63.5 and P-value 6.58E − 67.

4. Discussion

Exogenous environmental factors become operative through the endogenous metabolic processes of trees. The origination and spread of disease symptoms also can be considered as an interaction process between pathogen intrusion and plant resistance. Pathogen spreading is a complex action, which includes the intrusion of a hypha into host in the pattern of cell by cell. A hypersensitive response from the host usually confines the pathogen into a localized necrotic lesion even the pathogen fails to further intrude into the host if it is incompatible. This type of host defense action varies among cultivars with different sensitivities to the pathogen (Wharton et al., 2001) or varies between attached leaves and detached leaves (Liu et al., 2007). This kind of leaf-pathogen interaction even can be detected by using thermography before symptoms appearance (Chaerle et al., 1999; Jones,

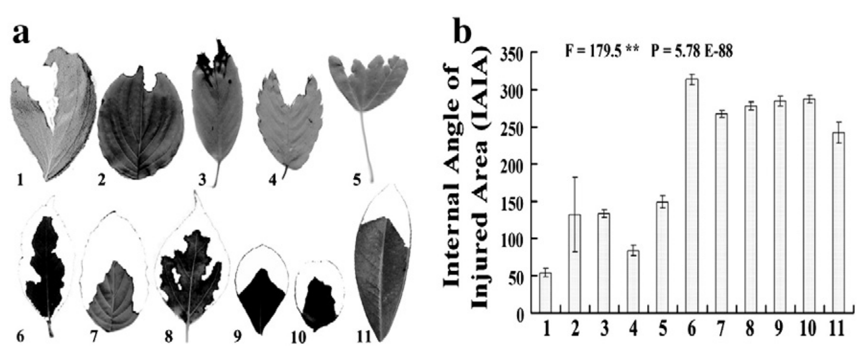

Fig. 5. Typical symptom (a) and internal angle of injured area (IAIA, b) of some landscape trees. (1) IAIA of leaf injury to kousa dogwood leaves caused by anthracnose disease (n = 5) in Yamaguchi, Japan. (2) IAIA of leaf injury to kousa dogwood leaves caused by both water stress and secondary disease (n = 26) in Yamaguchi, Japan. IAIA of leaf injury to (3) Japanese blue oak (n = 35), (4) zelcova (n = 28) and (5) trident maple (n = 4) leaves caused by strong wind during the leaf expanding stage in April 2009 in Yamaguchi, Japan. IAIA of leaf injury to (7) kousa dogwood leaves (n = 25) triggered by SD2007, (6) IAIA of leaf injury to Japanese blue oak leaves (n = 31) and (8) camphor tree leaves (n = 34) induced by T0613 in Yamaguchi, Japan. IAIA of leaf injury to (9) Japanese spindle (n = 26), (10) winter creeper (n = 23) and (11) red leaf photinia (n = 6) leaves caused by severe winter frozen dehydration in Jinan City, China.

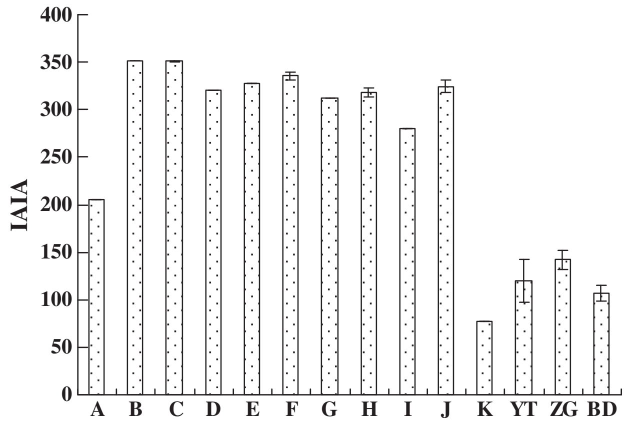

Fig. 6. IAIA value measured from the reports on leaf scorch and diseases. It includes leaf scorch on the linear leaf of Buckhorn Plantain (A), on the leaves of Common Oak (B), Europea Beech (C), European-haw (D), Poplar (E), Rose (F (n = 5)), America Linden (G), Buckeye (H), Kousa dogwood (I) and American elm (J (n = 17)); bacteria leaf scorch (Bls) on American elm (K); and the anthracnose/spot diseases symptoms from different plant disease books (Yt (n = 16), Zg (n = 53) and Bd (n = 57)).

2004; Omasa et al., 2002; Wang, 2010). Therefore, the necrotic lesion on a diseased leaf is usually impeded by the living cells all around if the intrusion point is located just within the leaflet. The spot/anthracnose disease induced by fungus as well as the mechanical damage induced by strong wind occurring on the juvenile leaves of some tree species had relatively smaller IAIA values because the symptom spread was often resisted from all directions, except for the leaf margin in the case of margin intrusion.

By comparison, the leaf scorch caused by severe meteorological extreme events such as summer drought or winter damage of some tree species often presented the resistance coming from the living tissues nearest to the major vein system. Kozlowski (1976) considered that visible symptoms of water stress responses of landscape trees often show temporal delay, and the rapid appearance of symptoms after rehydration suggests that the symptoms are initiated by a response to water stress that cannot be completed without adequate water. The symptom caused by this type of systematic shock often has characteristics similar to the defense to the drying back progress of the tissues furthest from water-way (Wang et al., 2009b). Leaf scorch caused by water stress appears as a pattern that constructs a barrier along an isoline of water potential to protect from further water loss (Wang et al., 2009b). The different mechanisms of these stresses cause distinct symptoms. In this study, we found that the leaf scorch originating from desiccation usually had large IAIA and PSCV values due to the thinner veins at the tips and margins of leaves. Thus, this result supports the hypothesis that leaf scorch often starts from the leaf parts furthest from water-way (Günthardt-Goerg and Vollenweider, 2007; Yapp, 1912), and it also suggests that image analysis may be a useful tool for comparing leaf scorch symptoms caused by desiccation and spot/anthracnose disease.

Leaf scorches often occurred on transplanting seedling/trees, shade trees (Hammerschlag et al., 1986; Kozlowski, 1985) and extreme environment planted trees, and on leaves of watershoot, which easily present water imbalance during striking by meteorological extremes. Some shade trees of Japanese blue oak subjected to a strong wind at Yamaguchi University presented leaf scorch on the windward side after T0613, which indicated that serious water imbalance occurred in the thin shade leaves facing the strong and dry wind. However, the remaining green parts of the scorched leaves maintained normal function for more than three years (Wang et al., 2009a). By comparison, the IAIA values of these leaves were significantly different from the IAIA values of leaves that experienced mechanical damage caused by strong early spring wind in 2009 and similar to the IAIA values of leaves that were hit by summer drought events in 2007.

Some diseases and mechanical damage caused the leaves of landscape trees to have similar symptoms with smaller IAIA values, which implied that the symptoms did not cause systemic damage in the trees. The leaf scorch symptoms caused by summer drought, dry typhoons and persistent winter frozen dehydration presented similar symptoms with larger IAIA values, which suggested that these results all triggered systemic variation through water metabolism. The recoverable symptoms of water–trail on some evergreen tree species during the severe frozen dehydration may be the actual evidence of its water imbalance. The red-color-trail appears at the same area of the water-trail, which suggests that it is the internal responses of trees to water stresses induced by extreme meteorological events.

In addition, the symptoms and injury mechanisms of polluted plants are usually different from the leaf scorch symptoms caused by extreme meteorological events (Mudd and Kozlowski, 1975; Omasa et al., 1981). Therefore, there is potential to diagnose the symptoms of leaf scorch caused by extreme meteorological events from other damages (Vollenweider and Günthardt-Goerg, 2006). In North America, bacterial leaf scorch is affected by both *Xylella fastidiosa* and water stress (McElrone et al., 2001; Wood et al., 1995). The dualism of their symptoms (Hammerschlag et al., 1986; McElrone et al., 2001) irregular leaf scorch symptoms (Thorne et al., 2006) indicates that the diagnosing method described in this paper may be used for morphologically determining which one is the major factor between water stress and bacterial infection.

Although IAIA differences among distinct injuries are consistent, it remains unclear for the universality of most plant or tree species and it needs to be further proven by measuring a large number of samples. The judgment of injuries was complicated because abiotic stresses usually predispose the occurrence of disease (Blodgett et al., 1997; Desprez-Loustau et al., 2006; Kozlowski, 1985; Schoeneweiss, 1981), sometimes abiotic stress and disease coexisted on the same tree, and the responses varied with tree species. Although the diseased leaves usually showed local lesions at leaf margins with small IAIA, some lesions occasionally connected together, which made the lesions look like the typical characteristics of water stress, especially during the second half of the disease process. Whatever, the typical disease characteristics can be statistically manifested when sample sizes are large enough in the early stage of the disease. In contrast, partial leaves from few water loss-resistant tree species, especially for some evergreen tree species with larger leaflets, sometimes presented local necrotic lesions away from the margin similar to disease symptoms. Tree species with these types of characteristics usually contained venations that lacked the veins with thin tip and margin or gradually thinner veins from base to tip and from central vein to margin. Therefore, measurements should be perfected before the universality of the symptoms on most plant or tree species is confirmed.

5. Conclusion

The IAIA, LSAP and PSCV become effective indices to respond to the scorch symptoms of dogwood trees etc. induced by extreme meteorological events. Meanwhile, the larger IAIA values for scorched leaves and smaller IAIA values for spot/anthracnose diseased leaves of the studied trees indicated that IAIA may be used as a potential diagnosing index of leaf scorch symptoms after further studies. This study suggested that digital image analysis can be a useful and low-cost tool in distinguishing leaf scorch symptoms from disease and mechanical damage on some landscape trees. It makes the study of leaf scorch being possible from experiential comparison to quantitative and statistical analysis in the scope of ecological informatics.

Acknowledgment

We express our gratitude to Guofan Shao, professor in Purdue University of USA, for his kindly help.

References

Adamsen, F.J., Pinter, P.J., Barnes Jr., E.M., Lamorte, R.L., Wall, G.W., Leavitt, S.W., Kimball, B.A., 1999. Measuring wheat senescence with a digital camera. Crop Science 39, 719–724.

Adamsen, F.J., Coffelt, T.A., Nelson, M., Barnes, E.M., Rice, R.C., 2000. Method for using images from a color digital camera to estimate flower number. Crop Science 40, 704–709.

Bai, J.H., Wang, K., CHU, Z.D., Chen, B., Li, Sh.K., 2005. Comparative study on the measure methods of the leaf area. Journal of Shihezi University (Natural Science) 23, 216–218 (In Chinese).

Blodgett, J.T., Kruger, E.L., Stanosz, G.R., 1997. *Sphaeropsis sapinea* and water stress in a red pine plantation in Central Wisconsin. Phytopathology 87 (4), 429–434.

Bréda, N.J.J., 2003. Ground-based measurements of leaf area index: a review of methods, instruments and current controversies. Journal of Experimental Botany 54 (392), 2403–2417.

Chaerle, L., Caeneghem, W.V., Messens, E., Lambers, H., Montagu, M.V., Van-Der-Straeten, D., 1999. Presymptomatic visualization of plant–virus interactions by thermography. Nature Biotechnology 17, 813–816.

Chinese Academy of Agricultural Science (CAAS) (Ed.), 1965. Illustrations of Crop Disease and Insect Pests of China. Beijing Agricultural Press, Beijing, pp. 50–120 (In Chinese).

Desprez-Loustau, M., Marçais, B., Nageleisen, L., Piou, D., Vannini, A., 2006. Interactive effects of drought and pathogens in forest trees. Annals of Forest Science 63, 597–612.

Günthardt-Goerg, M.S., Vollenweider, P., 2007. Linking stress with macroscopic and microscopic leaf response in trees, new diagnostic perspectives. Environmental Pollution 147, 467–488.

Hammerschlag, R., Sherald, J., Kostka, S., 1986. Shade tree leaf scorch. Journal of Arboriculture 12 (2), 38–43.

Ito, K., Aino, S., 1976. Illustrations of tree disease and insect pests. Sohbun, Tokyo, pp. 80–99 (In Japanese).

Jones, H.G., 2004. Application of thermal imaging and infrared sensing in plant physiology and ecophysiology. Advances in Botanical Research 41, 107–163.

Kozlowski, T.T. (Eds.), 1976. Water supply and leaf shedding, In "*Water deficits and plant growth*, *vol .4*", (T.T. Kozlowski, ed.). New York: Academic Press, p. 191–222.

Kozlowski, T.T., 1985. Tree growth in response to environmental stresses. Journal of Arboriculture 11 (4), 97–111.

Liu, G., Kennedy, R., Greenshields, D.L., Peng, G., Forseille, L., Selvaraj, G., 2007. Detached and attached *Arabidopsis* leaf assays reveal distinctive defense responses against Hemibiotrophic *Colletotrichum* spp. MPMI 20 (10), 1308–1319.

McElrone, A.J., Sherald, J.L., Forseth, I.N., 2001. Effects of water stress on symptomatology and growth of *Parthenocissus quinquefolia* infected by *Xylella fastidiosa*. Plant Disease 85 (11), 1160–1164.

Mudd, J.B., Kozlowski, T.T. (Eds.), 1975. Responses of Plants to air Pollution. Academic Press, New York, p. 4.

Omasa, K., 1990. Image instrumentation methods of plant analysis. In: Linskens, H.F., Jackson, J.F. (Eds.), Modern Methods of Plant Analysis. New Series, Vol.11. : Physical Methods in Plant Sciences. Springer-Verlag, pp. 203–243.

Omasa, K., Hashimoto, Y., Aiga, I., 1981. A quantitative analysis of the relationships between SO2 or NO2 sorption and their acute effects on plant leaves using image instrumentation. Environmental Control in Biology 19 (2), 59–67.

Omasa, K., Saji, H., Youssefian, S., Kondo, N. (Eds.), 2002. Air Pollution and Plant Biotechnology-Prospects for Phytomonitoring and Phytoremediation. Springer-Verlag, Tokyo, pp. 343–359.

Omasa, K., Hosoi, F., Konishi, A., 2007. 3D lidar imaging for detecting and understanding plant responses and canopy structure. Journal of Experimental Botany 58, 881–898.

Pearce, R.S., 2001. Plant freezing and damage. Annals of Botany 87, 417–424.

Pirone, P.P., 1978. Disease and Pests of Ornamental Plants. John Wiley & Sons, New York, pp. 3–471.

Richardson, M.D., Karcher, D.E., Purcell, L.C., 2001. Quantifying turfgrass cover using digital image analysis. Crop Science 41, 1884–1888.

Schoeneweiss, D.F., 1981. Infectious diseases of trees associated with water and freezing stress. Journal of Arboriculture 7, 13–18.

Thorne, E.T., Stevenson, J.F., Rost, T.L., Labavitch, J.M., Matthews, M.A., 2006. Pierce's disease symptoms: comparison with symptoms of water deficit and the impact of water deficits. American Journal of Enology and Viticulture 57, 1–11.

Vollenweider, P., Günthardt-Goerg, M.S., 2006. Erratum to "Diagnosis of abiotic and biotic stress factors using the visible symptoms in foliage". Environmental Pollution 140, 562–571.

Wang, F., 2010. Persistent and advanced reddening of sweetgum leaves after major veins severing. Journal of Forestry Research 21 (4), 465–468.

Wang, F., Yamamoto, H., Iwaya, K., 2008a. Quantitative research on vigor of ginkgo trees hit by Typhoon 0613 with ground-based digital image analysis. Japanese Group for the Study of Natural Disaster Science 30 (1), 45–53.

Wang, F., Yamamoto, H., Ibaraki, Y., 2008b. Measuring leaf necrosis and chlorosis of bamboo induced by typhoon 0613 with RGB image analysis. Journal of Forestry Research 19 (3), 225–230.

Wang, F., Yamamoto, H., Ibaraki, Y., 2009a. Responses of some landscape trees to the drought and high temperature event during 2006 and 2007 in Yamaguchi, Japan. Journal of Forestry Research 20 (3), 254–260.

Wang, F., Yamamoto, H., Ibaraki, Y., 2009b. Transpiration surface reduction of kousa dogwood trees during seriously losing water balance. Journal of Forestry Research 20 (4), 337–342.

Wang, F., Yamamoto, H., Ibaraki, Y., Iwaya, K., Takayama, N., 2009c. Evaluating ginkgo leaf necrosis and asymmetric crown discoloration induced by Typhoon 0613 with RGB image analysis. Journal of Agricultural Meteorology 45 (1), 27–37.

Wharton, P.S., Julian, A.M., Connell, R.J.O., 2001. Ultrastructure of the infection of *Sorghum bicolor* by *Colletotrichum sublineolum*. Phytopathology 91 (2), 149–158.

Wood, B.W., Reilly, C.C., Tedders, W.L., 1995. Relative susceptibility of pecan cultivars to fungal leaf scorch and its interaction with irrigation. Hortscience 30 (1), 83–85.

Yapp, R.H., 1912. *Spiraea Ulmaria* L. and its bearing on the problem of xeromorphy in marsh plants. Annals of Botany os-26, 815–870.

Zhao, J.-b., Zhang, Y.-p., Tan, Zh-h, Song, Q.-h., Yu, L., Liang, N-sh, Zhao, J.-f., 2012. Using digital cameras for comparative phenological monitoring in an evergreen broad-leaved forest and a seasonal rain forest. Ecological Informatics 10, 65–72.