PH. D. Dissertation

Research on Responses from Some Landscape Trees to T0613 and Summer Drought with Digital Image and Spectral Analysis

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General Introduction

Morphological expression of landscape trees is usually the equilibrium between endogenous metabolic processes and exogenous metamorphic actions exerted by the environment. Landscape trees grow in the unremittingly altering environment and respond to it at any time and in varied patterns. Under the favorable conditions they make a response of rapid growth. However, the extremely unfavorable or catastrophic environments occasionally happen in field, even induce them into protective response or directly damage to them. Especially in recent years, many reports indicate that the unfavorable meteorological extreme events have increased as the large-scale climate changed in some area (Neilson and Drapek, 1998; Easterling et al., 2000; Frich *et al.*, 2002). Among them, the summer hot wave and the strong typhoon associated with elongated less rainfall often trigger many landscape trees, which is still in the situation of rainfed growing, into significantly visible injuries, such as leaf or branch abscission, leaf necrosis, branch dieback even death of overall plant (Kozlowski, 1973; Bhat *et al.*, 1986; Addicott, 1982; Rust and Roloff, 2004; Günthardt-Goerg and Vollenweider, 2007; Yapp, 1912).

Although no unique definition of the meteorological extreme event has been found in the related fields, it is an event with small probability is confirmed. Here the meteorological extreme events were considered as the events that the spread value of meteorological variables reached 2.0 times more (or less) than that of standard deviation. From 2004 to 2008 it appeared a significantly varied and strongly contrasted climate in Yamaguchi, Japan. During this period a lot of meteorological extreme events happened, particularly the exceptional typhoon 0613 (T0613), extreme summer drought in 2007 (SD2007). Apparent responses or damages were found on many landscape trees hit by T0613 and SD2007, which comprise the main content of this study.

The Mediterranean type summer drought and tropical cyclone are two special types of meteorological phenomena and often induce significant response from landscape trees. Serious disturbance to forest and trees by this kind of meteorological extremes was more common in many area of the world. Both high temperature and strong wind, associated with less rainfall, easily result in plants or trees into serious water imbalance even desiccation (Lange *et al.*, 1976; Whitehead, 1963). The combination of them evidently decreases the threshold of plant or tree responses to the extreme stresses.

Under extreme water stress conditions, many of them can save their lives from lethal desiccation status at expense of partial organs that comprise major parts of the damage character. It directly results in leaf abscission, necrosis, branch dieback, crown discoloration and so on. In fact, these terminal parts are the sensitive or frail points in their hydraulic architecture. The characteristics of tree responses to these kinds of extreme events usually show genetic specific diversity and stability. The structure of leaf, branch and vascular system and so on in a large extent manifest the adaptation pattern of them to extreme desiccation. As a result, they indicate different characteristics during the hit by these meteorological extreme events.

Visible symptoms of responses from landscape trees often showed temporal delay. The postponement of the metabolic procedure under water deficit status often defers the leaf shedding or partial death. The rapid leaf falling or necrosis after rehydration suggests that they are initiated by a response to water stress that cannot be completed without adequate water (Kozlowski, 1976). From the report of some oak species, a time lag of three weeks between the onset of drought stress and increased severity of abscission of leafy twigs (Rust and Roloff, 2004). By observation, the kousa dogwood leaf defense barrier usually occurred during night after serious summer drought stress during the day. Various symptoms of many tree or shrub species appeared numbers of days after hit by strong T0613. This kind of delay further suggested that the injured symptoms were the integration of the extreme stress and the responses from landscape trees. The delay of the tree responses to one extreme hit also increases the possibility of further hit by the other extremes. The longer delays of landscape tree response and their invisible responses may be more interesting to the change in the vigor status of them. However, the visible symptoms at present are the main focus.

Landscape trees are usually selected and planted by their characteristics of ornamental values. Partial of them are aesthetically or mechanically planted and regenerated at their unfavorable site so as to be sensitive to the environmental changes. They hit by the environmental extremes one after another, especially the individuals at constricted site condition that are in the situation of higher sensitive to the meteorological extreme events. It is more common that before they perfectly recover from an extreme shock another hit has occurred. By observation, a few of landscape trees grown at poor site condition are even in the cycle of branch sprout and dieback, and remain a small, narrow or stem alone crown. These kinds of continual damages cause them impossible to put up an all-round effective defense against the biotic and abiotic intrusion, and trigger the low vigorousness or abnormal form of them even accelerate senescence and/or death. The merge of the persistent meteorological extreme events may be one of the major inductive causes of accelerating senescence and/or death of some landscape trees. Persistent hit to one direction or part of them and the self-shelter one part of them by another as well as the asymmetric growth during the restoring period often cause asymmetry of some landscape trees in the restricted sites. It should affect the vigor status to respond the future meteorological extreme events like Typhoon 0613.

The studies concerned extremely environmental impacts involve in varied layers covering forest communities, populations, individual tree, organ, tissue, cell and molecules. In this study, the individual trees, branches and leaves as well as small area of bamboo canopies compose the main research objects studying with the method of combining image and spectral analysis, field visual observation and laboratory measurements. Since the big body of landscape trees, the conventional approaches in observing the damage characters of them in field was visual scale method. To some extent, they are observer specific and affected by subjective judgment. As the rapid advancement of information technology, it is emerging a trend for developing the objective methods to determine damages by typhoons and other disasters, especially using imagery analysis. The main objective of this study is focused on evaluation of responses from some landscape trees to two meteorological extreme events, T0613 and SD2007, by using the nondestructive and noninvasive methods. It is carried out at Yamaguchi University combining with analysis of meteorological data and using spectral analysis, RGB image analysis, thermography as well as water content measurement. During the study, it was found that the RGB image, reflected spectrum and the thermography are especially sensitive to the necrotic part of leaves or branches, which becomes the bases of damage evaluation hit by T0613 and SD2007. It may be originated from the special spectrum characteristics of necrotic parts.

The main architecture of this thesis is composed of five sections. The first is a general introduction. The second comes the Part one, which presents the climate character from 2004 to 2008 in Yamaguchi City, especially the two meteorological extreme events, T0613 and summer drought in 2007 in Chapter one, and then the representative characteristics of some landscape tree responses to them are described and analyzed in Chapter two. The Part two is the quantitative evaluation of the symptoms of ginkgo and bamboo induced by T0613 with spectral and image analysis. It includes Chapter three, four, five and six respectively. Estimating and measuring the responses from some normal and transplantation-shocked dogwood trees to the 2007 and 2008 summer drought or hot stresses by using the RGB image, spectral analysis method and thermography are arranged in Part three which include Chapter seven and eight. Finally, it presents the general discussion and summary. It is by the way of response description and analysis in Part one and the quantitative measurement of them in Part two and three complete the research of this thesis, in which includes some cause analysis.

Contents

Concept system and Abbreviations

A. Concept system

Meteorological extreme events— usually were considered as the events that the spread value of meteorological variables reached 2.0 times more or less than that of standard deviation. It is mainly focused on the extreme events of T0613 and SD2007.

Response— it is the reaction from landscape trees. It gives more importance to the reply from the trees to the meteorological extreme events. In the consideration of the symptoms caused by meteorological extreme events, it has some inter-crossing with 'damage'.

Damage— the symptoms caused trees less attractive, useful or valuable, it directly reduces the vigor of landscape trees.

Vigor—it is thought as one kind of ability to form a perfect individual and healthily grows of trees, which varies with the cultivated conditions, increases with fine nurtures and decreases by serious pest damages, disaster destroys and various kinds of stresses, such as drought, salt, nutrition shortage.

Landscape Trees—the trees used for making the land greening, beauty, in this thesis especially the trees planted in the park, along the street, highway and river, which are some tree or shrub species common seen in Yamaguchi City.

Necrosis— it means the death of tissue, organ and overall individuals of trees. In the thesis, it mainly study the death caused by the two meteorological extreme events or aboitic factors.

Dieback—the characteristics of twig or branches of trees and shrubs died from distal to proximal

Discoloration—tree crown or leaves lose their green color, especially the loss of chlorophylls as well as the crown color changes caused by leaf necrosis

Defoliation—the symptoms that tree lose their leaves and make the crown become more openness.

Windward-- A profile of crown against the extremely strong wind hazard

Leeward-- A profile of crown reverse to the windward

Sideward-- A profile of crown being perpendicular to leeward or windward

Asymmetric crown—the crowns that showed significantly difference of covered area or discolored area between windward and leeward from sideward profile of the crown

Normal—the meteorological variables averaged from the data more than 30 years.

Threshold—the point just before the leaf or branch becoming necrosis or dieback.

Imaging temperature—temperature value from thermo image analysis. In some extent, it is the near synonym with surface temperature.

Sunshine heating—the process of leaves and branches heated by the direct sunshine

Shading cooling—the cooling process under the shade condition after sunshine heating.

B. Abbreviations

LNAP—leaf necrotic area percentage
SD2007—summer drought event in 2007
T0613—typhoon number 13 in 2006
T0418—typhoon number 18 in 2004, ……, the rest can be deduced similarly.
AD13—aridity index of thirteen days
HD13—humidity index of thirteen days
GW33—gusty wind index of typhoons with maximum gusty wind over 33 m/s
TMAD—three month aridity index
AMeDAS—Automated Meteorological Data Acquisition System
G/L_{crown}—the ratio of green and luminance values of RGB images for tree crown

G/R$_{crown}$—the ratio of green and red values of RGB images for tree crown

G/L$_{leaf}$—the ratio of green and luminance values of RGB images for tree leaf

G/R$_{leaf}$—the ratio of green and red values of RGB images for tree leaf

RGL—relative G/L value

RGR—relative G/R value

WLAR—the percentage of area between windward and leeward of crown divided from main stem

CGAP—the crown green area percentage

LAR—single leaf area ratio between windward and leeward of crown

BDP—branch dieback percentage

LBP—living branch percentage

WLP—Water loss percentage

LSD—leaf desiccation speed

SPAD—the values measured by using SPAD-502 chlorophyll meter

NDVIR—normalized difference vegetation index reputing value

NDVI$_{755/679}$—normalized difference vegetation index at 755 and 679 nm wavelength

CDAP—crown discolored area percentage

IP—inflection point

DC—the shortest distance from coastline

ADC—average distance from AMeDAS stations to the coastlines of west, southwest, south and southeast

CC—crown coverage

VI — vigor index

AT—average temperature

RH—relative humidity

F—F test value

*— 95% proberbility of significant defference in F test

**—99% proberbility of significant defference in F test

TSR—transpiring surface reduction

WC—water contents

Part 1

Two Meteorological Extreme Events and Responses from Some Landscape Trees

According to the meteorological data from Yamaguchi Observatory, a tendency of changed climate character from 1967 to 2007 has been found. Recently the meteorological extreme events showed a trend of number increment, particularly the extraordinary strong typhoon and high temperature associated with prolonged less rainfall. In the recent 20 years, both extremely high annual temperature and low annual precipitation occurred in 1994 and 2007 respectively. The exceptional T0613 associated with long period no/less rain became the extreme events that haven't occurred for more than 40 years. From 2004 to 2008, the climate in Yamaguchi showed a special changed and strongly contrasted character. It caused many meteorological extreme events occurred. The meteorological extreme events of typhoon 0613 (T0613) and summer drought 2007 (SD2007) should be the proper examples.

Exogenous environmental factors often become operative through the endogenous metabolic processes of trees. In the normal weather conditions, the role of meteorological factor is not easy to be segmented from others in field, since the complication of their impact on the phenotype of landscape trees. However, the meteorological extreme events usually become the limit factor or catastrophic origin and often cause these trees to appear significantly visible symptoms that are important feedback information of these extremes. Both T0613 and SD2007 induced many landscape trees into abnormal status even apparent protective responses or damage characters. Combined analysis of leaf water conservation property, meteorological data and digital images of leaves/branches and the comparison among landscape tree species, they are described and analyzed in this part.

Chapter 1 Two Meteorological Extreme Events in Yamaguchi from 2004 to 2008

1.1 Introduction

In the surroundings of atmospheric CO_2 elevation and the persistent increment of air temperature in the past 20 years, the annual mean temperature in Japan rose up like the other areas in the world. Significant characteristics of climate change indicated that the numbers of abnormal lower air temperature decreased and extreme higher air temperature (>35 ℃) increased recent years in Japan (Kurihara, 2007). Although it is difficulty to find significant difference of precipitation from normal (Kurihara, 2007), a trend of raising number of days of no-rain (Kimoto *et al.*, 2005) and the days of heavy rain over 100mm or 200mm (Kurihara, 2007) was anticipated. Therefore, a tendency of adding probability of the meteorological extreme events characterized by higher temperature and both lower and higher precipitation would be expected (Easterling et al., 2000; Frich *et al.*, 2002; Meehl & Tebaldi, 2004, Bachelet *et al.*, 2001). Under the condition of no increasing of the total global precipitation, rising of rainfall in one region implies the reduction of the precipitation in other area. In the same region, seriously positive gain of rainfall in a period of time seems to induce the coming of dry period. The disproportional changes in the upper end of the precipitation frequency distribution in United States, most area of Canada and northeast Mexico might be one special case (Groisman et al. 2007). The drought in 1994 after the year with heavy precipitation in 1993, and the persistent less rainfall in 2007 should be another in Yamaguchi, Japan. From 2004 to 2008, significant variation characteristics of climate appeared in Yamaguchi, Japan accompanying with some meteorological extreme events.

1.2 Materials and methods

This study was carried out in Yamaguchi City, Japan. In the study, the annual, monthly, daily meteorological data from 1967 to 2007 for Yamaguchi and other 150 main observatories was obtained from Automated Meteorological Data Acquisition System (AMeDAS) of Japan to study the climate variance from the beginning of the AMeDAS in Yamaguchi. The daily maximum temperature, precipitation and gusty wind over 33 m/s from 2004 to 2008 were used to calculate the aridity index of thirteen days (AD13), the humidity index of thirteen days (HD13) and the gusty wind index of typhoons with maximum gusty wind over 33 m/s (GW33) as well as the three month aridity index (TMAD). They were calculated with Equation I1, I2, I3 and I4 respectively.

$$AD13_i = \sum_{j=0}^{12} MT_{i+j} \Big/ \sum_{j=0}^{12} PR_{i+j}$$

or

$$AD13_i = \max imum\ value\ of\ coordinate \quad \text{when} \sum_{j=0}^{12} PR_{i+j} = 0 \qquad (I1)$$

$$HD13_i = \sum_{j=0}^{12} PR_{i+j} \Big/ \sum_{j=0}^{12} MT_{i+j} \qquad (I2)$$

Where, i=1,2... 365 and i=1 on the January 1. j=0,1,2... 12. MT_{i+j} is daily maximum temperature at the day of i+j and PR_{i+j} is daily precipitation at the day of i+j. The 13 days of up limit was screened by repeat calculations of different days to reduce the numbers that denominator equals zero.

$$GW33_i = Guwd_i / 30 \qquad (I3)$$

Where, i=9/2004, 9/2005 and 9/2006, which the T0418, T0514 and T0613 took place respectively. The Guwd is the maximum gusty wind over 33m/s during hit by typhoons. The divisor of 30 was decided for integrating it into same coordinate system with AD13 and HD13 in the graph.

$$TMAD_i = \sum_{j=0}^{2} MMT_{i+j} \Big/ \sum_{j=0}^{2} MPR_{i+j} \qquad (I4)$$

Where, i=1, 2... 10 and i=1 in January, j=0,1,2. MMT_{i+j} is monthly maximum temperature in the month of i+j and MPR_{i+j} is monthly precipitation value in the month of i+j.

1.3 Characteristics of climate variation in Yamaguchi

From the beginning of the AMeDAS observation from 1967 in Yamaguchi, the annual mean temperature drew a fluctuated increasing line (Fig. C1-1a), like the most of other cites in Japan. By calculation, the air temperature increased 1.68 degree centigrade from 1967 to 2007. Although, the annual precipitation almost remained at same level (Fig.C1-1a), it turned to raise the fluctuations of their standard deviation in recent 21 years especially in the second half of a year (Fig.C1-1b). The tendency of amplified precipitation deviation even appeared in more than 60% of 150 central observatories in Japan. In recent years, not only the heavy rainfall has increased in some regions (Kurihara,2007; Matsumoto and Yamamoto, 2007), but also the probability of meteorological extreme events have raised (Easterling *et al.*, 2000; Frich *et al.*, 2002).

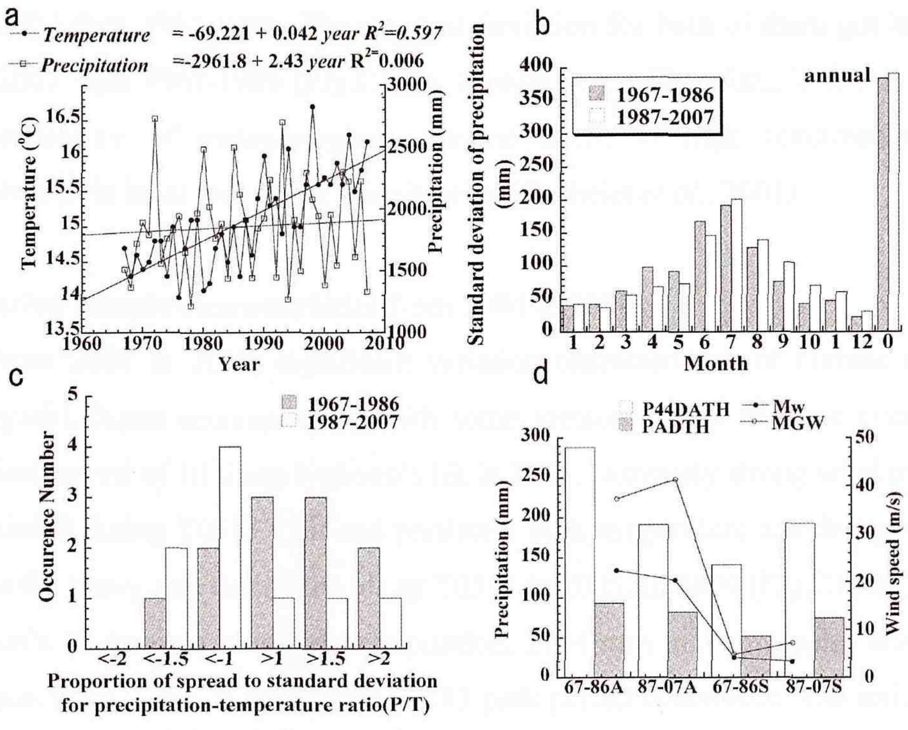


Fig.C1-1 Characteristics of climate variation in Yamaguchi, Japan; C1-1a represents the temporal series of annual mean temperature and precipitation from 1967 to 2007, which appeared a slant and a level line for temperature and precipitation respectively. C1-1b showed the yearly and monthly distribution characteristics of standard deviation of precipitation in the period of 1967-1986 and 1987-2007 for Yamaguchi City and showed a characteristic of larger precipitation standard deviation at all months in second half year during recent 21 years. C1-1c presents the occurred number of different folds of spread to the standard deviation value of precipitation-temperature ratio at Yamaguchi Observatory. It showed more occurrences of minus value of spread and standard deviation ratio and less occurrence of positive value in 1987-2007 than in 1967-1986. C1-1d was a graph of max gust wind speed (MGW) and max wind speed (Mw) of strong typhoons whose gust wind speed is over 33 m/s, the precipitation in the day typhoon's hit (PADTH) and the rainfall during 44 days after typhoon's hit (P44DATH). Both the average value (A) and the standard deviation (S) of them showed significant variance.

Integrated the meteorological extreme events from 1967 to 2007, there appeared a trend of more negative extreme spread value of the precipitation-temperature proportion (P/T), less positive extreme of it in Yamaguchi from 1987 to 2007 (Fig.C1-1c). It is indicated a trend of more years with high temperature and low precipitation and less years with low temperature and high precipitation occurred. Meanwhile, the occurrence of strong typhoons, gust wind speed over 33 m/s, increased during 1987- 2007 comparing to that of 1967-1986 and the standard deviation of them also raised (Fig. C1-1d, line) being consistent with average. Both the mean value of precipitation 44days after strong typhoon's hit and rainfalls in the day strong typhoon's hit was lower in 1987-2007 than 1967-1986. The standard deviation for both of them got larger during 1987-2007 than 1967-1986 (Fig.C1-1d, Histogram). Therefore, it seems to increase the probability of meteorological extreme event of high temperature and low precipitation in local area under this situation (Bachelet *et al.*, 2001).

1.4 Varied climate characteristics from 2004 to 2008

From 2004 to 2008, significant variation characteristics of climate appeared in Yamaguchi, Japan accompanying with some meteorological extreme events, such as historical record of 10 times typhoon's hit in 2004, extremely strong wind mingled with less rainfall during T0613's hit and persistent high temperature and drought in 2007 as well as the heavy rain during the hit by T0514 in 2005. In 2004 (Fig.C1-2a), numbers of typhoon's hit brought plentiful precipitation, 2224 mm in Yamaguchi, and poured on the Japan Islands, which means less AD13 peak period occurrence. The seriously strong gusty wind (maximum 50.3 m/s in Yamaguchi) during hit by T0418 was also fenced in a large HD13 peak (Fig.C1-2a). Both AD13 and HD13 during 2005 (Fig.C1-2b) showed significant dissimilarity to that in 2004. Not a large quantity of precipitation in all year, 1613 mm, led many AD13 peak appeared (Fig.C1-2b). However, the T0514 was inlaid into the HD13 peak in September (Fig.C1-2b). By contrast, in 2006 it was almost same as in 2004 during the first eight months (Fig.C1-2c). Nevertheless, the T0613 characterized by strong wind and less rain (max gusty wind speed 42.4 m/s), merged into a persistent AD13 peak period of more than one month (only once in 2006).

Although there was no serious typhoon's hit in Yamaguchi during 2007 and 2008, the prolonged extreme weather of high temperature and less rainfall (annual precipitation 1321 and 1691 mm in 2007 and 2008 respectively), especially in July, August and September (Fig.C1-2d, C1-2e) became the weather extremes during these two years.

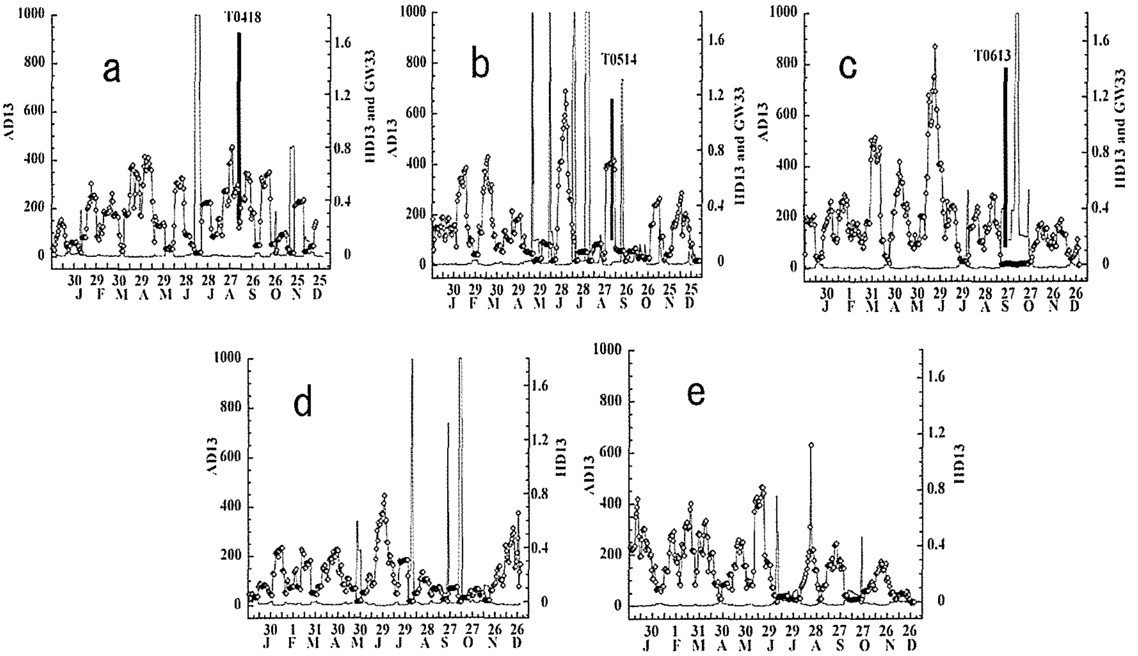


Fig.C1-2 The characteristics of meteorological extreme events from 2004 to 2008 in Yamaguchi City. AD13 (—), HD13 (○—○) and Gw33 (▬) values in 2004 (a), 2005 (b), 2006 (c), 2007 (d) and 2008 (e), and their peaks (extreme weather). The characters of "J F M A M J J A S O N D" stand for January, February, ... December.

During this period, a lot of meteorological extreme events happened, particularly the T0613 and SD2007.

1.5 Extreme typhoon event-T0613

The Typhoon 0613 (T0613) originated from the sea area east to the Philippines on Sep.9, 2006 and took the similar track as the catastrophic T9119 and T0418 (Fig. C1-3). It hit the Japan Islands starting from the vicinity of Sasebo City, Nagasaki Prefecture. The center of it passed through the Japan Sea and shaved the southwest corner of Yamaguchi Prefecture with characteristics of strong wind and less rainfall in Yamaguchi City. Its max gusty wind speed reached 42.4 m/s and minimum air pressure at sea level was 980.4 hPa as well as less rainfall associated when it passed through Yamaguchi City (Fig. C1-3). It even made a new meteorological record of lowest precipitation 44 days after hit by T0613 at Yamaguchi Observatory (Table 1-1). According to the data from Yamaguchi meteorological observatory, the precipitation was only 26 mm during the period hit by Typhoon 0613 and as the max wind speed reached to the peak almost no rainfall associated.

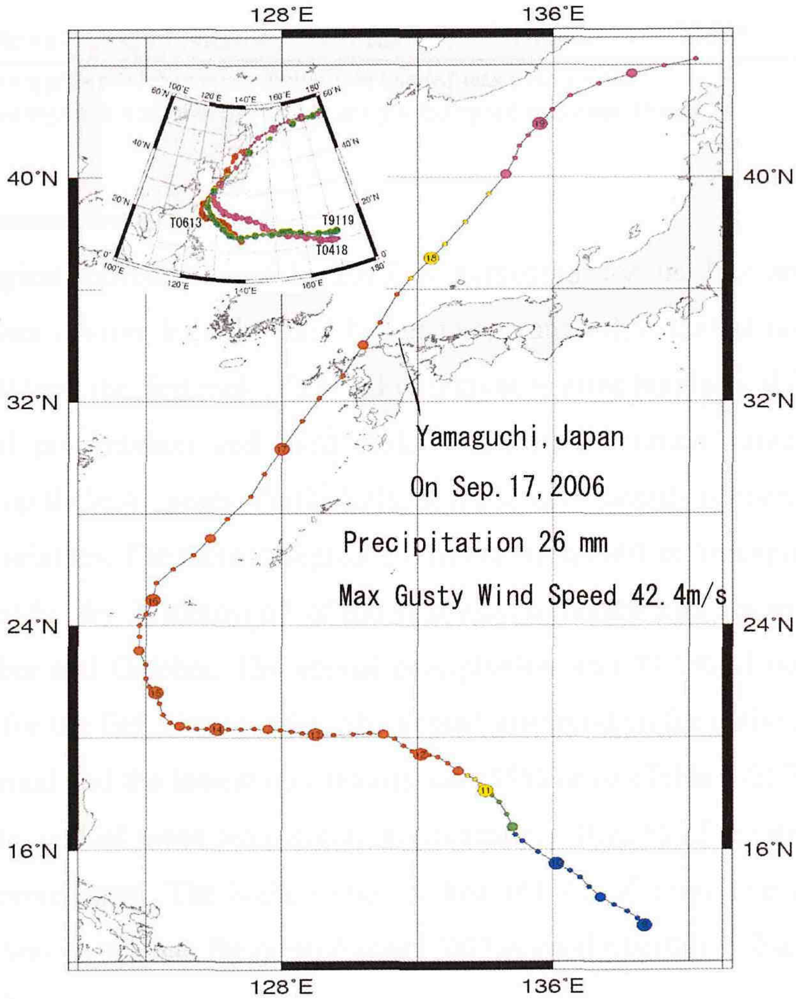


Fig. C1-3 Track of the T0613, T9119 and T0418; The center of T0613 passed through the Japan Sea and shaved the southwest corner of Yamaguchi Prefecture with characteristics of strong wind and less rainfall in Yamaguchi City. When T0613 hit Yamaguchi City on Sep. 17, 2006, the max gusty wind speed reached 42.4 m/s and the precipitation was 26 mm. Almost no rainfall associated when the wind reached the maximum speed during hit by T0613.

Table 1-1. Related meteorological data for Yamaguchi

	During	Past 40 years		
	Typhoon 0613	Max	Mean	Min
Max gusty wind (m/s)	42.4	53.1#	39.5#	33.2#
Max wind speed (m/s)	20.0	28.8*	21.0*	15.4*
Precipitation during T0613 (mm)	26.0	247.0*	91.2*	5.0*
Precipitation in 44 days after T0613 (mm)	8.5	544.0*	233.1*	8.5*

* The data came from typhoon's hit that maximum wind speed was over 15 m/s.
# The data came from typhoon's hit that maximum gusty wind speed was over 33 m/s.

1.6 Extreme summer drought event

The meteorological extreme event in 2007 is expressed for its less and uneven precipitation, lower relative humidity and higher temperature than that of normal year (1967 to 2007). It took the first rank of annual minimum relative humidity, third rank of minimum annual precipitation and third rank of annual maximum value of mean temperature during these 41 years. Particularly, it made new records of many monthly meteorological variables. The meteorological environment in 2007 in Yamaguchi, Japan was characterized by dry in almost all of the first eleven months and hot in February, August, September and October. The annual precipitation was 71.6% of normal year and only 60.1% for the first nine months. The annual precipitation for entire Japan was 87.6% to the normal and the lowest observatory was 55% or so (Table 1-2, Fig. C1-4). In Yamaguchi, the annual mean temperature accounted for 107.3% of the normal year and 106.7% in entire Japan. The highest one reached 113.5% of normal year and only one observatory was lower than the normal year (2007/normal <100%) in 2007 in entire Japan (Fig. C1-4).

The extreme weather from August seventh to eighteenth could be considered as the key of meteorological extreme event in August 2007 in Yamaguchi. Although hit by typhoon 0705 on August 3, 2007, its max wind speed was lower than 10 m/s accompanying with heavy daily rainfall (77.5mm) and not very higher temperature (daily highest temperature 29.8°C) in Yamaguchi. Then, more than 15 days anticyclone weather occurred. During these days, as the average temperature and minimum temperature maintained higher than the normal year (1971-2000), the max wind speed and gusty wind speed reached the peaks at 9.1 and 17.7 m/s and associated with no rain. Meanwhile, the relative humidity drew a 'U' shaped curve and the period of no rain persisted seventeen days. All of these led to a foehn like weather.

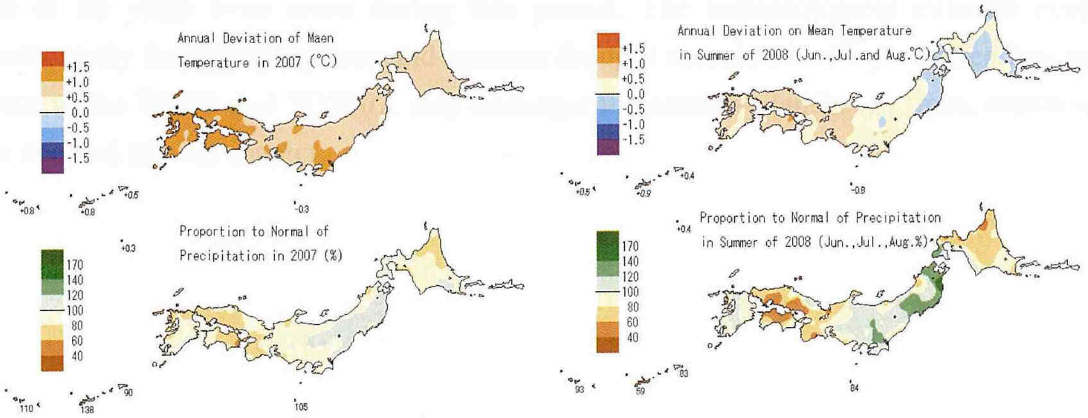


Fig. C1-4 Annual deviation of mean temperature and proportion to normal of precipitation in Japan in 2007 and in summer of 2008 (Jun., Jul. and Aug.)

Table 1-2 Spread and ratio of annual precipitation and temperature in 2007 to normal year

	Precipitation (mm)		Temperature (℃)	
	Yamaguchi	Japan	Yamaguchi	Japan
Ratio %	71.6 (60.1*)	87.6	107.3	106.7
Max ratio%	-	137.4	-	113.5
Min ratio%	-	55.0	-	98.9
Spread	-517.1	-215.9	1.1	0.75

The data of Japan was mean value from 150 observatories. The data with * means from the first nine months.

During the summer of 2008, the annual deviation of mean temperature was more than 0.5℃ degree compared to normal. Meanwhile, the precipitation was less than 80% of normal years at Yamaguchi (Fig. C1-4). During the hottest day from Jul. 22 to Aug.14 in 2008, only 11mm rainfall was recorded at the Yamaguchi Observatory. The maximum daily temperature in all of these days during this period maintained higher than 33 °C.

1.7 Conclusion

From the beginning of the AMeDAS observation in Yamaguchi, especially from 2004 to 2008, although a changed and strongly contrasted climate was found in Yamaguchi, whether it is persistent and irreversible or not is still unclear and needs further observation. However, many meteorological variables became the events occurred once more than 40 years and the complex of these variables maybe longer than 50 or 60 years even more during this period. The meteorological extreme events, particularly the strong typhoon and summer drought associated with prolonged less rain, such as the T0613 and SD2007, may endanger the sensitive landscape trees, which will be showed in next chapter.

Chapter 2 Responses from Some Landscape Trees

2.1 Introduction

The Mediterranean type summer drought and tropical cyclone are two special types of meteorological phenomena, and often induce significant protective responses (LIU at al., 2007) from trees. Both high temperature and strong wind associated with less rainfall easily result in trees or shrubs into serious water stress, desiccation as well as the energy imbalance (Lange *et al.*, 1976; Maki *et al.*, 1991; Whitehead, 1963). As a result, the responses from plants or trees at first stage usually appear the variation of metabolism and photosynthetic pigment especially for the chronic responses that is often recoverable (Balaguer et al., 2002). The abscission of plant organs or tissues is one of the most apparent responses (Kozlowski, 1973). Leaf abscission was considered as a drought resistant mechanism to reduce the transpiring surface (Orshan, 1954) and prevent dehydration of plants to lethal levels (Kozlowski, 1976). The abscission response to drought are usually aggravated and accelerated by dry wind (Addicott and Lyon, 1973). Leaf scorch and "windburn" are associated with hot and dry wind during serious drought stresses (Yapp, 1912) and even apparently stimulate branch abscission (Millington and Chaney, 1973) or dieback of some perennial trees. Historically, in the early 1930's the severe drought at the central states of United States and unusually dry weather in Australia in 1965, many trees appeared early defoliation, leaf scorching, discoloration and so on (Kozlowski, 1976; Bachelet *et al.*, 2001). These kinds of climate extreme even triggered or accelerated the tree mortality (Guarín & Taylor, 2005), tree decline (Jurskis, 2005), forest defoliation (Zierl, 2004), reduction of radial growth of trees (Pichler and Oberhuber, 2007), wide-spread primary productivity reduction (Ciais *et al.*, 2005; Barber *et al.*, 2000) particularly in Mediterranean region (Bussotti and Ferretti, 1998), Australia (Jurskis, 2005) as well as the specific area and constricted sites (Van der Werf *et al*, 2007) in some countries. In Japan, the rainfed rice crop in west Janpan (Yamamoto *et al.*, 1996) and forest trees (Kotani, 1997) suffered from the extremely droughty and hot weather in 1994.

The characteristics of tree responses to these kinds of extreme events usually show genetic specific diversity and stability. The difference of leaf structure, function and water conservation strategy between deciduous and evergreens lead to different expression in response to the extreme stresses. Most of the deciduous tree species possess relative light, thin and poor-covered leaves, which complete the trade off among the water use efficient, energy balance and CO_2 obtainment. By contrast, most evergreen leaves have relative thick and well-covered and desiccation resistant cuticles and some of them contain more complex transfusion tissues (Fahn, 1990). Cuticle layer construct first and the most important barrier to prevent water loss from leaves after stomata closed, which is a major property for trees to maintain hydraulic status during serious water stress. In a great part, it manifests the ability of trees to resist desiccation. However, this kind of desiccation process in plants or trees has less thoroughly studied than other aspects, mainly because it is not of great significance in agriculture; few crops are grown where there is consistent risk of plant desiccation (Fitter and Hay, 2002) except the landscape trees hit by above mentioned meteorological extremes. From limited record about it (Schreiber and Riederer, 1996; Schönherr and Schmidt, 1979), the cuticle transpiration of conifers is apparently lower than that of annual herb species. For example, the rate of cuticle transpiration of impatiens is about 130 mg/hour^{-1} gm.$^{-1}$ (fresh weight), *Pinus* species 1.5 and *Quercus* species 24.0 (Thomas, 1973). Wind and high temperature can evidently enhance transpiration (Whitehead, 1963; Baig and Tranquillini, 1980; Martin et al., 1999) and the cuticle transpiration at temperature higher than 35℃ (Riederer, 2006; Schreiber, 2001). The combination of them can evidently cause a decreased threshold of their responses to the extreme water and hot stresses. The striking responses from some landscape trees should be triggered by the extreme high temperature and strong typhoon associated with prolonged less rainfall.

In normal growing conditions symmetry is a marked aspect in the structural development of leaves and crowns of trees and shrubs, and is usually morphological hereditary (Greulach, 1973), although there is increasing facts appeared a fluctuated asymmetry of this character recently (Kozlo, 2003). Trees usually develop a symmetric shoot or crown except when exposed to substantial environmental gradient (Lawrance, 1939). In some cases internal or external environment can alter even prevent the symmetrical development. Tree deformation was often considered as the results of wind pressure where exists prevailing wind (Noguchi, 1979; Lawrance, 1939), salt spray damage (Boyce, 1954) near seacoast, and the mechanically abrading or attacking by snow or ice particles at the timberline. Some others held that strong wind pressure under severe water stresses should be the main cause of the asymmetric crown of some tree species (Wardler, 1968). In fact, the environmental factors merged together seem the main cause of tree deformation and they usually acted together so as to significantly decrease the threshold of tree responses. From this perspective, researchers in different opinions have their special highlight to the key of the ultimate reason. In the history of the research of tree deformation or asymmetric crown formation, large amount of research was focused on the damage to the trees by environmental factors, especially the decisive factor of damage. The argument and controversy were usually concentrated in several physical or chemical elements. Field trees affect by a complex of aboitic and biotic environments. The symptoms appear on trees are often the results of their responses to the environmental effect and show genetically specific. Among the environmental factors, the one that directly or significantly change the characteristics of tree response should be expected the decisive factor. To the tree species with special physical property of branches, the mechanical training seems more important to their deformations (Lawrance, 1939). To the trees sensitive to salt damage, the salt injury may be the major cause to the death or partial death of them (Van Der Valk, 1974). The characteristics of big body and complex spatial structure of trees or shrubs usually result in self-shelter one part of them by another. Injury often was most severe on the parts of crowns uncovered or exposing to the hazard. Leaves in the extreme crown periphery or top, un-sheltered by other parts, were injured more than those in the crown interior or proximal (Kozlowski, 1976) during extreme water stress. The sequential effects of the self-shelter usually result in significant asymmetry of some landscape trees. During the restoring process from hurt by the extreme typhoon events, the asymmetric growth of different parts may be another reason of the asymmetric crown of landscape trees.

Water is essential for life and constitutes a large part of the fresh weight of most herbaceous plants. In the complicated architecture of woody plants, over 50% of the fresh weight is also made of water (Kramer, 1983). The internal water involved in photosynthesis process, turgor and temperature maintenance, and nutrition transportation and so on (Clements, 1934). Proper amount of water supply can be considered as the safeguard element for plants to sustain many abnormal environmental effects. Under extreme water stress conditions, many trees can save their lives from lethal desiccation status at expense of partial organs (Tyree and Zimmermann, 2002), such as abscission or death of tissues, leaves, branches (Orshan, 1954, 1989; Addicott and Lyon, 1973; Addicott, 1982; Kramer, 1983; Kozlowski, 1973, 1976; Günthardt-Goerg and Vollenweider, 2007), although it appear significant plasticity and diversity. For example, needle tip necrosis and branch dieback as well as the needle abscission occurred on krummholz trees of Engelmann spruce under the severe winter wind and unavailability of soil water supplies in the studies of Wardler (1968). It was considered the main cause of Engelmann spruce tree deformation. The well-known phenomenon of "red belt" was also occurred in the similar desiccation environmental conditions (Bella and Navratil, 1987; Henson, 1952; Treshow, 1970). Edged part necrosis or death was often appeared on trees that affected by vascular, root or stem diseases (Talboys, 1968), for example, root rot disease of many tree seedlings or saplings, grapevine Pierce's disease (Thorne *et al.*, 2006) and son on. It was observed meteorological extreme events of summer high temperature and strong typhoon, associated with no rain and persistent drought stress, induced the similar visible responses from some landscape trees or shrubs, such as leaf necrosis, branch dieback as well as asymmetric death of tree organs. The injured symptoms appeared on these landscape trees or shrub species are shown and analyzed in this chapter.

2.2 Materials and methods

2.2.1 Meteorological data and related indices

By meteorological data analysis, photo image analysis, water status measurement of leaves, die-backed branches and crown asymmetry analysis, the responses from some landscape trees and shrubs to the two meteorological extreme events T0613 and SD2007 in Yamaguchi, Japan were studied, in order to show a special example of this kind of response. The investigation of T0613's hit was practiced in a long and narrow area from seashore to inland. It includes the circled sites of Ube, Aio, Ogori, Yamaguchi, Miyano, Mitani and Tokusa that don't match up the administrated area with same name (Fig. C2-1), and runs from southwest to northeast.

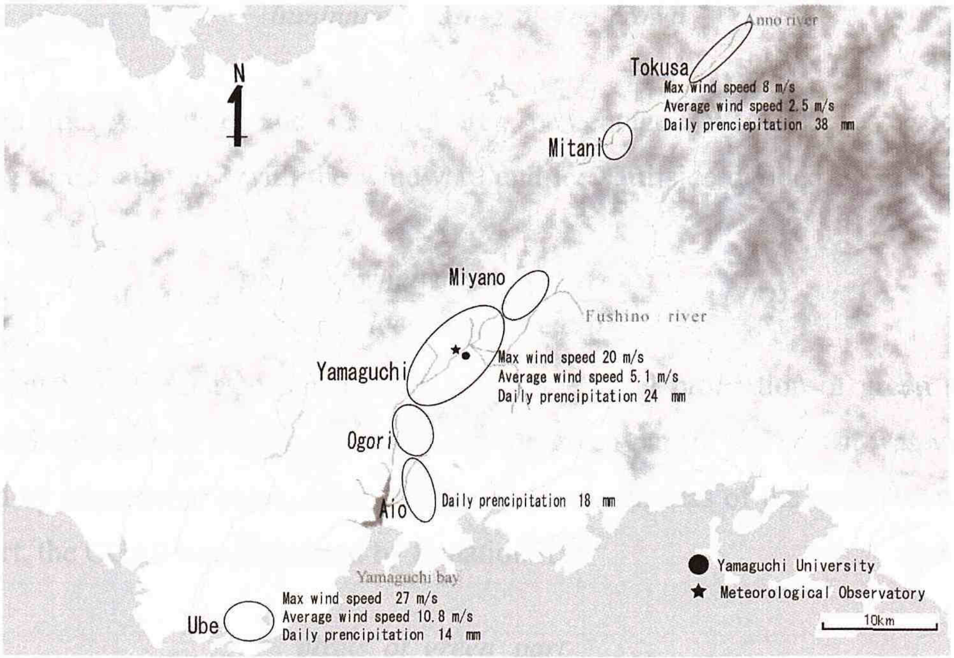


Fig. C2-1 The map of studied area and meteorological data. It includes the circled sites of Ube, Aio, Ogori, Yamaguchi, Miyano, Mitani and Tokusa. ● is the position of Yamaguchi University. ★ stands for the location of Yamaguchi Meteorological Observatory.

The research on the extreme summer drought events was carried out in the area less than 2.0 km from Yamaguchi Meteorological Observatory where is about 13 km from coastline. In Yamaguchi University, water status of leaves and branches was measured at indoor natural condition.

2.2.2 Image analysis originated indices

The crown coverage of vertical profile of trees or shrubs was estimated by image analysis method. Photos of vertical profile of objective trees or shrubs were taken on ground and by using a CCD digital camera (Canon IXY 6.0). The photo-taking distance was determined according to the sizes of crowns and making crowns fit the screen of the camera. Positions of photo taking were fixed by observing the sampled tree and make sure to take the exact sideward photo image. After removing the objects except the objective crown, the image green (G) and luminance (L) values were read from Photoshop. The image G/L_{crown} value was calculated with Equation II1.

$$G/L_{crown} = \frac{green\ value\ of\ the\ crown}{luminance\ value\ of\ the\ crown} \qquad (II1)$$

Then the windward and leeward area percentage (WLAR) was calculated according to Equation II2 with the windward and leeward side divided by reference of main stem.

$$WLAR = \frac{pixels\ of\ windward\ of\ the\ crown}{pixels\ of\ leeward\ of\ the\ crown} \qquad (II2)$$

The crown green area percentage (CGAP) is the pixel proportion of green part to entire profile of crown. During measurement, the green part of the crown was visually extracted by transitional color. After getting the pixel numbers of the entire crown and green part, the CGAP was calculated by Equation II3.

$$CGAP = \frac{pixels\ of\ green\ part}{pixels\ of\ overall\ crown} \times 100 \qquad (II3)$$

The single leaf area ratio between windward and leeward of crown (LAR) is the proportion of average pixels of single leaves between windward and leeward of a crown. It was calculated according to Equation II4 by using the images respectively scanned from detached leaves with a flat bed scanner (Canon d125u2) or taken from attached leaves in equal distance of 20 cm with the CCD digital camera (refer to Appendix 1.8). The leaf area was expressed by image pixels read from Photoshop. Before getting the pixel value, the images were treated to remove the part except the leaves.

$$LAR = \frac{\sum_{n=1}^{30} lpw_n}{\sum_{m=1}^{30} lpl_m} \qquad (II4)$$

Where, lpw_n is image pixels of the leaf number n on windward and lpl_m is image pixels of the leaf number m on leeward; m=n=1, 2, 3…30.

As a result of hit by the meteorological extreme events, crown asymmetric discoloration and branch dieback were more common on some tree crowns. It was measured using image-analyzing software of Image-Tool 300. The branch dieback percentage (BDP) is a ratio of total length of branch dead part to the total length of the branches and was calculated by Equation II5. The living branch percentage (LBP) equals to 100 minus BDP.

$$BDP = \frac{100 \times \sum_{i=1}^{n} ld_i}{\sum_{i=1}^{n} lt_i} \qquad (II5)$$

Where, ld_i is the length of dead part on i branch, lt_i is the total length of i branch and n is the total branch number measured.

2.2.3 Water related indices

Five functional and water saturated current year leaves of 15 tree and shrub species were picked at a rainy day in middle of June in 2008, from normal growing trees to study the water loss procedure and leaf desiccation speed of detached leaves. They include kumazasa bamboo (*Sasa veitchii Carr.*), kousa dogwood (*Cornus kousa Buerg.*), sweet gum (*Liquidambar styraciflua L.*), japanese blue oak (*Quercus glauca Thunb.*), trident maple (*Acer buergerianum Miq.),* sasanqua camellia (*Camellia sasanqua Thunb.),* metasequoia *(Metasequoia glyptostroboides Hu et Cheng),* zelkova *(Zelkova serrata Murr.),* ginkgo *(Ginkgo biloba L.),* red leaf photinia (*Photinia glabra* (*Thunb.) Maxim.*), fragrant olive (*Osmanthus fragrans var. aurantiacus*), camphor tree (*Cinnamomum camphora (L.) J. Presl.*), fortune's osmanthus (*Osmanthus ×fortunei Carr.*), kaizuka juniper (*Juniperus chinensis L. var. kaizuka Hort.*) and Yedda Hawthorne (*Rhaphiolepis indica var. umbellata*). Leaves were picked up from selected trees and then taken back to lab with plastic bags. They were dehydrated under the indoor environment of RH 60%-70% and AT 25-30℃and weighed in a planned time interval. Water loss percentage (WLP) was measured by rapid weighing method with 1/10000 g electronic weighing balance in room. The weight of sampled leaves or leaf sections was weighed after sampling from field site without delay. Water loss percent was calculated by using the Equation II6.

$$WLP_i = \frac{FW - DW_i}{FW} \times 100 \qquad (II6)$$

Where, FW is the fresh weight of sampled leaf and DW_i is the weight of it after i hours water loss procedure.

The last dry weight of leaf samples obtained by 90 ℃ windy Oven, the total water content was also calculated by using Equation II6 with the DW_i equals last dry weight.

The leaf desiccation speed (LDS) of these fifteen tree/shrub species was calculated by using Equation II7 to estimate the water protection ability of them. It might be a near estimation value of the cuticle transpiration character. (Cape and Percy, 1996; Slavik, 1974)

$$LDS = \frac{1000 \times (\sum_{i=1}^{5}(FW_i - DrW_i))}{T \times \sum_{i=1}^{5} FW_i} \qquad (II7)$$

Where, LDS (mg. hr.$^{-1}$ g.$^{-1}$) stands for the leaf desiccation speed value, FW_i is the fresh weight of the leaf number i and DrW_i is the dry weight of the same leaf, T is the number of hours when logistic threshold water loss curve (Thornley, 1976) reached maximum value.

It was observed that the water loss procedure of detached leaves was fit to logistic function as Equation II8.

$$WLP(t) = \frac{k}{1 + e^{a-rt}} \qquad (II8)$$

Where, *WLP* (t) stands for water loss percentage at t temporal section. *K* is the maximum value that water loss percentage can reach. R is a regression coefficient and the character 'a' is a constant. T is the number of sections.

Based on the mathematic principle, inflection point (IP) of Equation II8 will exist only when the secondary differential value equals to 0 (t=a/r), and the $\frac{d^2WLP}{dt}$ >0 when t<a/r and $\frac{d^2WLP}{dt}$<0 when t>a/r. In the analysis of leaf desiccation speed of detached leaves for different tree species, the IP was also used as one index of water loss extent.

Branch water content of sweet gum, metasequoia and ginkgo was measured by rapid weighing method with 1/100 g electronic weighing balance in room. Branches were sampled from normal growing trees and cut into 10 cm sections from proximal to distal. The weight of sampled branch sections was weighed after sampling from field site without delay and dehydrated at natural room environment with RH 50-60% and AT

20-25℃. After obtained the weight at i hour (Wi), last weight (WL) and fresh weight at the beginning of the measurement (FW), the water content (WC_i) was calculated by using Equation II9.

$$WC_i = \frac{Wi - WL}{FW} \times 100 \qquad (II9)$$

Leaf water potential of sweet gum was measured using a pressure chamber (PMS 600) in a clear windy day on Aug. 11, 2007. The maximum gusty wind and high temperature in this day were 7.1 m/s and 31.7 degree centigrade respectively. Each ten leaves were measured soon after sampling from windward and leeward of a garden tree in Yamaguchi University without delay.

2.2.4 SPAD value

The SPAD values of individual leaves were average value of 30 duplications per leaf impartially measured by using SPAD-502 chlorophyll meter.

2.3 Responses of sweet gum trees to the meteorological extreme events from 2004 to 2008

Following the abnormal droughty spring, hot and dry summer in 2007 in Yamaguchi, many landscape trees showed abnormal status, especially the trees planted on coarse sand soil, rock mountain site and the site with root growing limitation etc. Many kousa dogwood trees appeared leaf necrosis on tip and margin from late August (Fig.C7-2, C7-5), which will be described in detail in Part three. Some sasanqua camellias also dropped all of their leaves during this period (Fig.C9-7b). During the flower season, the number of flowers (Fig.C9-7c) on these sasanqua trees was significantly less than that in 2006 season (Fig.C9-7a). A lot of Japanese red pines (*Pinus thunbergii L.*) on mountain sites died, whose needles turned brown first. Some deciduous tree species dropped partial leaves early from late August. Especially, leaves on particularly the leader and upper crown branches of sweet gum tree began to turn to dull colored from mid-September and reddish-brown or purples by mid-October (Fig.C2-2d, C2-2e). The other tree species might be affected by it without visible signs.

During this study, the AD13, HD13, Gw33 and so on were established to analyze their impact on the landscape trees (Fig.C1-2). Result showed an obvious difference among the years from 2004 to 2008. In 2004 no red top characteristic of sweet gum tree in fall of this year seems directly resulted from the plenty rainfall and less AD13 peak period occurrence. Persistent vegetative growth of sweet gum trees was benefited from the abundant precipitation during this period (Fig.C2-2a, C1-2a). In the year 2005, no significant red top and asymmetric crown discoloration of sweet gum tree appeared in fall might be attributed to the rainfall being mainly poured on them during hottest July, August and September (Fig.C2-2b, C1-2b) and the T0514 was also inlaid into the HD13 peak in September. However, the T0613, characterized by strong wind and less rain (max gusty wind speed 42.4 m/s) accompanying with a AD13 peak period of more than one month (only once in 2006) made the crown of sweet gum trees asymmetrically discolored from windward to leeward and no red top on leeward side of these trees simultaneously (Fig.C2-2c, C1-2c). Although there was no serious typhoon's hit in Yamaguchi during 2007 and 2008, the persistent extreme weather of high temperature and less rainfall (annual precipitation 1321 and 1691 mm in 2007 and 2008 respectively), especially in July, August and September (Fig.C1-2d, C1-2e), induced sweet gum trees into asymmetric discoloration from top to base of the crown in fall (Fig.C2-2d, C2-2e).

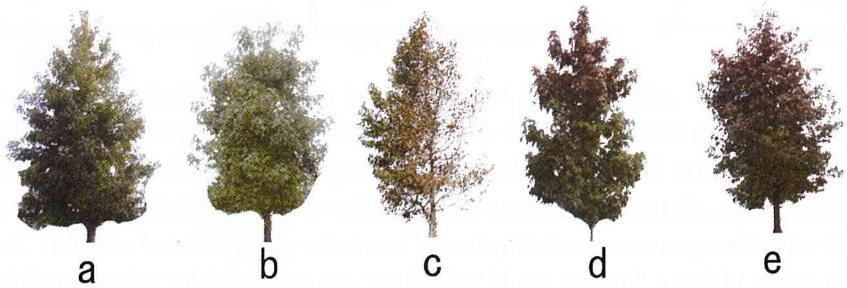


Fig.C2-2 Crown characteristics of sweet gum in 2004 (a), 2005 (b), 2006 (c), 2007 (d) and 2008 (e). The heavy precipitation in 2004, 2006 and summer HD13 peak in 2005 seems has something to do with the normal green crown top in fall. Whereas the red or purple crown top in 2007 and 2008 perhaps triggered by summer peak period of AD13. The eye-catching symptom of asymmetric crown discoloration and defoliation in 2006 is attributed to the strong T0613 accompanying with the persistent peak period of AD13. It is worth able to take attention in T0418 (Fig. C1-2a), although its gusty wind was larger than T0613, no asymmetric crown discoloration and defoliation of sweet gum occurred.

By observation, most of the asymmetric responses occurred during these AD13 peak and GW33 peak period. But not all peak periods surely appeared these kinds of responses, for example the great AD13 peak and GW33 peak respectively in July and September 2004. There is a tendency they are adjusted by the situation of longer period of peaks. By integration, the red top crown phenomenon was consistent with the TMAD index during July, August and September in 2007 and 2008 (Fig.C2-3a, C2-3b). It also indicated that the heavy rainfall in 2004, 2006 and the summer of 2005 provided sufficient water supply to soil system and met the normal transpiration cooler requirement of trees, and reduced the impact from summer heat weave. According to the similar principle, it was the heavy rainfall during hit by T0418 and T0514 counteracted the strong gusty wind's hit for the reason of the lower ratio between gusty wind index and humidity index. It resulted in no occurrences of asymmetric discoloration from windward to leeward of these sweet gum trees (Fig. C2-3c) although the maximum gust wind exceeded 50 m/s and made a great property loss of local people during the hit by T0418.

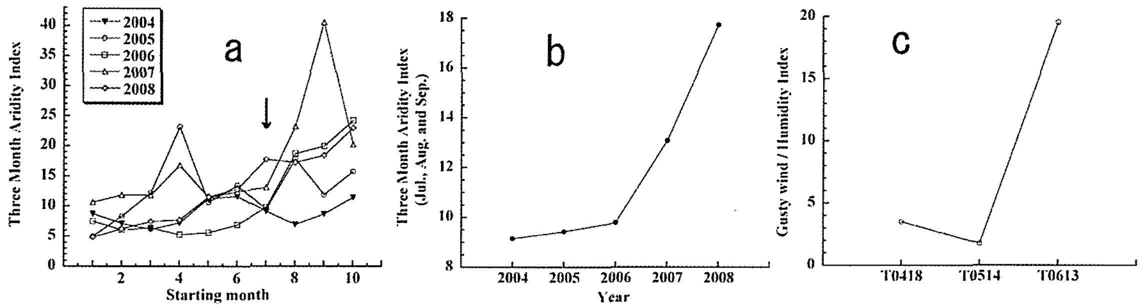


Fig.C2-3 The key meteorological variables inducing sweet gum response. Three months aridity index (TMAD) of Yamaguchi Observatory from 2004 to 2008 (a), the three months aridity index starting at July (b) and the ratio between gusty wind and humidity index (c) was showed in this figure. The key period influences the top crown discoloration of sweet gum trees seems occur in July, August and September (b and arrow in a). The ratio between gusty wind and humidity index seems responding for the asymmetric defoliation and discoloration of sweet gum tree hit by T0613 (c), and is 5.6 and 11 times more than those hit by T0418 and T0514, respectively.

It was noticed that besides water supply to soil system and trans-evaporation power reduction by precipitation, tree pruning also can counteract the impact of the extremely dry weather condition even the serious typhoon's hit like T0613 since it increased root-shoot ratio, reduced transpiring surface and maintained water balance of trees. During 2007 and 2008, many new pruned sweet gum trees responded the extremely meteorological condition differently from those unpruned (Fig.C2-4a-2007). It resulted in no appearance of red top crown and maintaining overall crown green till leaf fall down. It also evidently appeared on the G/L value of entire crown of them (Fig.C2-4b). As the time extended after pruning, this kind of effect decreased gradually even disappeared (Fig.C2-4a-2008). It seems being the result that root-shoot ratio of them gradually return to normal.

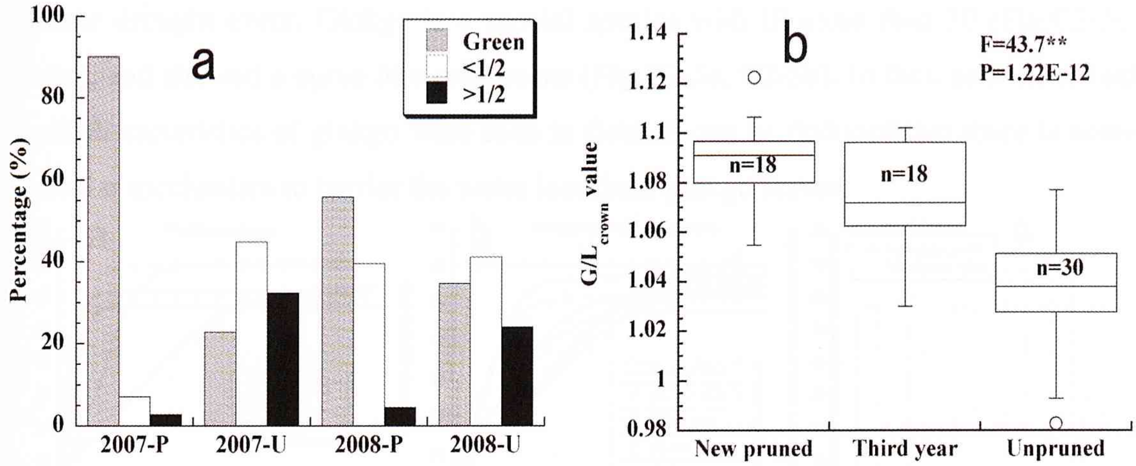


Fig.C2-4 The effect of pruning on the crown discoloration of sweet gum trees. Difference between pruned and unpruned trees investigated by visually counting the percentage of different scale of the red top sweet gum (a), image analysis of G/L value of entire crown for new pruned trees, unpruned trees and the trees at the third year after pruning (b). During the hot and dry summer in 2007 and 2008, a lot of investigated sweet gum trees pre-discolored from top to base of crown. The single sweet gum trees along the high way or street were visually scaled into classes of entire crown green (green), <1/2 crown discolored (<1/2) and >1/2 crown discolored (>1/2). In graph a, 2007-P, 2007-U, 2008-P and 2008-U respectively stand for the pruned and unpruned trees investigated in 2007 and 2008.

2.4 Leaf desiccation speed of 15 tree species

Based on above analysis, there is an indication that the responses from sweet gum trees to both meteorological extreme events related to water and energy balance to maintain normal metabolism. Different tree species with different adaptive characteristics to the summer drought like SD2007 seem relating to the distinct ability to maintain water and energy balance and their adaptation strategy. The water conservation ability of leaves may be one of them.

By measurement, 15 tree and shrub species showed significantly different water loss curves (Fig.C2-5a, C2-5b) and IP values (Fig.C2-5c, C2-5d). It appeared less homogeneity between deciduous and evergreen tree species. Most of the deciduous trees, with relative light and thin leaf, have fast leaf desiccation speed according to their threshold water loss curves except the ginkgo (Fig.C2-5a). The IP of threshold water loss curve for most of them are less than 7 hours (Fig.C2-5c). Leaf rolling or scrolling was reported being related to leaf water status (O'Toole and Maya, 1978; O'Toole and Cruz, 1980). It was observed that the leaves of these deciduous trees often scroll during summer drought event. Ginkgo is a special species with IP more than 30 (Fig.C2-5c, C2-5d), and showed a curve like evergreens (Fig.C2-5a, C2-5b). In fact, seldom of leaf scroll characteristics of ginkgo were seen in field. It can be deduced that there is some particular mechanism to barrier the water loss from ginkgo leaves.

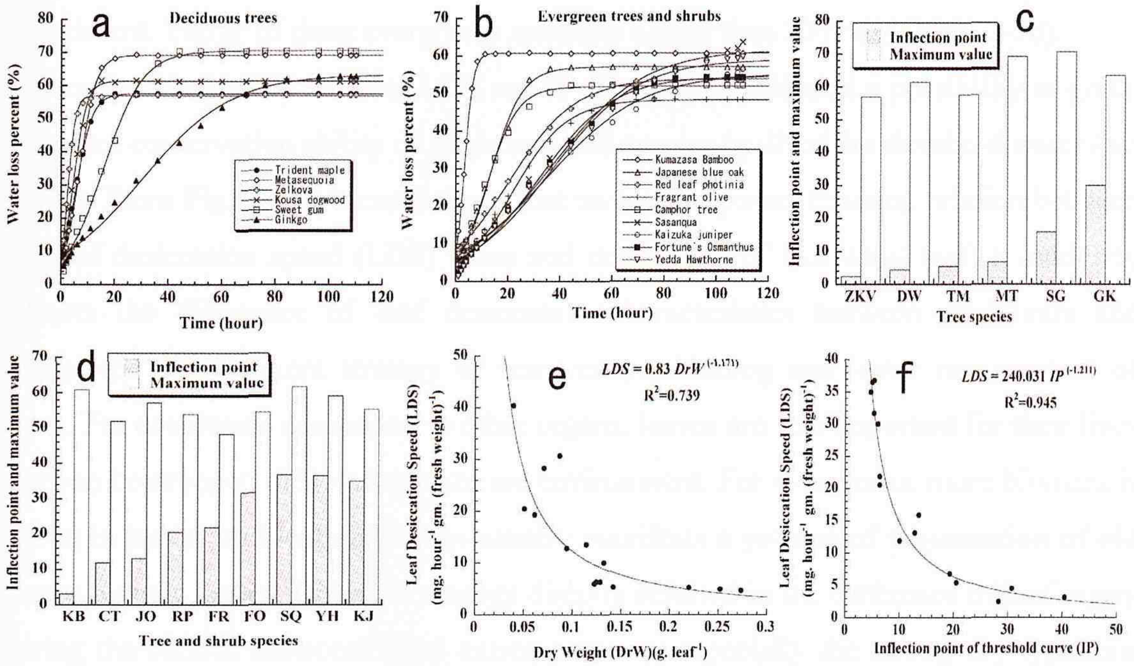


Fig.C2-5 Desiccation characteristics of detached leaves of 15 landscape tree species. Water loss threshold curves for detached leaves of deciduous trees (a) and evergreen trees and shrubs (b); their inflection points (IP) and maximum values (c, d); in which, the tree and shrub species include zelkova (ZKV), kousa dogwood (DW), trident maple (TM), metasequoia (MT), sweet gum (SG), ginkgo (GK), kumazasa bamboo (KB), Camphor tree (CT), Japanese blue oak (JO), red leaf photinia (RP), Fragrant olive (FR), Fortune's Osmanthus (FO), sasanqua camellia (SQ), Yedda hawthorne (YH) and kaizuka juniper (KJ) ; Further, the regression relation between leaf desiccation speed (LDS) and dry weight of individual leaf (DrW) was showed in e, and the regression relation between LDS and IP showed in f.

Contrarily, most of the evergreens, with thicker and leather or wax covered leaves, have slow leaf desiccation speed comparing to deciduous (Fig. C2-5b) except kumazasa bamboo (IP=3.17). It is not surprise that kumazasa bamboo leaves appeared serious rolling under the same environment mentioned above, and a similar IP as the deciduous was found in threshold water loss curve of it (Fig. C2-5c, C2-5d). In fact, kumazasa bamboo usually necroses out partial of their leaf blade during winter period. Vigorous leaves of kumazasa bamboo still roll after detached from branch except the senescent or necrotic leaves. Therefore, leaf rolling or scrolling may be a special adaptation mechanism to trade off between maintaining higher water content and serious cuticle transpiration, while the other evergreens did not show leaf scroll even at the end of measurement. Only few of them, with smaller IP value such as Japanese blue oak, appeared a little leaf turning. Some evergreen tree species, like kaizuka juniper with the lowest leaf desiccation speed, still had cuticle trans-evaporation until the end of experiment. The IP of these evergreens maintain higher than 20 hours (Fig.C2-5d).

Closing relationship between LDS and IP (Fig C2-5f) indicated a possibility to group the water conservation ability of landscape tree species by IP of the threshold water loss curves. From Fig.C2-5e, it can be seen that an inverse power function relation between the leaf desiccation speed (LDS) value and dry weight of individual leaf. It evidently reflects the difference of leaf desiccation characteristics between deciduous and evergreens and different strategy of resource partitioning and water conservation of them. For deciduous, comparing to other organs, leaves are less important for their lives and can be dropped off to adapt extreme environment. For evergreens, more biomass is stored in leaves and leaf abscission usually manifests a process of regeneration of old leaves by new leaves. Different strategy directly resulted in the difference of leaf injury during the serious meteorological extreme events, especially the strong dry typhoons like T0613. It was found that bamboo leaves showed lower biomass conservation per leaf area and faster water loss at leaf tip than leaf base (Fig. C9-4c). Their normal leaf necrosis characteristics perhaps have something to do with this character. Summer deciduous of many tropical evergreens (Addicott and Lyon, 1973) may be the result of trade off between water and energy metabolism of them. During the summer meteorological extreme event in 2007 in Yamaguchi, the sasanqua leaf shedding and Japanese red pine death might be a special example of this kind of trade off.

2.5 Response from some typical tree species to the meteorological extreme event -T0613

Among the meteorological extreme events from 2004 to 2008, no injury to the landscape trees could be peerless to the hit by T0613 accompanied with persistent less rainfall. After hit by T0613, various symptoms appeared on the crown of the landscape trees (Fig. C2-6). Although the site conditions and growth status of these trees distinguished each other, the stress inducers and damaged tendency were similar for the given landscape tree species. This kind of tendency may be available for the further study of more landscape trees to respond the meteorological extreme events like T0613 accompanied with less precipitation.

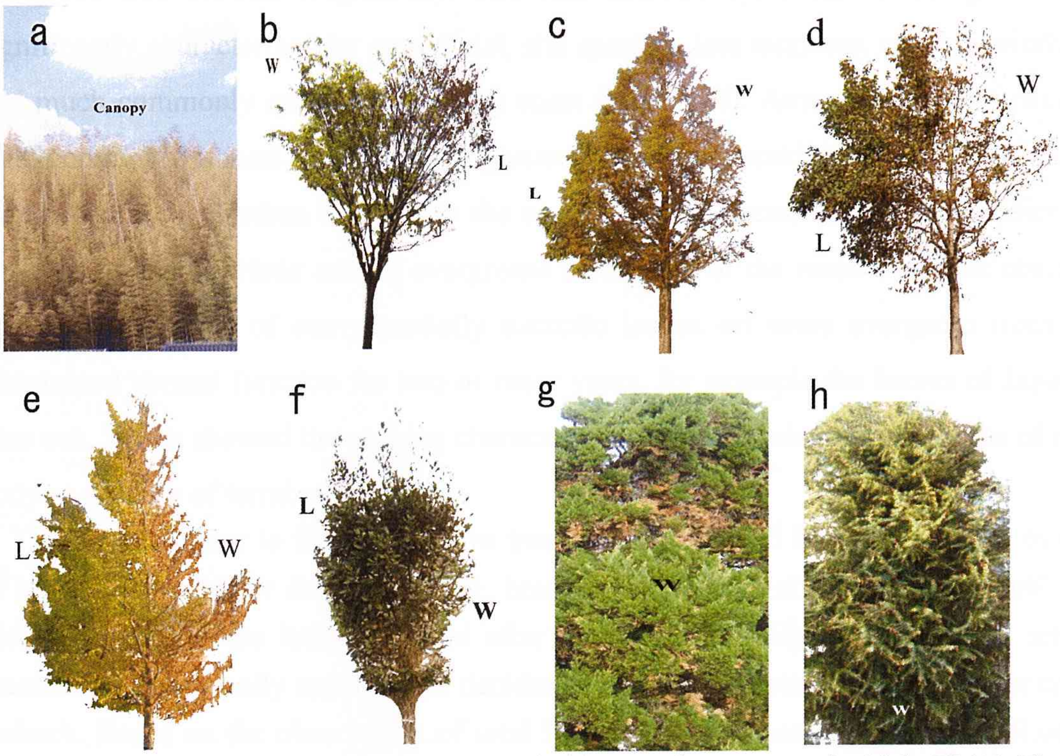


Fig.C2-6 Typical responsive symptoms from some deciduous and evergreens after hit by T0613; They include bamboo (a, canopy), zelkova (b, sideward), metasequoia (c, sideward), sweet gum (d, sideward), ginkgo (e, sideward), Japanese blue oak (f, sideward), kaizuka juniper (g, windward) and Himalayan cedar (h, windward). The direction was marked with "W" for windward and "L" for leeward.

Leaf necrosis is a pattern of some trees responding to the extreme water stresses. After hit by T0613, the most serious symptom was characterized by almost entire leaf necrosis of bamboos. It occurred on overall crown of bamboo and presented no apparent distinguish between windward and leeward of the bamboo individuals, which made the canopy of them appeared significant discoloration (Fig. C2-6a). The discolored bamboo canopies even spread into the area more than 25 km from coast (Wang *et al.*, 2008). Although both ginkgo and sweet gum showed leaf necrosis too, the severity was not as same as bamboos. Both entire leaf necrosis and tip or margin leaf necrosis can be seen on the windward of the crown of ginkgo and sweet gum. Serious asymmetric injury characteristics between windward and leeward of crowns of these two species (Fig C2-6d, C2-6e) should result from the relative lower leaf desiccation speed of them among the deciduous (Fig.C2-5a) and self-shelter of the leeward by windward leaves. In the most situations, only tip or margin necrosis appeared on the windward of some evergreen tree crowns (Fig.C2-6f). The leaf necrotic symptom of evergreens was significantly characterized by superficial, site specific, less numbers, only on windward and much commonly on the trees along coast (Fig.C2-6f). Among them, leaf necrosis was commonly found on trees of *Quercus* species. Besides the special internal physiological mechanism to adapt to the environmental stress, their relative faster leaf desiccation characteristic among evergreens seems one of the reasons. It was observed that the green part of many partially necrotic leaves on some evergreen trees still maintained normal function for two or more years, for example the leaves of Japanese blue oak, which showed the striking characteristic of maintaining normal status of main body at expense of terminal tissues.

The serious injury to these landscape trees is characterized by various kinds of twig or branch dieback. For deciduous trees, branch dieback cannot be confirmed until next spring because of the leafless period after hit by T0613. However, the most serious branch diebacks usually appeared on deciduous tree species, even big branches or apical dieback. Based on the observation of total 91 and 70 individual trees, almost all of the dieback on kousa dogwood trees, cherry trees in a park in Yamaguchi is apical dieback with apical dieback percentage of 68.1% and 76.7% respectively. The die-backed twig or branches of ginkgo mainly located at the windward of their crowns might partially attribute to their relative resistance to water loss of leaves. According to statistics from 109 ginkgo trees in the investigated area, among the die-backed ginkgo trees over 90% of them are windward branch dieback. Branch or twig dieback of evergreens was expressed in varied patterns since their different adaptation strategies; for example, the apical even entire aboveground dieback of bamboos was similar to some deciduous and often observed in the area near coast. The Himalayan cedar (*Cedrus deodara (Roxb.) G. Don.*), an evergreen tree species originated in Himalaya mountain area, responded the serious T0613 with significantly and evenly distributed windward twig tip dieback (Fig.C2-6h). Dead twig tips hanged on the branch top in a pattern of fishing hook. Another fact came from the kaizuka juniper, one kind of water loss resistant evergreen tree species, manifested a common symptom of partially distributed twig dieback at windward of their crowns (Fig.C2-6g). There is an indication that, with desiccation resistant leaves, kaizuka juniper takes a response of superseding the disadvantaged twigs, which can be considered as an accelerated senescence or self-pruning process of these twigs to regulate or acclimate their crown architecture (Rust and Roloff, 2004). It was also observed that Japanese cedar (*Cryptomeria japonica*) was more evident to respond the extremely dry T0613 with self-pruning symptom, and showed twigs dieback from less vigorous and suppressed ones or by the order of lower part first. This kind of character had also been seen on the trees of *Thuja orientalis,* and some of them appeared a "burned cave" on the lower part of windward of their crowns after hit by T0613, especially at the wind draughty or unfavourable site condition. The lower part of the twigs in the cave were significantly discolored or blowed away after their death, while the top of the branches still alive. In fact, many evergreen species react by abscising their weaker organs when competition becomes sufficiently severe (Addicott and Lyon, 1973; Addicott, 1982).

Defoliation manifests a special mechanism for deciduous tree species to respond the seriously strong typhoon associated with less rainfall, especially after the starting of their normal leaf fallen mechanism. In figure C2-6b, it can be seen a zelkova tree after hit by T0613 with new sprouting leaves on windward of the tree after defoliation. Defoliation also appeared on many deciduous tree species after hit by T0613 such as dogwood, cherry, persimmon tree and so on with fast LDS. Although premature defoliation is not the patent for most of evergreens, few of them did drop partial of their leaves after the serious hit by T0613. The fragrant olive was one of them. Leaf falling mainly appeared on the windward of their crowns and left the increased crown openness on windward of them.

From Table 2-1, it can be seen that the fragrant olive and fortune osmanthus showed dissimilar adaptation pattern to serious dry typhoon hit from Japanese blue oak and camphor tree. Almost no difference of leaf water content, green leaf area and slight difference of NDVI value appeared between windward and leeward of them since no leaf necrosis occurred on windward of them. While a large variance of leaf area and leaf number between them can been seen for the reason of more leaf defoliated on windward. On contrary, the Japanese blue oak and camphor tree showed no difference of leaf area and slight difference of leaf number between windward and leeward because of no significant defoliation occurred on windward of them. The lower water content, green leaf area and the NDVI value of windward leaves should attribute to the leaf necrotic symptoms of windward leaves.

Table 2-1 Variation of defoliation and necrosis among four evergreen trees in Yamaguchi University after hit by T0613 (windward/leeward)

	Leaf water Content	Leaf area	Green leaf area	Leaf Number	Leaf $NDVI_{755/679}$
Japanese blue oak	0.888 (6D)	1.094 (210S)	0.674 (210S)	0.978 (797S)	0.599 (18D)
Camphor tree	0.889 (6D)	1.207 (152S)	0.696 (152S)	0.931 (355S)	0.686 (18D)
Fragrant Olive	0.987 (6D)	0.690 (376S)	1.000 (376S)	0.662 (549S)	0.963 (18D)
Fortune Osmanthus	1.029 (6D)	0.768 (120S)	1.000 (120S)	0.777 (1022S)	0.916 (18D)

*All data in the table is the proportion between windward and leeward of crown, in which the water content is measured with repaid weighing method, leaf area and green leaf area with image pixels method and NDVI value by reference paragraph 3.2.1. The data comes from each three typical branches of these trees. The numbers in brackets were the amount of samples (S) /duplications (D).

Majority of trees responded the serious stress from strong wind and fewer water supplies during T0613's hit not by a single way. Entirely necrotic leaves often fell down before the end of growing season (Fig. C2-6d) and die-backed or pre-abscised branches usually attached necrotic leaves (Fig.C2-6g, C2-6h). The metasequoia showed a special example of mixed response to T0613 including the leaf blade necrosis from tip to proximal and twig dieback or abscission (Fig. C2-6c). Rapid leaf cuticle transpiration and normal twig cladoptosis (Millington and Chaney, 1973) characteristics should have some relations to the appearance of these symptoms.

2.6 Asymmetric response to the T0613 by some landscape trees and shrubs

After hit by T0613, various symptoms appeared on the crown of some landscape trees. Asymmetric leaf necrosis on the crowns is one responsive pattern of some tree species to this kind of extreme water stresses. As early 1912, Yapp had noticed many tree species appeared tip and/or margin necrosis when they expose to extra-strong wind. There is a tendency of leaf necrosis starting at the part farthest from the central vein. Twig or branch dieback was another origin of asymmetric crown of some landscape trees hit by typhoons like T0613 in Yamaguchi. It is interesting that more rapid water loss from distal than that from proximal of branches was measured for some tree species, since the tip of branches is usually less lignifications, less cork bark coverage and slightly higher water content (Fig.C2-7a, C2-7b, C2-7c), especially for the young leaves and unsuberized branches (Shull, 1934; Larcher, 1975; GAO and ZHANG, 1995). These terminal parts of trees are usually far from water resources *in situ*. It seems having some kind of relation to the asymmetric branch dieback mechanism of one side desiccated trees.

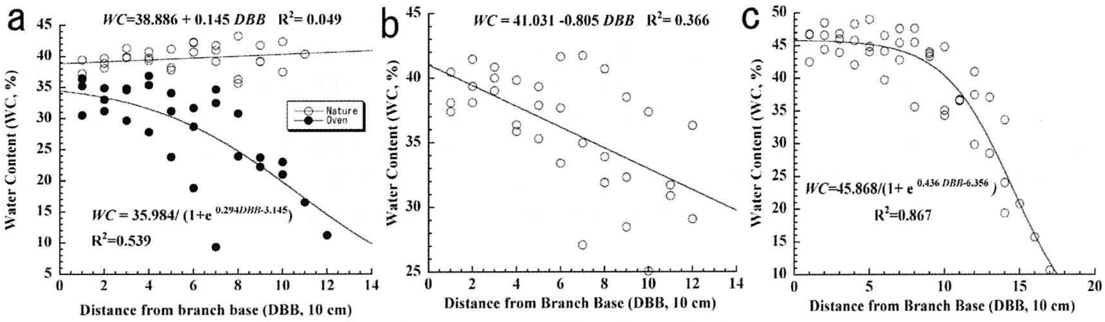


Fig.C2-7 The decreasing tendency of branch water content from proximal to distal of ginkgo (a), sweet gum (b), metsequoia (c) after 54 hours water loss at room condition with RH 60% and AT 20 or so. A tendency of faster water loss from branch tip than base showed in all the three tree species. Ginkgo showed a high water loss resistance from branches that possess a special cork covered bark. Under normal room environment (○—○), it is not easy to appeared this kind of tendency for ginkgo (a); while during 90℃ oven with wind (●—●) the same tendency has been found.

It was found that during hit by hot summer wind on August 13, 2007, a sweet gum tree appeared different water potential between windward and leeward with the windward and leeward ratio (W/L) equaling to 0.86 (Fig.C2-8a). Windward leaves showed different kinds of wilt (Fig. C2-8c); while leaves on leeward of the crown almost maintained turgor (Fig.C2-8b) because of the self-shelter from windward leaves, branches and stem (Fig.C2-8d). Two days late, as the windy weather passed, this kind of difference soon disappeared and no visible symptom was seen on the tree. However, it was the serious strong dry wind blown by T0613 accompanying with less rainfall made the same sweet gum tree asymmetrically discolored and windward leaf necrosis occurred. Therefore, windward excessive water loss and the self-shelter to the leeward seem the main cause of its asymmetric symptoms.

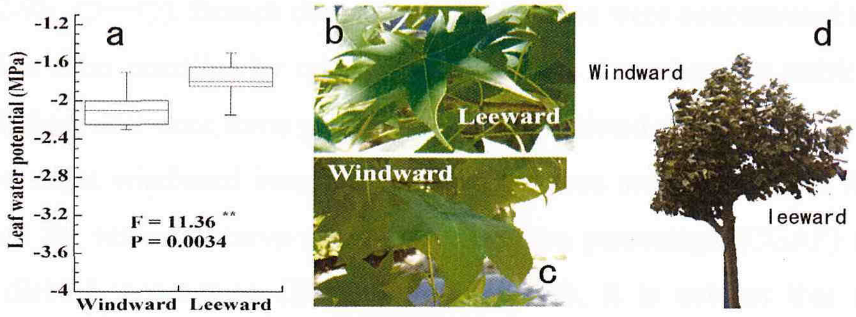


Fig.C2-8 Self-shelter character of the sweet gum crown. Water potential (a) of windward and leeward leaves (n=10) of sweet gum was measured by pressure chamber (PMS 600)on Aug. 11, 2007, a clear day with dry wind and the maximum gusty wind and temperature 7.1 m/s and 31.7 degree centigrade, respectively. Leaves were sampled from a garden tree in Yamaguchi University. From the photograph in b and c, a wilted leaf sample (c) on windward and a normal leaf sample (b) on leeward of the tree can be seen. However, two days late, this kind of wilt was not appeared accompanying with the wind slowing down and the cloudy day. The self-shelter character of the crown with twisted braches and leaves on windward and relative static leaves and branches on leeward showed in (d).

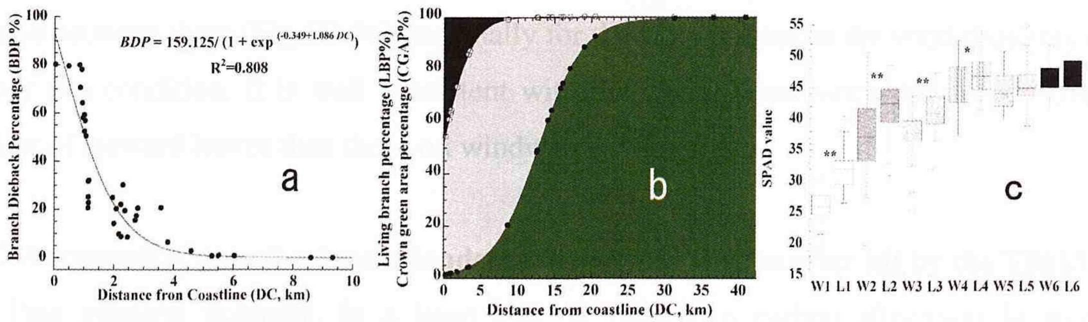


Fig.C2-9 Branch dieback, crown discoloration and leaf SPAD value of ginkgo tree hit by T0613. Relation between branch dieback percentage (BDP) and distance from coastline (DC, measured as 3.2.4) (a); relations between living branch percentage (LBP) and DC (b, ○—○), and between crown green area percentage (CGAP) and DC of ginkgo trees after hit by T0613 (b, ●—●). The curves in graph b were drawn by the predicted value. The different SPAD value between windward (w1, w2, ... w6) and leeward (L1, L2, ... L6) of six ginkgo sample trees (c, n=30).

Serious asymmetric discoloration characteristics of ginkgo and sweet gum tree crowns resulted from the difference of leaf necrosis between windward and leeward after hit by T0613. A different regional variance of asymmetric discoloration of ginkgo trees was also observed (Fig. C2-9b, ●—●) from coast to inland. As mentioned above, dieback of ginkgo branches usually appeared on windward of their crowns since the effective shelter the leeward from windward. Ginkgo trees with different distance from coastline also showed significant regional variance of windward branch dieback (Fig. C2-9b, ○—○). Branch die-backed ginkgo trees were concentrated in the area less than 8 km from coastline by criterion of threshold curve become stable (Fig. C2-9a), although there still were some ginkgo trees on constricted site or with lower vigor status appeared slight windward branch dieback in the area more than 8 km from coastline. Integrated the response curve of crown green area percentage (CGAP) and windward branch dieback percentage (BDP) into Fig.C2-9b, it is evident that there exists a difference between branch dieback and crown discoloration. It left a large area of gray space to think why ginkgo trees with serious leaf necrosis even overall crown discolored after hit by T0613 sprouted new leaves next spring; Is there any unhealthy effect on ginkgo trees in this area? The results of SPAD value measurement during next growing season after T0613's hit for some sampled ginkgo trees indicated that there was no significant difference between windward and leeward for the slightly shocked trees, while the serious damaged trees showed statistically significant difference of SPAD value between them (Fig.C2-9c), especially for the trees planted at the wind droughty or poor site condition. It is well consistent with the visual sense since the deeper green color of leeward leaves than those on windward.

2.7 Asymmetric growth of some landscape trees and shrubs after hit by the T0613

Tree growing potential, in a large part, is related to carbon allocation in stem, branches, buds and leaves, which directly respond the healthy status of them including the capability of obtaining moisture and nutrition and so on (Robichaud *et al.*, 1991; Kozilowski, 1973). It is usually showed in various characters, such as the perfections of vascular system, especially the leaf area during the restoring procedures of the trees and shrubs. By measurement of LAR of 30 ginkgo trees in the gray colored area in Fig.C2-9b, especially trees located in more than 10 km from coastline where there is neither significant prevailing wind (Fig. C9-3, Yearly wind rose map is near round) nor serious salt spray (Rossknecht *et al.*, 1973, Malloch, 1997), a statistically meaningful variance between windward and leeward was observed, although leaf area among different trees showed big difference (Fig.C2-10a). However, this kind of difference was not found on the ginkgo trees clearly pruned (only left an main stem about a few tenth years old) after hit by T0613 till the end of growing season in 2008 (Fig.C2-10b). According to the WLAR value between windward and leeward of vertical profile of crowns, a statistically meaningful smaller value of this ratio for the unpruned ginkgo trees and the ginkgo trees pruned before hit by T0613 had been observed. While no significantly statistical difference was found on ginkgo trees pruned not long after T0613's hit, and the WLAR was almost near 1.0. Therefore, the asymmetric crown of ginkgo after hit by T0613 seems having something to do with the lower growth ability on windward of them and it can deduce that the influence to these ginkgo trees were mainly limited in branch level because of the positive pruning result and the interconnection or spiral growth characteristics of vascular system in the main stem of trees (Kramer, 1983), especially for the individuals far inland.

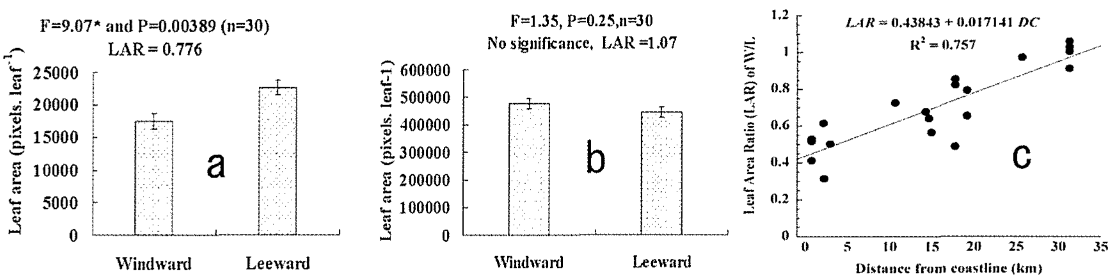


Fig.C2-10 Single leaf area and crown coverage comparison between windward and leeward of ginkgo for pruned trees (b, pruned after T0613 in 2007 spring and leaf area was measured in Nov. 2008, n=30) and unpruned trees (a, measured in Nov. 2007, n=30); Every 30 leaves from windward and leeward were obtained by aimlessly hitting the objective tree and pick up all, about 30, leaves for scanning the images to calculate leaf area by using Equation II4. The detached leaves were used to measuring the leaf area for the reason of high crowns of ginkgo. The relationship curve of LAR of fragrant olive and the distance from coastline was showed in c. Every 30 largest attached leaves from windward and leeward were taken into images at distance of 20 cm for calculating their leaf areas by using Equation II4. The reason of using photo taking images from attached leaves was due to the short crowns of the fragrant olive.

Based on measurement of leaf area ratio (LAR) between windward and leeward of some fragrant olives (*Osmanthus fragrans var. aurantiacus*), not only there existed a tendency of different LAR between windward and leeward, but also a descent tendency from far inland to the coastline was found (Fig.C2-10c). It was observed that severely injured fragrant olive trees appeared not only small leaves but also varied windward leaf curls on their crowns and serious asymmetry of individual leaves. It suggested that the ability of acquiring resources of windward branches had been seriously inhibited after continual hit by typhoons like T0613 so as to affect the development of new expanded leaves. It was also observed that the trees planted on poor site conditions, such as rocky, sandy, and root growing constricted site, showed more serious asymmetric leaf growth even dieback symptoms and great difference between windward and leeward. It indicated that the coexistence of multiple limit factors on these sites, in a great degree, reduced the threshold of their responses.

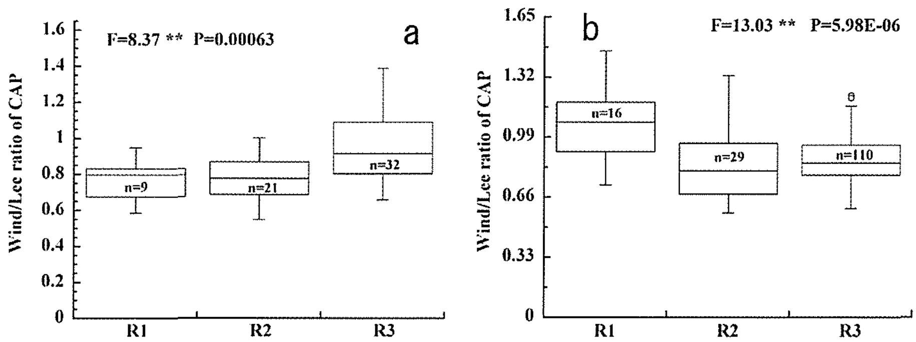


Fig. C2-11 Crown area percentage (CAP) ratio between windward and leeward of sweet gum in 2007 (a) and in 2008 (b) beside three roads (R1, R2, R3). In 2007, no indication of the sweet gum trees at R1 and R2 have been pruned, while sweet gum trees at R3 were pruned before T0613 in 2006. In 2008, it was newly pruned for the trees at R1, and no pruned sign has been seen at R2 and R3.

The sweet gum trees with red top crown symptom during extreme summer events in 2007 (Fig.C2-11a) and 2008 (Fig.C2-11b) mentioned above also showed statistically significant different CAP between recently pruned and recently unpruned trees. These differences varied as the root-shoot ratio restores and trees grow (Fig.C2-11a-R3, C2-11b-R3). Asymmetric crown between windward and leeward was found on them except the trees pruned after T0613's hit with W/L ratio more than 1.0 (Fig.C2-11b, R1). This suggested that the increase of root-shoot ratio by clearly pruning maintained sufficient water supply to the new sprouted branches and minimized the endogenous resource competition among them so that no statistically significant asymmetry could be seen on their crowns after hit by T0613 (Fig.C2-11a-R3, C2-11b-R1). Therefore, it indicated that the relative resources restriction during the meteorological extreme events laid the injured windward branches into disadvantageous condition of resources competition so as to induce their asymmetric growth.

A few of ball-shaped Convexa Japanese holly (Ilex crenata 'Convexa') planted in a wall-flowerbed, 6m long, 1.5m wide and 60cm height, showed significant symptoms of leaf necrosis on windward after the hit by T0613 (Fig.C2-12a), even no more else of this shrub species were found in the same situation in the area nearby. But some Convexa Japanese holly plants, planted in even smaller wall-flower-bed, were also found with leaf necrosis on windward of their crown in Ube City of Yamaguchi Prefecture hit by T0613. The limited root growing space and the faster growth previous the T0613's hit may be the main reason of their symptoms. In this situation, the excessive transpiration surface needs more water supplies during strong dry T0613 from the constricted root system.

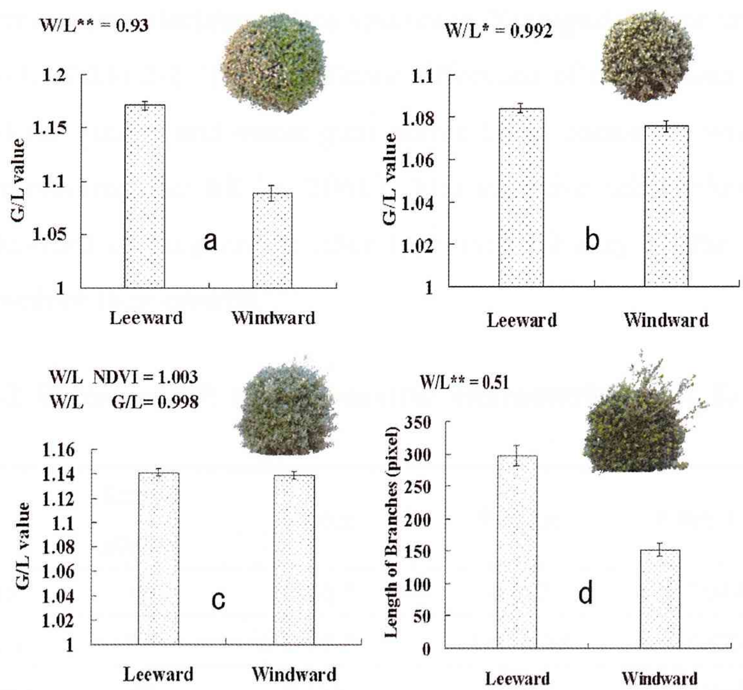


Fig.C2-12 Responses to the severe T0613 from some Japanese holly balled shrubs (near Yamaguchi Observatory) and their restoring process. The half-crown G/L value was significantly different between windward and leeward after hit by T0613 since serious leaf necrosis on windward of their crowns (a, Oct.20, 2006). There is still statistically meaningful G/L difference between windward and leeward in next spring because the new shallow colored windward leaves sprout earlier than that of leeward (b, April. 21, 2007). In the summer days (c, Jun. 28, 2007), it is difficulty to find the difference of both G/L and NDVI values (measured *in situ* and calculated with same method as paragraph 3.2.1) between windward and leeward. However, the length of new branches on leeward of their crowns showed significant superiority at the end of the growing season (Oct, 21, 2007).

Their new sprouting leaves were also first thriving on the windward next spring

(Fig.C2-12b). It is an evident phenomenon of trees responses to the extremely strong typhoon's hit and may come from the internal physiological variation during the restoring process. This kind of shocked part sprouting first was also found on many other landscape tree species, such as ginkgo, zelkova during the investigation. However, although both NDVI and G/L value on both side of their crown gradually achieved same level (Fig.C2-12c) in the summer of 2007, their new branches on leeward were significantly longer than that of windward at the end of the growing season in this year (Fig.C2-12d). It directly resulted in the asymmetrical growth of the balled crowns. If their crowns were not pruned again they would show asymmetrical shape with less doubt. It is evident the uninjured leeward indicate more vigorous status than that of windward.

By integrated some deciduous tree species in Yamaguchi, their crown characteristics were shown in Table 2-2. The significant difference of crown area between windward and leeward for ginkgo and sweet gum seems being consistent with their asymmetric crown discoloration after hit by T0613. The effective self-shelter and less necrotic leaves on leeward of their crown after typhoon's hit may be the cause of the faster leeward growth of their crowns.

Table 2-2 F test result of asymmetric characteristics of four landscape tree species

	Sample number	F-value	P-value	F threshold	Mean w/l Ratio
Ginkgo	49	5.881 *	0.017	3.940	81.0
Sweet gum	139	34.798 **	1.07E-08	3.875	84.7
Dogwood	40	0.155	0.695	3.963	97.4
Zelkova	88	8.238*	0.005	3.891	90.3

*statistical significance while $\alpha = 0.05$; ** statistical significance while $\alpha = 0.01$

The w/l stands for the crown area proportion between windward and leeward.

The insignificant asymmetric crown characteristics of dogwood may have some relation to their fast water loss characteristics of leaves. The cuticle transpiration of their leaves was too fast to make an effective shelter to the leeward leaves from windward. Therefore, they possess special mechanism, for example their special branch architectural characteristic, to adapt to the strong typhoon's hit and making them only showed fluctuated asymmetry of their crowns. Although the zelkova trees appeared a statistically significant difference between windward and leeward, the W/L ratio and the branch characteristic of them are still similar to that of dogwood. The difference may have something to do with the characteristics of fast sprouting new leaves on windward of zelkova crowns. Whatever, less of these four landscape tree species showed perfect symmetric crowns in the investigated area under the continual hit by the extremely strong typhoon events (Table 2-2).

Unlike the trees along seacoast or at timberline, almost no one-side trees had been observed in the area near Yamaguchi Observatory since no severe prevailing wind and salt spray exist. However, various asymmetric crowns can be found from top to base and from one side to another, affected by the meteorological extreme events. The most special crown characteristics of some tree species may be the difference among quarters of crown, if they were divided into four quadrants from main stem horizontally and the middle of the crown vertically. There is a tendency of smallest coverage in first quadrant reasonably due to the coexistence of both typhoon and extremely hot and dry weather's effect, and largest coverage in third quadrant because of the shelter from top and windward, for example, the crowns from metasequoia, sweet gum and ginkgo (Fig.C2-13a, b, and c).

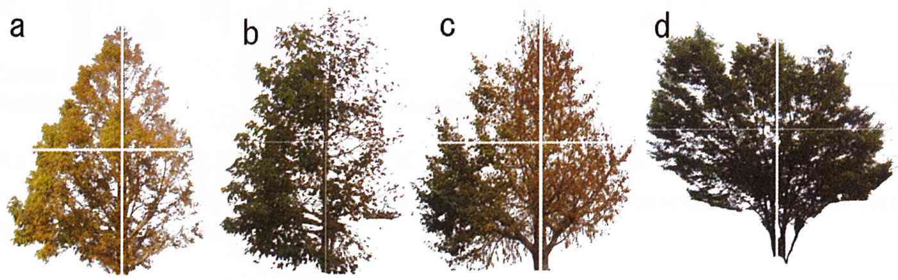


Fig.C2-13 Example of asymmetric tree crowns of metasequoia (a), sweet gum (b), ginkgo (c) and zelkova (d); A common tendency of larger third quadrant and smaller first quadrant can be seen in the figure (a), (b) and (c), while from another type of crowns, a larger second quadrant and smaller first quadrant also observed (d).

However, the maximum crown difference may appear between first and second quadrant for the shade intolerant species, whose lower branches usually self-pruned, for example the zelkova (Fig.C2-13d). It was also noticed a significant difference of single leaf area between the windward and leeward, especially between first and third quadrant for some evergreen shrub species such as fragrant olive and fortune's osmanthus (*Osmanthus* ×*fortunei Carr.*). At some constricted sites or wind draughty, even deciduous trees also showed this kind of leaf area asymmetry.

It is observed that trees seem hit by the environmental extremes one after another, especially the individuals at constricted site condition and some tree species with great branch endurance. It is more common that before they perfectly recover from one extreme shock another hit occurred. Some trees grown at poor site condition was observed they remained asymmetry and not easy to restore (e.g. Fig.C2-14a), although the windward coverage immediately recovered from defoliation after hit by T0613 (Fig.C2-14b). The leaf chlorophyll status of them was still different in the next growing season according to the SPAD measurement (Fig.C2-14c). It is this kind of persistent hurt at same direction or part to some trees trained them into asymmetric characteristics. It should affect the vigor status to respond the further serious hit by storms like T0613.

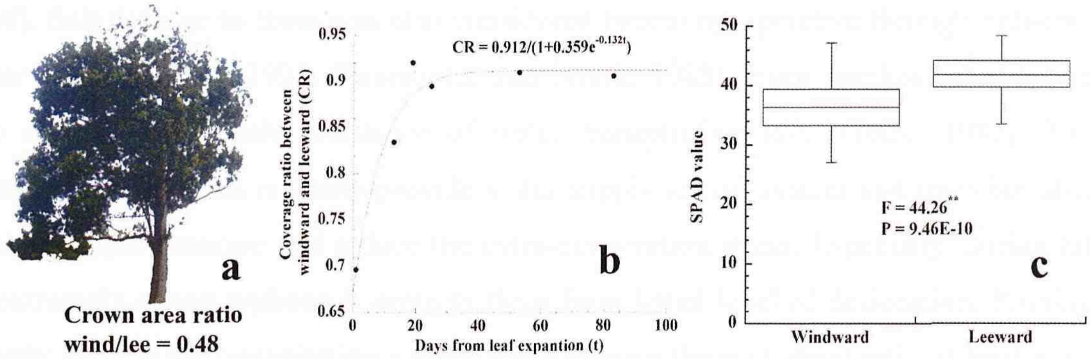


Fig.C2-14 An asymmetric oak tree in Yamaguchi about 13 km from coastline (a), its coverage restoring process from defoliation (b) and the comparison of SPAD value between windward and leeward (c, n=65) in June of 2007.

2.8 Conclusion

It was observed a significant varied and serious dissimilar climate in Yamaguchi, Japan from 2004 to 2008 accompanying with some meteorological extreme events. Unexpected shock or hurt to some landscape trees occurred during the meteorological extreme events from 2004 to 2008 in Yamaguchi. There is an indication that the meteorological extreme events, especially short-term Mediterranean type weather or strong dry typhoon often trigger the significant responses from landscape trees, particularly to trees on constricted site conditions, even to the trees in relative humid area like Yamaguchi with average annual precipitation 1856 mm. More and more seriously damages to them will be expected during this kind of extreme when it mingled with longer droughty period. The difference of genetic structure and function, especially the leaf or branch cuticle properties cause different cuticle transpiration and adaptation pattern of them to desiccation. The leaf discoloration from upper to the base of the crown for sweet gum tree seems one of the striking adaptive characteristics during the extreme weather event in 2007. Distinct adaptation strategy between researched deciduous and evergreens gave another example. The characteristics of superficies, localization, less number of these evergreens indicates that they possess special ability to resist the desiccation.

External environment factors usually injured plants or trees through the impact on changing their internal status. Besides the mechanically training, wind often affects plants or trees through deteriorating their water relations (Whitehead, 1963; Wardler, 1968). Salt damage to them was also considered becoming operative through inducing water stress (Munns, 1993; Pammenter and Smith, 1983). Even mechanical abrasion also reduced the cuticle resistance of water transpiration loss (Grace, 1982). The abundant precipitation not only provide water supply to soil system and trees but also alter the vapor pressure and reduce the extra-evaporation stress. Especially, during hit by extremely strong typhoon it protects them from lethal level of desiccation. Pruning directly reduces the transpiration surface and increases the root-shoot ratio of landscape trees, and maintains the water balance of them (Kozlowski and Davis, 1975; Evans and Klett 1984). It is no surprise that pruned trees sustain more serious typhoon's hit and dry hot wave influence. Under many constricted site conditions, such as rocky mountain site, shallow sandy soil and root growing restricted area and so on, water and nutrition shortage is often the main cause of more serious landscape tree response to these meteorological extremes. Increasing in temperature alone tends to cause an increase in the rate of transpiration through its effect on saturation water vapor density (Fitter and Hay, 2002) and aggravated the water stress of them. Therefore, it is not difficulty to understanding the injury symptoms of many landscape trees like that under the water stress status.

Actually the symptom caused by all of them often has some commonality, such as leaf necrosis, branch dieback and abscission of organs and so on. There is a tendency in many tree species that under serious and acute stresses they respond the unfavorable extremes from distal to proximal, such as leaf tip, twig tip, crown top that is far from source of water and nutrition, and less vigorous terminals. It seems that many tree species have the mechanism to save their lives at the expense of these terminal parts under extremely lethal environment, even by mean of HR-like response (Günthardt-Goerg and Vollenweider, 2007). Under these kinds of extremes, many trees immediately reduce most of the large resource consumption part before hurt the main body of them. Terminal organs or parts abscission is one of them, which is characterized by self-shearing from pre-established area or belt, such as segregation zone at petiole base, abscission zone at branch junction and so on. Tip and margin tissue dieback or necrosis is another, which is characterized by partially reducing water resources consumed tissues from post-established defense belts or node position. They cut off the way of further losing the water resources from main part of the trees. During this process, vascular occlusion, cellular death, resources partitioning etc. may be effective approach to perfect the segregation of the partial tissue or organ to barrier the excessive water loss and protect them from extinct hazard. During the study, it is often observed that some plants of *Quercus spp.* showed the death of all of their branches, while leaves clustered around the main stem. The most serious hurt trees only the lower part of stem remains leaves (Fig.C2-15).

Fig.C2-15 A recent transplanted tree of Quercus spp. with serious symptom of dieback and only at the base of main stem remained leaves.

The self-shelter during hit by strong storm lead the leeward of the tree crowns into less affected. The resources competition in post-growing period induces the leeward faster growth so that gradually become larger than windward, and the asymmetric crown. If it were in favorable condition and no similar post meteorological extreme's impact, the windward of slight hurt trees could recover from these kind shocks. Some ginkgo trees far from coast and growing on deep fertile soils were seen that almost no difference of leaf area, crown coverage and SPAD value etc. between windward and leeward during the next growing season after hit by T0613.

Many managing approach to improve the resource balance or energy balance within landscape trees themselves seems to be able to change their response to the meteorological extremes. Tree pruning, especially clear pruning out all branches from main stem, directly increase the root-shoot ratio of them and reduce the resource consumption organ or tissues. It results in raising the ability to respond the serious hit by summer drought or strong typhoon. In fact, tree pruning is a popular managing technique for local landscapes and various shaped trees can be seen in Yamaguchi. It is proved an effective method to treat the asymmetrical trees and to reform the tree shape.

Landscape trees are usually selected and planted by their characteristics of ornamental values. Partial of them are aesthetically or mechanically planted and regenerated at their unfavorable site so as to be sensitive to the environmental changes. It is observed that trees seem hit by the environmental extremes one after another, especially the individuals at constricted site condition. It is more common that before they perfectly recover from one extreme shock another hit has occurred. Some trees grown at poor site condition are even in the cycle of branch sprouting and dieback, and remain a small, narrow and even stem alone crown. These kinds of continual damages cause trees impossible to put up an all-round effective defense against the biotic and abiotic intrusion, and induce the low vigorousness or abnormal form of trees even accelerate senescence or death. The merge of the persistent meteorological extreme events may be one of the major triggering causes of accelerating senescence or death of some landscape trees.

Part 2

Quantitatively Evaluating Symptoms of Ginkgo and Bamboo Induced by T0613 with Spectral and Image Analysis

As one kind of disaster, typhoons can cause serious damage to landscape trees both mechanically (Yamamoto, 1979; Takahashi, 1981; Chiba, 1994) and physiologically (Marki, 1991; Nobel, 1980). The T0613 was characterized by strong wind associated with less rainfall when it passed through Yamaguchi City, Japan. Salisbury (1805) had noted that great leaf injury occurred when rain was not associated with strong wind. The rainless or less rainfall during and after hit by T0613 reveals the symptoms of some landscape trees in Yamaguchi City is just like Salisbury's note. Although seldom damage to the local people, constructions and roads occurred and there was no severely mechanical damage to trees during hit by T0613 in Yamaguchi city, it did lead to significant responses from many landscape trees. The direct results of their responses were partial death of organs or tissues as well as abscission. As mentioned above, severe bamboo leaf necrosis caused their canopy significantly discolored. Tip and margin leaf necrosis appeared on many ginkgo trees in Yamaguchi after hit by it. It made the crown of ginkgo trees became asymmetrically discolored with the green and non-green parts clearly distinguishable. Due to the big body of ginkgo trees, this kind of phenomenon was often described by visual scale method characterized by significant deviation and observer specific. To study the symptoms of them damaged by T0613 with a rapid, low cost, noninvasive and nondestructive method, spectral and image analysis were used in the study. The feasibility for describing damaged status of ginkgo trees hit by T0613 with spectral reflectance analysis and RGB image analysis was studied. It is less doubt that the similar research will be benefit to the qualitative and quantitative analysis of the effect from meteorological extreme events.

Chapter 3 Estimation of Ginkgo Leaf Necrosis Induced by T0613 with Spectral Reflectance

3.1 Introduction

Ginkgo (*Ginkgo biloba L.*) is a showy ornamental tree species due to its special leaf morphology and golden yellow leaf color in fall. It is widely planted in China, Japan and to be a reasonable tree species for urban planting in Europe and America etc. (Santamour *et al.*, 1983). Nevertheless, it sometimes appears leaf necrosis (Okinaka *et al.,* 1990) and twig die back (Shimizu, 2004) after hit by strong typhoon or damaged by high temperature (Treshow, 1970), under abnormal meteorological event and in the unfavorable site condition (Tian and Jing, 2006), especially along the coast. The partial tissues segregation characters appeared on many ginkgo trees after T0613's hit in Yamaguchi City. By observation, there is a significant difference between living part and dead part of ginkgo leaves and made the crown of ginkgo trees obviously different between windward and leeward. The ginkgo trees with symptoms of leaf necrosis extended to inland even as far as 100 km from coastline during hit by the T8218 in the area of the Kanto plain, Japan (Okinaka *et al.*, 1984). But, the visual scale method was more common in the research on ginkgo crowns damaged by typhoons. In this chapter, the spectral reflectance was used to estimate the damaged status.

As an important non-destructive approach, the near-infrared spectral analysis method has been widely utilized in the area of agriculture, medicine and industries of food, fiber and chemistry. In the field of agriculture, it was originally used for the things with lower water content and its application in fruits, vegetables and crops with higher water content began in modern times (Iwamoto *et al.,* 1994). However, the spectral reflectance method has been found in estimating the plant leaf area index (Yamamoto, 1998; Guan and Nutter, 2002), chlorophyll concentration (Carter *et al.,* 1994,2001; Ito *et al.*, 2003), nutrient elements (Hinzman *et al.*, 1986), water content (Yamamoto *et al.,* 1995; Carter *et al.,* 1993; Ito *et al.,* 2003), and so on. Carter *et al.* (1994) had ever considered that spectral reflectance in narrow wavebands within the 690–700 nm range and its ratio with near-infrared reflectance should provide earlier detection of stress-induced chlorosis compared with broad bands systems or narrow bands located at lesser wavelengths. Ito *et al.* (2003) diagnosed the chlorophyll content by the ratio of spectral reflectance at 800nm and 680nm. Under water stresses, the change of plant spectral reflectance in near-infrared range has been reported by some other researches (Moran *et al.,* 1989; Yamamoto *et al.,* 1995; Penuelas *et al.*, 1999). Thorhaug *et al.* (2006) stated that browning and necrosis resulted in a clear change in the shape of reflectance spectra for *Thalassia* leaves and suggested that the reflective spectra at 750 nm might be a suitable stress index. Riedell *et al.* (1995) noted that chlorosis and necrosis within crop canopy in small grain fields infested with greenbugs etc. could be used as a diagnostic tool to detect crop damage from cereal aphid population outbreaks. Yamamoto *et al.* (1996) reported that it was possible to detect the leaf area of soybean damaged by common cutworm with normalized difference vegetation index (NDVI) at 750/600 nm. Steddom *et al.* (2005) reached a conclusion that the use of radiometric methods has potential to increase the precision of assessments of Cercospora leaf spot foliar symptoms of sugar beet while eliminating potential bias.

Nevertheless, whether it can be used in estimating the damaged status of landscape trees hit by strong typhoons like T0613 or not still needs to be researched. What is the optimum wavelength to evaluate the damaged status and are there any difference among tree species and the trees planted at different sites with different distance from coastline? In the study, after selecting the optimum spectral reflectance wavelength, the leaf necrosis of ginkgo tree induced by T0613 was estimated by spectral reflectance analysis combined with the visual scale method. By measuring the leaf necrotic area percentage (LNAP) and $NDVI_{755/679}$ of necrotic leaves, the relation between them and the difference of spectral reflectance of ginkgo leaves among different sites and between ginkgo and other tree species were studied.

3.2 Materials and methods

In the study, three experiments were carried out. The first was to study the spatial distribution of differently necrotic leaves in the crown of ginkgo tree. The second was to study the difference of spectral reflectance between ginkgo and other tree species after hit by T0613. The third was to study the difference of ginkgo leaf necrosis among three sites with different distance from coastline.

3.2.1 Measurement of spectral reflectance

To study the percentage of necrotic leaves in the crown of ginkgo tree, six standard branches, three each respectively from leeward and windward, from three trees in a shelterbelt were sampled from Yamaguchi University. All leaves on the branches were visually divided into five necrotic scales according to the standard of necrotic area percentage.

After counting the leaf number, the spectral reflectance for leaves of each scale was measured respectively by a radiometer, EKO-MS720, made by EKO Instruments Co. Ltd. Its resolution of spectra is 10 nm, interval of wavelength is 3.3 nm and the specified wavelength ranges from 350 to 1050 nm. Leaves were measured with special method at indoor environment in order to avoid the effect of gap fraction (Ito *et al.*, 1996) and light condition between windward and leeward of trees in field measurement, because it is not easy to obtain comparable data of spectral reflectance for trees under these kinds of conditions. The radiometer was mounted on a tripod 30 cm above the sample leaves. The sampled leaves were smoothly filled in a tray in 20×30×4cm size and vertically measured under 40w incandescent lamp light. 25° of Field of View was selected and the area coverage was 139 cm^2 approximately being equal to a circular area with diameter 14cm. Measurements were controlled by a piece of white paper corrected by standard white board of barium chloride and 3 (or 4) duplications for each scale were conducted at different positions of the tray. The spectral reflectance was used to calculate the NDVI as Equation III1,

$$NDVI_{m/n} = \frac{NIR_m - VIB_n}{NIR_m + VIB_n} \qquad (III1)$$

Where, NIR_m is the spectral reflectance in near-infrared region, VIB_n is the spectral reflectance in visible region and m equals to 750, 760, ……, 900 and n equals to 630, 640,……, 690. According to the wavelength analysis, the optimum wavelength to calculate the NDVI was at 755 nm and 679 nm for NIR and VIB. Therefore, all of NDVI values and NDVI reputing values (NDVIR) in the paper were calculated by the spectral reflectance value at these two wavelengths except the NDVI values in the optimum wavelength analysis.

3.2.2 Measurement of leaf necrotic area percentage (LNAP)

The leaves were scanned with a Canon scanner (D125u2) and the LNAP for each leaf was calculated by image pixel method. LNAP is a proportion of necrotic area to overall leaf area. It was determined by getting pixels of overall leaf and then separated green part from the leaf with eraser tool of Photoshop (Fig. C3-1). The LNAP was calculated as Equation III2 and the LNAP value for each leaf scale was the average of LNAP value of every leaf in the related scale.

$$LNAP = 100 - \left(\frac{Pixels\ for\ green\ area}{Pixels\ for\ overall\ leaf} \times 100\right) \qquad (III2)$$

Fig. C3-1 Overall leaf and green part of a necrotic leaf

3.2.3 Measurement for comparison between ginkgo and other tree species

The tree species used to compare with ginkgo include metasequoia *(Metasequoia glyptostroboides Hu et Cheng*), trident maple (*Acer Buergerianum Miq.*) and kaizuka juniper (*Juniperus chinensis var. Kaizuka Hort.*) that are widely planted in Yamaguchi City. Leaves were mechanically sampled from shelterbelts of ginkgo, metasequoia and kaizuka juniper, and from an individual trident maple tree in Yamaguchi University (site B). The spectral reflectance for leaves of every species was measured by the method mentioned with four duplications for each species. Average of the four duplications of spectral reflectance was used to calculate the NDVI value as Equation III1. The NDVIR is an average between the NDVI value for leaves on windward and the NDVI value for leaves on leeward. It was calculated as Equation III3.

$$NDVIR = \frac{NDVI\ for\ leaves\ on\ windward + NDVI\ for\ leaves\ on\ leeward}{2} \times 100 \qquad (III3)$$

3.2.4 Measurement for comparison among three sites

To study the difference of leaf necrosis among the sites with different distance from the coastline, site A, site B and site C were selected. Site A is located at Tokusa in the Anno Canyon, site B at Yamaguchi beside the Fusino River and site C at Ube near the Yamaguchi Bay which are 40.1, 12.6 and 1.7 km away from the coastline respectively (Fig. C3-2). It was on Nov. 1 and Nov. 2, 2006 for site A and site B and on Nov. 6 and

Nov. 8, 2006 for site C, the sampling and measurement were carried out. The distance from coastline (DC) is the shortest distance from the three sites to the coastline measured by a tool of electronic atlas named Atlas Z Proffessional5. The meteorological data for these three sites was obtained from the AMeDAS of Japan.

Six standard branches, three each respectively from windward and leeward, were also sampled for each of the three sites respectively. The leaf counting method is as same as the scale method above mentioned.

The spectral reflectance for leaves of every site was also measured by the method mentioned with three duplications for each site. Average of the three duplications of spectral reflectance was used to calculate the NDVI value as Equation III1. The NDVIR values were also calculated as Equation III3.

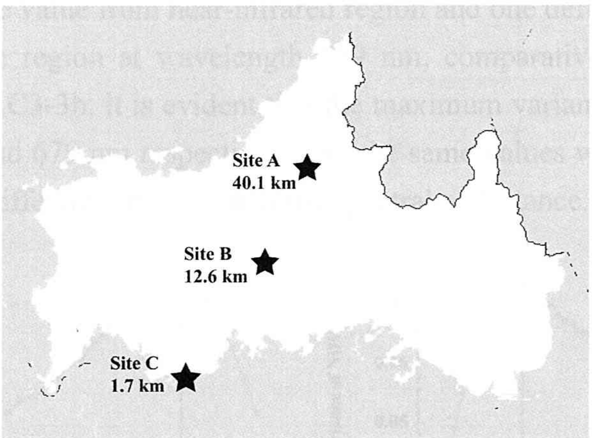


Fig. C3-2 The map of Yamaguchi Prefecture and three sampling sites with the distance from coastline

3.3 Selection of the optimal spectra wavelength for the measurement of ginkgo leaves

After summarizing a number of studies linked with responses to physiological stress, Carter *et al.* (2001) considered that the maximum difference in reflectance within 400 – 850 nm wavelength range between control and stressed states occurred at wavelengths near 700 nm. Spectral reflectance is affected by strong chlorophyll absorption in the range of 670–680 nm and changes with the variation of leaf anatomy or water content in response to stresses beyond 730 nm in near-infrared region (Carter *et al.*, 2001). Slaton *et al.* (2001) thought of leaf reflectance in the near-infrared region is primarily affected by leaf structure and the position of red edge correlated to chlorophyll content, plant phenological stages, as well as plant stresses. Chlorophyll loss, leaf drying and the leaf structure variation were the common characteristics of leaf necrosis. Therefore, the optimal wavelength should exist in these regions to detect the spectral reflectance of necrotic leaves.

According to the definition of NDVI, a lot of NDVI values can be calculated by measuring spectral reflectance. In this research, the proper wavelength for calculation of NDVI was determined by maximum variance of NDVI for the ginkgo leaves in different necrotic scales. Ginkgo leaves for selecting the optimal spectra wavelength were sampled from a ginkgo shelterbelt in Yamaguchi University. After measuring the spectral reflectance at visible region and near-infrared region, the NDVI values for all of the wavelengths from 600 to 900 nm were calculated. For the visible region, all the NDVI values were calculated by every spectral reflectance value at visible region and one definite spectral reflectance value from near-infrared region at wavelength 755 nm (Fig. C3-3a). For the near-infrared region, all the NDVI values were calculated by every spectral reflectance value from near-infrared region and one definite spectral reflectance value from visible region at wavelength 679 nm, comparatively (Fig. C3-3b). From Fig.C3-3a and Fig.C3-3b, it is evident that the maximum variance of NDVI values is at wavelength 755 and 679 nm respectively and the same values were obtained when they are calculated by different values of definite spectral reflectance.

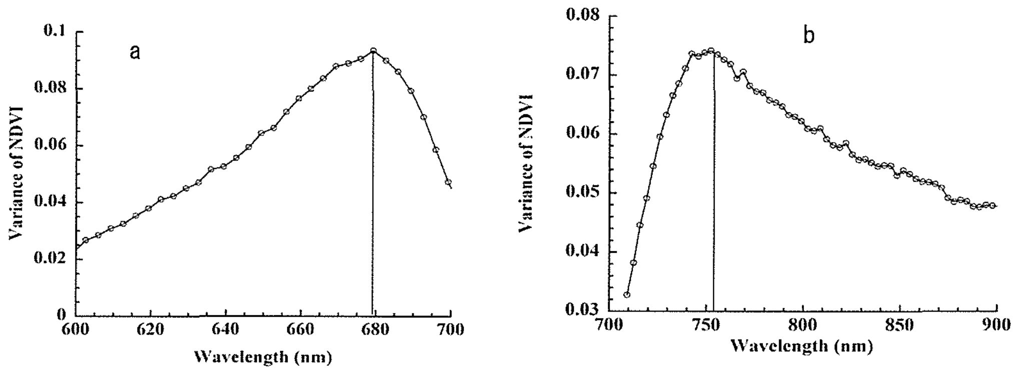


Fig. C3-3 Variance of NDVI value for ginkgo leaves with different necrotic scales at visible band (C3-3a) and near-infrared band (C3-3b). All of the NDVI values in figure C3-3a were calculated by every spectral reflectance value at visible region and one definite spectral reflectance value from near-infrared region at wavelength 755 nm. All of the NDVI values in figure C3-3b were calculated by every spectral reflectance value from near-infrared region and one definite spectral reflectance value at visible region at wavelength 679 nm. From this figure, it is evident that the maximum variance of NDVI value located at the wavelength of 679 nm and 755 nm and maintains the same values when they are calculated by different definite spectral reflectance values.

3.4 Difference of leaf necrosis between windward and leeward of ginkgo tree

It was observed that some landscape trees showed necrosis from leaf tip and margin to entire leaf after T0613's hit. It appeared a large variance in leaf necrosis and presented a significant difference between windward and leeward of ginkgo trees after hit by T0613 (Fig. C3-4). From Figure C3-4, it can be seen that most leaves on leeward of the sampled crowns are non-necrotic leaves, accounting for 70.9%, and no leaves become entire brown. Most leaves on windward of the sampled crowns are necrotic leaves and dried leaves, and only 7.83% of them are overall green. It means that it was the difference of the percentage of necrotic leaves between windward and leeward made the crowns of damaged ginkgo tree appear different colors on both sides of crown.

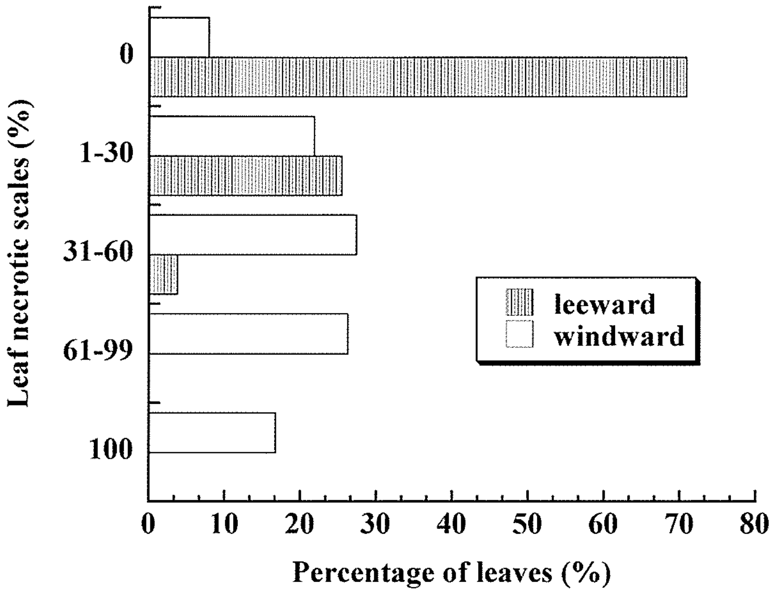


Fig. C3-4 Percentage of leaves with different necrotic scales for windward and leeward of ginkgo trees sampled from Yamaguchi University. During the investigation, all leaves on the branches were visually counted into five scales including 0, 1-30, 31-60, 61-99 and 100%.

Many previous researches on typhoon damage to trees have involved ginkgo (Okinaka *et al.*, 1984, 1990; Shimizu, 2004). But, seldom ginkgo researches focused on spectral reflectance characteristics. The visual scale method was more common used to observe the damage characters of crowns (Okinaka *et al.*, 1984, 1990; Shimizu, 2004; Muhammed *et al.*, 2003), and seldom of them focused on the quantitative study of leaf necrotic area percentage. In this study, spectral reflectance for different necrotic scales of ginkgo leaves appeared great difference. An inverse liner relationship between LNAP and $NDVI_{755nm/679nm}$, R^2=0.985, was obtained and shown in Figure C3-5. It means that NDVI value decreases as the leaf necrotic area increases. The NDVI values well responded the ginkgo leaf necrotic area. Evidently, it is possible to estimate the necrotic area by measuring the spectral reflectance of leaves.

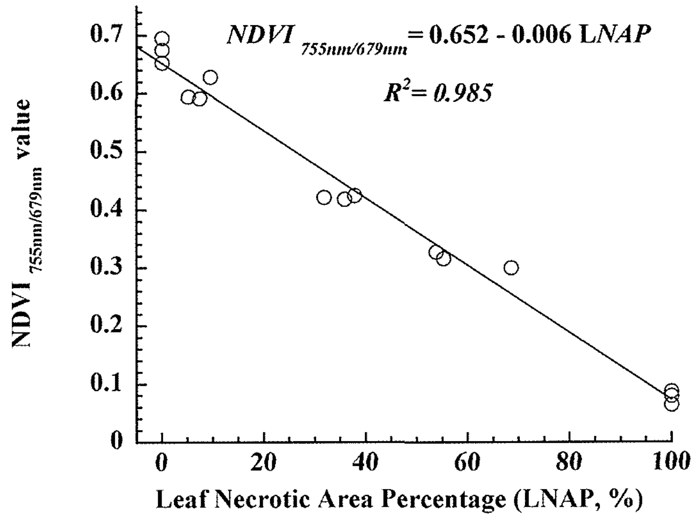


Fig. C3-5 Relation between Leaf Necrotic Area Percentage (LNAP) and $NDVI_{755nm/679nm}$ value.

3.5 Leaf necrosis and spectral reflectance of different tree species

As mentioned above, many plants can appear symptoms of leaf necrosis after damage by unfavorable extreme environmental conditions (Treshow, 1970). Spectral reflectance may be usable to evaluate the necrotic status of other tree species besides ginkgo. By spectral reflectance analysis of leaves sampled from windward and leeward of tree crowns at site B (Fig. C3-2) after hit by T0613, the kaizuka juniper, an evergreen tree species being resistant to the typhoon damage (Shimizu, 2004), obviously differed from the other three deciduous tree species. Almost no difference between windward and leeward of kaizuka juniper crown was found in the spectral reflectance curves since there was no necrosis occurred on their leaves (Fig. C3-6d). For the other three deciduous tree species, ginkgo, metasequoia and trident maple, it can be clearly distinguished the windward and leeward from spectral reflectance curves because of more necrotic leaves on windward (Fig. C3-6a, C3-6b, C3-6c).

From Table 3-1, much clear difference between evergreen kaizuka juniper and the other three deciduous tree species can be seen from NDVI R. The NDVIR of the crown is respectively 43.9, 47.3, 43.6 and 75.1 for the sampled trees of ginkgo, metasequoia, trident maple and kaizuka juniper. The difference among ginkgo, metasequoia and trident maple was clearly smaller than the difference between the three deciduous trees and kaizuka juniper. The reason seems to be the necrotic leaves on windward of these deciduous trees and the different response characteristics of spectral reflectance to normal green leaf and necrotic leaves.

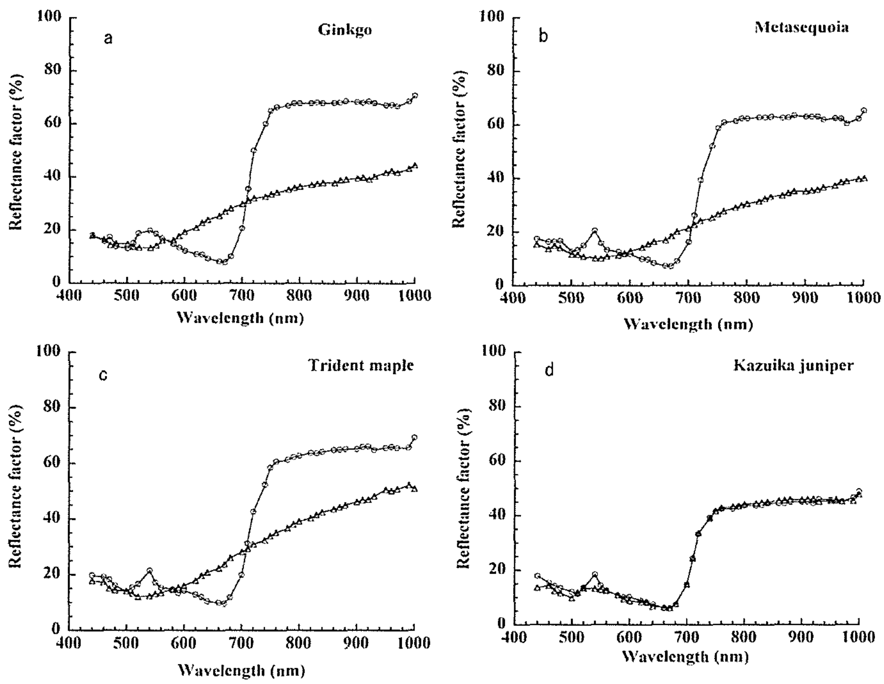


Fig. C3-6 Spectral reflectance curves for leaves sampled from leeward (○—○) and windward (Δ—Δ)of 4 tree species. In which, Ginkgo (Fig.C3-6a), Metasequoia (Fig.C3-6b) and Kaizuka juniper (Fig.C3-6d) sampled from shelterbelts, and Trident maple (Fig.C3-6c) sampled from an individual tree.

Table 3-1 NDVI and NDVI Reputing (NDVIR) value for necrotic leaves of 4 tree species

	NDVI (755nm/679nm)		NDVIR*
	Windward	Leeward	
Ginkgo	0.098	0.781	43.9
Metasequoia	0.166	0.780	47.3
Trident maple	0.167	0.705	43.6
Kaizuka juniper	0.753	0.750	75.1

* NDVIR is the NDVI reputing value that is a proportion of the $NDVI_{755nm/679nm}$ for the leaves of windward to the $NDVI_{755nm/679nm}$ for the leaves of leeward.

3.6 Difference of leaf necrosis and spectral reflectance among different sites

According to this study, the spectral reflectance of leaf samples from the sites with different DC also varied significantly. It indicated that almost all leaves sampled from ginkgo trees in site A, which is far and more than 40 km from coastline, were mainly non necrotic leaves (Fig. C3-7). By contrast, most leaves sampled from site C, less than 2 km from coastline, were necrotic leaves and dried leaves. The leaf samples from site B, about 13 km from coastline, were at middle position. Therefore, the symptoms appeared on damaged ginkgo trees in three sites were mainly attributed to the difference of percentage of leaves after hit by T0613. The nearer is to the coastline, the more leaves with serious necrosis after hit by it.

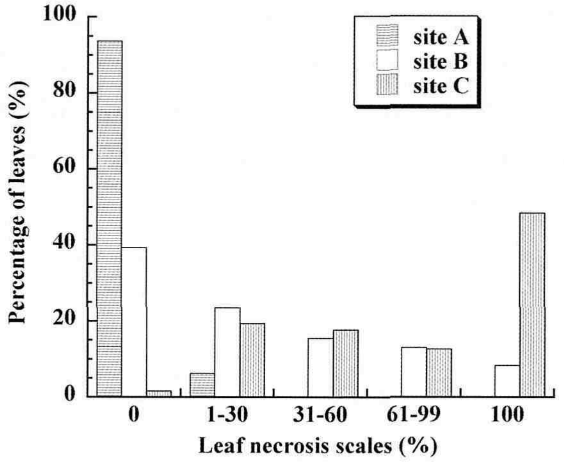


Fig. C3-7 Percentage of leaves with different necrotic scales for ginkgo trees sampled from three sites (site A, site B and site C) by visual scale method. During the investigation, all leaves on the branches were visually counted into five scales including 0, 1-30, 31-60, 61-99 and 100%.

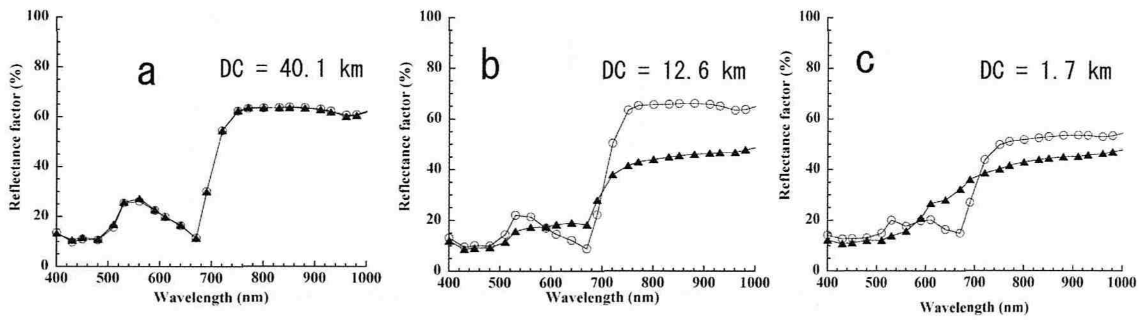


Fig. C3-8 Spectral reflectance curve for leaves sampled from leeward (○—○) and windward (▲—▲) of ginkgo crowns in three sites with different Distance from Coastline (DC, km). In which, 9-a, 9-b and 9-c are respectively the data for site a, site b and site c. Every line was an average value of three duplications and the NDVI value was calculated by average spectra reflectance values. The sampling and measurement were carried out on Nov. 1 and Nov. 2, 2006 for site A and site B, on Nov. 6 and Nov. 8, 2006 for site C, respectively.

Figure C3-8 showed the spectral reflectance curves of ginkgo leaves sampled from three sites after hit by T0613. It is clear that there was also a big difference of spectral reflectance among the leaves sampled from windward and leeward of ginkgo trees from the three sites. For the samples from site A, with the NDVI value=0.679 for both leeward and windward respectively, the spectral reflectance curves almost overlapped together that they could not be distinguished from each other (Fig. C3-8a). It means almost no difference of leaf spectral reflectance between windward and leeward of ginkgo trees at this site. Although the samples from site B and site C showed a similar tendency, the spectral reflectance curves for both windward and leeward of ginkgo trees were separated from each other, clear difference still can be found (Fig. C3-8b, C3-8c). The spectral reflectance for the leaves of ginkgo tree in site B, with NDVI value being 0.749 and 0.373 for leeward and windward respectively, was significantly higher than that of site C with NDVI value being 0.528 and 0.096 for leeward and windward. It implied that the trees in site C contained more leaves with necrosis. It is evident that the spectral reflectance characteristics are consistent with the result of visual scale observation.

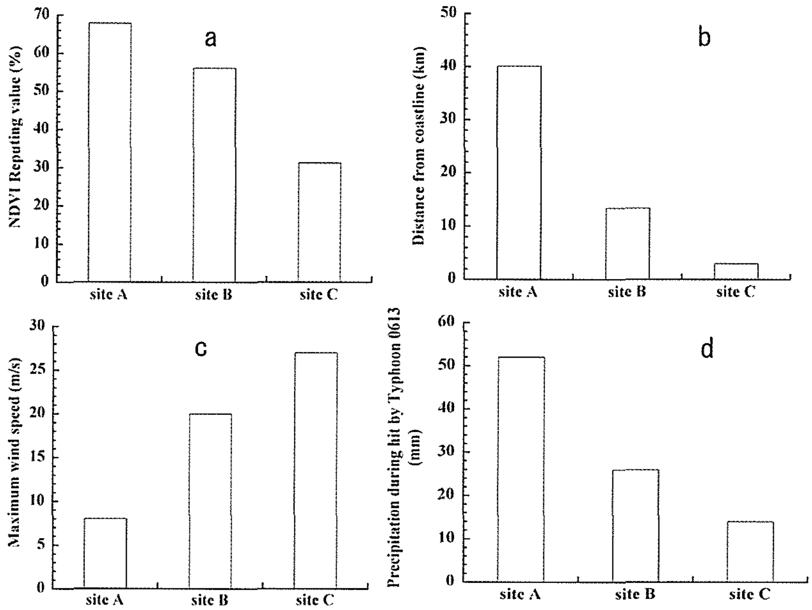


Fig. C3-9 NDVI reputing (NDVIR, C3-9a) value, Distance from Coastline (DC, C3-9b), Maximum wind speed (C3-9c) and Precipitation (C3-9d) during T0613 for sampled leaves from three sites.

Comparing to the NDVI value, the NDVIR responded even more damaged status of ginkgo trees, which combined the spectral reflectance of both windward and leeward. Figure C3-9 showed the NDVIR (Fig. C3-9a), DC (Fig. C3-9b), max wind speed (Fig. C3-9c) and the precipitation of the three sites during T0613's hit (Fig. C3-9d). The NDVIR values were respectively 67.9, 56.1 and 31.2 for site A, site B and site C. The related max wind speeds were respectively 8, 20 and 27 m/s, rainfall 52, 26 and 14 mm, and the distance from coastline were 40.1, 12.6 and 1.7 km. It means that the nearer was to the coastline, as the wind speed increased up accompanying with the decrease of rainfall during hit by T0613 for the investigated sites, the smaller the NDVIR values were. In other words, the nearer is to the coastline, the more serious the leaf necrosis of ginkgo. The result of spectral reflectance was well in accordance with the difference of wind and precipitation. It was also consistent with the result of visual scale observation of other researchers (Okinaka *et al*., 1984).

3.7 Conclusion

In brief, based on this study it is the difference of leaf necrotic status between windward and leeward of ginkgo crowns caused the variance of discoloration between them. This kind of variation also appeared on the sites with different distance from coastline. They can be estimated by measuring the spectral reflectance of ginkgo leaves with different necrotic status by using the handhold radiometer of EKO-MS720. The optimum wavelength for the calculation of NDVI for necrotic ginkgo leaves is at 679 and 755 nm. The result of measurement of $NDVI_{755nm/679nm}$ is well consistent with the result of direct visual observation. The close inverse relationship between $NDVI_{755nm/679nm}$ and LNAP of ginkgo leaves indicates that it has potential to evaluate the damaged status of ginkgo and to be an alternative tool to evaluate the segregated character of ginkgo induced by typhoons like T0613, especially by using the NDVIR value.

By comparison between ginkgo and other three tree species, it indicated that the spectral reflectance was more sensitive to the necrotic part of three deciduous tree species than evergreen tree of kaizuka juniper. Ginkgo leaf necrosis is common sight in the areas typhoon frequently occurs, especially along the coast and the smaller tendency of NDVIR values for ginkgo trees was also observed near coast after hit by T0613.

Chapter 4 Estimating Bamboo Leaf Necrosis and Chlorosis Induced by T0613 with RGB Image Analysis

4.1 Introduction

As mentioned above, leaf necrosis is a pattern of bamboo trees responding to the extreme stresses induced by T0613. It showed characteristics of entire leaf necrosis, occurring on overall crown and hardly identifying the windward and leeward of the bamboo individuals. It made the bamboo canopies appeared significant discoloration. During symptoms appearing procedure, leaves on the same crown or canopy appeared not only necrosis but also chlorosis for a period of time.

The striking difference of bamboo leaves/canopies with different injured status could be analyzed by image analysis. The image analysis and concerned studies used in measuring plant chlorophyll, nitrogen and stress status have been much reported (Kawashima and Nakatani, 1998, Okado and Nakamura, 1993, Suzuki, *et al.* 1995). Suzuki *et al.* (1999) used the G/(R+G+B) for broccoli identification. Since the G and R values in the RGB color system were sensitive to the green and dead leaves, it was found that the G/R value was used in measuring the leaves and plant canopy. To evaluate the degree and scope of typhoon damage, analyze the damage mechanism and automatically diagnose the typhoon damage, objectively and accurately measuring and analyzing the symptoms of injured trees is necessary. However, it was reported that the light specific characters of photo images affected the image analyzing result; even made it not easy to be in progress in clear daylight condition (Kawashima and Nakatani, 1998). The persistent anticyclone weather after T0613's hit led to difficulty to find persistent and evenly scattered light conditions. Photo images taken during this period usually contained clear blue background. In order to improve the accuracy of image analysis, we had to search the proper color indices to reduce the light effect. In the Lab color system L value stands for "luminance" which is a linear combination of the R, G and B values and increases with the enhanced brightness (Equation IV2). Based on general mathematic principle, the G/L will decrease with the L value increasing. It can be considered as an improved G/(R+G+B) value fitting the bright environment. Iwaya and Yamamoto (2005) studied the relationship between panicle water content of paddy rice with 19 color indices, in which the G/L value was the highest one related to panicle water content of paddy rice in 1998. It was used in determining bamboo leaf necrosis or chlorosis and has obtained proper result in this study.

4.2 Materials and methods

52 and 50 bamboo leaves respectively with chlorosis and necrosis were typically sampled from a bamboo stand in Yamaguchi University for image taking. The images for RGB analysis were taken at a position of 50 cm above the sampled bamboo leaves at natural room light condition with a CCD camera (Nicon D70S) mounted on a tripod. Images were stored in the form of JPEG with image resolution of 300 dpi and 3000×2000 pixels. According to the known researches (Adamsen *at al.*, 1999; Iwaya and Yamamoto, 2003; Cai *et al.*, 2006) and the screening of indices in this study, the G/R and G/L values were selected for RGB image analysis.

The measuring and calculating method of leaf necrotic area percentage (LNAP) is same as III2.

The G/R_{leaf} and G/L_{leaf} values were measured by following process with same images prepared in calculation of LNAP. Image background was selected with Magic Wand Tool （A selection tool which can select the pixels with similar RGB values） of Photoshop and the leaf was extracted by inverse selection. The green (G), red (R) and luminance (L) values of leaves were read from average histogram value. G/R_{leaf} and G/L_{leaf} are the proportion of green value respectively to red value and luminance value from the RGB image of individual leaf. They were calculated with Equation IV1 and IV3. Since the parts except the leaves are removed by hand treating, the impact of image noise had been minimized.

$$G/R_{leaf} = \frac{\sum_{i=0}^{255} N_i \times i \Big/ \sum_{i=0}^{255} N_i}{\sum_{j=0}^{255} N_j \times j \Big/ \sum_{j=0}^{255} N_j} \qquad (IV1)$$

Where, N_i is the pixel number in i (green) gradation, i=0,1,2…255. N_j is the pixel number in j (red) gradation, j=0, 1, 2…255.

The L value is a linear combination of R, G and B values shown in Equation IV2.

$$L = 0.299R + 0.587G + 0.114B \qquad (IV2)$$

$$G/L_{leaf} = \frac{green\ value\ of\ the\ leaf}{luminance\ value\ of\ the\ leaf} \qquad (IV3)$$

Images for comparison of G/R_{leaf} value and G/L_{leaf} value were taken from different light conditions, both indoor and outdoor, from early morning to afternoon, with the same camera and image taking method mentioned above. The shutters of camera were respectively 1/1000, 1/50, 1/30, 1/4, 1/3 and 1 for different image taking conditions. Meanwhile, SPAD values of individual leaves with chlorosis were impartially measured by using same method as described in paragraph of 2.2.4, in order to study the relationship between mean SPAD value and G/R_{leaf} or G/L_{leaf} values.

The most seriously damaged bamboo stands in each investigated area were selected from windward of mountains for the comparison of G/R_{canopy} and G/L_{canopy}. The image of bamboo canopy was taken by using a CCD digital camera (Canon IXY 6.0) about 30-50 m away from the bamboo stands. It is characterized by horizontally taking the image on ground level. The preparing method of image was similar to that of individual leaf. The Distance from Coastline (DC) was defined and measured as same as that in paragraph of 3.2.4. The calculation of G/R_{canopy} and G/L_{canopy} is similar as Equation IV1 and IV3.

4.3 Estimating chlorosis and necrosis by image G/R_{leaf} values for individual bamboo leaves

Based on the mechanism of SPAD value measurement, it is a sensitive method to the chlorophyll of plant leaves, especially the paddy rice etc. But one measuring data of SPAD value measured by SPAD-502 only respond to the leaf chlorophyll status of 6 mm^2. To perfectly respond the chlorophyll status of overall leaf, a large number of random measurements must be taken to reduce variability and make statistical data comparable. In the study, one sampled leaf was measured with 30 duplications that was the maximum memory number of SPAD-502 chlorophyll meter. Therefore, it should be the proper estimating value of the chlorophyll status of sampled leaves. However, the G/R_{leaf} value from RGB image analysis in this research was characterized by measuring the overall leaf fast and easily.

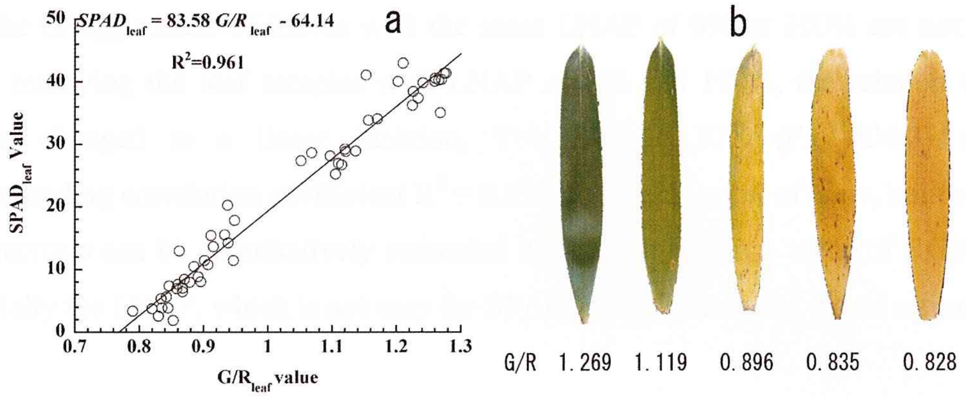


Fig.C4-1 Relation between SPAD and G/R_{leaf} for individual chlorotic leaves (a), and the typical images of bamboo leaf blade with different chlorosis (b). In the common situations, bamboo leaves usually existed small necrotic leaf tip. In order to measure the G/R_{leaf} or G/L_{leaf} value of chlorotic leaves, the leaf tip was cut off before image analysis in the research

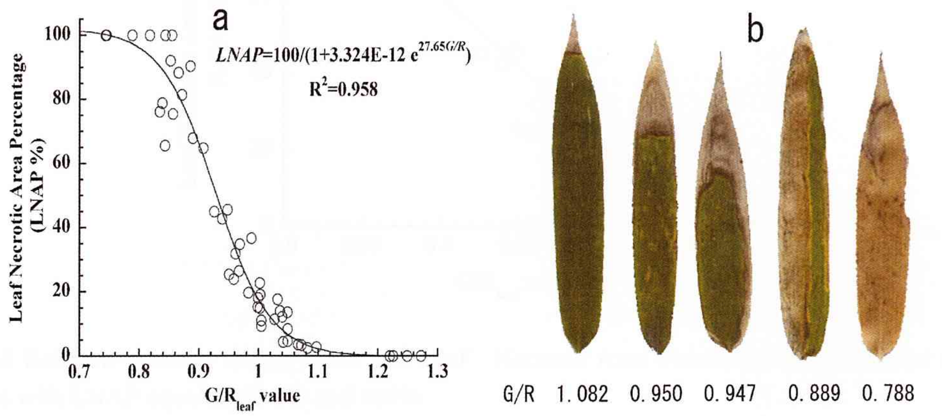


Fig. C4-2 Relation between G/R_{leaf} value and Leaf Necrotic Area Percentage (LNAP) for individual leaves (a), and typical image of bamboo leaf blades with different necrosis (b)

Figure C4-1a shows a positive linear relationship between G/R_{leaf} value and SPAD value, with $R^2 = 0.961$. The G/R_{leaf} value ranges from 0.7 to 1.3 (Fig.C4-1b) and the SPAD value from near 0 to 43. The related function is Y= - 64.14 + 83.578 X. Higher relationship between SPAD value and G/R_{leaf} value of RGB image implies that the G/R_{leaf} value of bamboo individual leaves can be recognized as a way responding to leaf chlorosis status.

In the research, the LNAP was considered as the criterion of necrotic status of individual leaves. The relation between G/R_{leaf} value and LNAP of bamboo leaves showed an inverse logistic relationships, with function Y= 100 / (1 + 3.32E-12 $e^{21.65X}$), R^2 = 0.958 (Fig. C4-2a, C4-2b). It means that as the LNAP increases the G/R_{leaf} value deceases smoothly, then sharply, and then becomes stable. The relation function seems that the G/R_{leaf} values of leaves with the same LNAP of 0% or 100% are not unique. After removing the leaf samples with LNAP of 0% and 100%, the relation function almost changed to a linear function, Y= 386.3-362.77X (Fig. C4-3) and the corresponding correlation coefficient R^2 = 0.895. From this point of view, both chlorosis and necrosis can be quantitatively estimated by using the G/R_{leaf} value of RGB image, especially the LNAP, which is not easy for SPAD measurement and visual estimation.

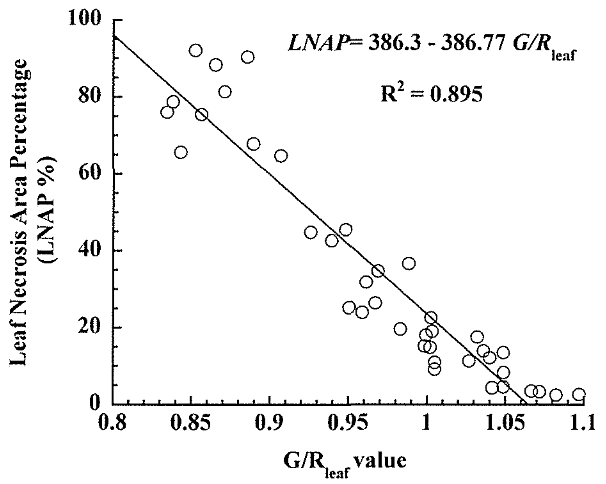


Fig. C4-3 Relation between G/R_{leaf} value and Leaf Necrotic Area Percentage (LNAP) after removing the leaves with LNAP equaling to 0% and 100%

4.4 Comparison of G/R value and G/L value of RGB images with big luminance difference

Kawashima and Nakatani (1998) stated that leaf color discrimination with a portable video camera would be difficult under clear conditions with direct solar radiation. Okado and Nakamura (1993) considered that the variance of sunlight could make a negative effect to the result of chlorophyll estimation and it could be treated by image correction. We have met the same problem and tried to reduce the effect of light condition by selecting proper indices. Based on our test by taking photo image at different light environment for the same leaf, it appeared bigger variance of G and R value, especially for the G/R_{leaf} value of green leaves. As the G/R_{leaf} value gets bigger, the difference also becomes larger (Fig. C4-4a). Theoretically speaking, G/L_{leaf} value decreases with the increasing L value. It may be an index that can reduce the impact of luminance from photo images. The G/L value (Equation IV3) exists a similar structural character (Equation IV4) to G/(R+G+B) and R/(R+G+B) as used by other researchers (Suzuki *et al.* 1995; Cai *et al.* 2006).

$$G/L = G/(0.299R + 0.587G + 0.114B) \qquad (IV4)$$

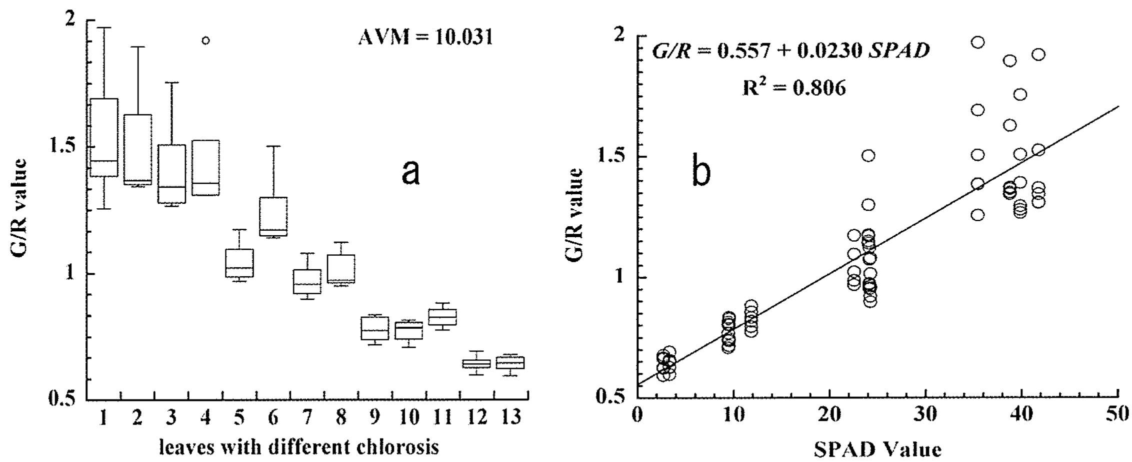


Fig. C4-4 C4-4a is the variation of image G/R_{leaf} value for different leaves taken at different light conditions. The horizontal axis is a visual arrange order of leaves from deep green to light brown. The AVM in C4-4a is an average value of variance/mean. C4-4b is the relationship between G/R_{leaf} and SPAD.

By comparison, the SPAD is much closely related to the G/L_{leaf} value than G/R_{leaf} value for the situations of leaf images with big luminance difference (Fig.C4-4b, Fig.C4-5b). It is clear that there is a large difference of variance between G/R_{leaf} value and G/L_{leaf} value for the same leaf at different photo taking conditions. The variance of G/L_{leaf} is about 1/12 of the G/R_{leaf} value and the average variance/mean (AVM) value of G/R_{leaf} and G/L_{leaf} are 10.03 and 0.798, respectively. It is evident that the variance of

G/L$_{leaf}$ value among the different images with big luminance difference is significantly lower than that of G/R$_{leaf}$ value. (Fig.C4-4a, Fig.C4-5a).

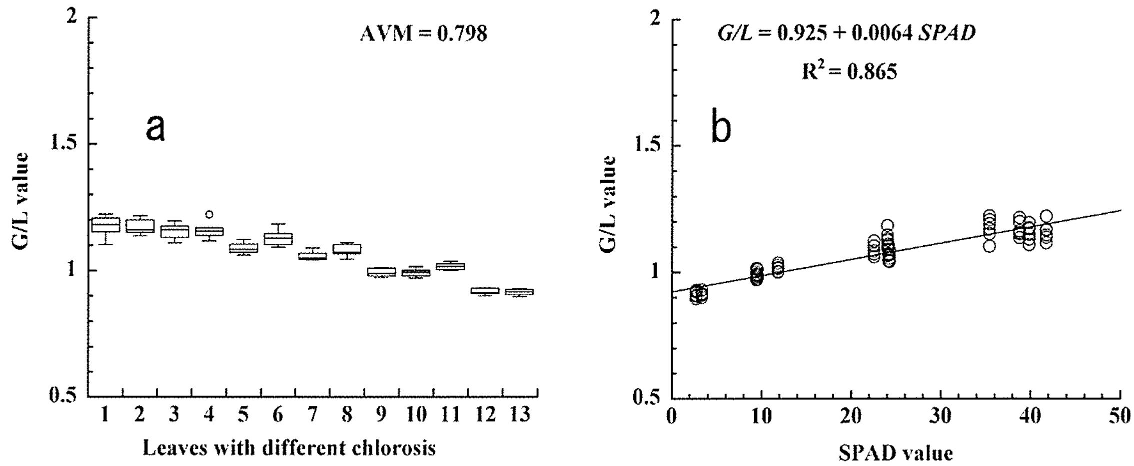


Fig. C4-5 C4-5a is the variation of image G/L$_{leaf}$ value for different leaves taken at different light conditions. The horizontal axis is as same as Fig.C4-4a. The AVM in C4-5a is an average value of variance/mean. C4-5b is the relationship between G/L$_{leaf}$ and SPAD value for these leaves.

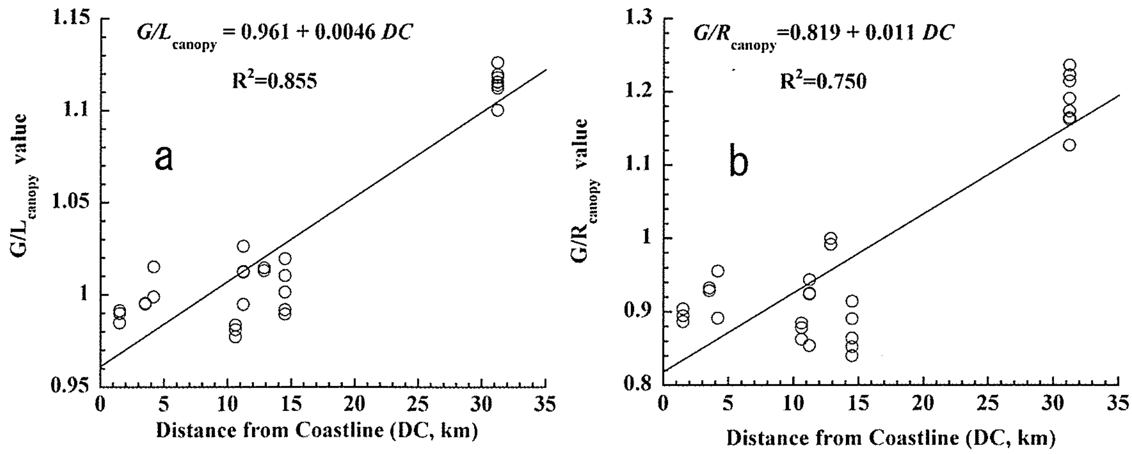


Fig. C4-6 C4-6a is the relationship between image G/L$_{canopy}$ value for bamboo canopies and the Distance from Coastline (DC); C4-6b is the relationship between image G/R$_{canopy}$ value for bamboo canopies and the Distance from Coastline (DC).

Although the G/L$_{leaf}$ value is not able to improve RGB analysis result to perfectly same for the images token in a large different light condition, it can give a nearer corrected value. According the study of dogwood leaves (Fig. C7-1), the relative G/L$_{leaf}$ value in same image could further decrease the variance among the images with larger luminance difference. By the image analysis of bamboo canopies, a similar result was obtained. The relationship between G/L_{canopy} value of bamboo and the Distance from Coastline (Fig. C4-6a) was also much closer than that of the G/R_{canopy} value for the images taken at field sites with big light difference (Fig. C4-6b).

However, based on the research, the G/R_{leaf} value can be much closely related to SPAD value of leaves for the RGB image taken at less light difference conditions, such as scatter light condition of cloudy day or indoor natural light conditions. For example, Figure C4-1 showed a close relationship between G/R_{leaf} value and SPAD value. It was the result coming from three images taken at indoor scatter light condition. The concerned correlation coefficient for G/L_{leaf} value was 0.843, with regression function $Y= 0.0032x + 0.985$. At this kind of condition, G/L_{leaf} value may go beyond the proper limits in correcting the big luminance difference.

4.5 Conclusion

In brief, based on the RGB image analysis, not only chlorosis but necrosis also can be quantitatively evaluated by measuring image G/R_{leaf} or G/L_{leaf} value of bamboo leaves. It appears a positive linear relationship between G/R_{leaf} value and SPAD value of bamboo individual leaves, and a significant inverse logistic relationship between G/R_{leaf} value and LNAP of them for indoor taken images. Almost no research has been found to compare G/R_{leaf} value and G/L_{leaf} value before. Based on this research, the G/L_{leaf} value can get a closer relation with the SPAD value of sampled leaves for the RGB image taken at conditions with bigger luminance difference, and the variance of G/L_{leaf} value is lower than that of G/R_{leaf} value, especially for green leaves. It indicates that the relationship between G/L value for bamboo canopies and the DC can also be much closer than that of the G/R value for the images taken at field sites with big light difference. The G/R value is more suitable to be used to analyze the RGB image taken at the conditions with small light difference. Comparing to traditional visual scale method, the RGB image analysis provides a simple and fast tool to estimate the leaf necrosis and chlorosis hit by typhoons like T0613. It may make it possible to a mass investigation in a large scale of area for its less labor need and less time consumption.

Chapter 5 Evaluating Ginkgo Leaf Necrosis and Asymmetric Crown Discoloration Induced by T0613 with RGB Image Analysis

5.1 Introduction

Historically, a lot of researches had focused on the storm effect on trees, even making trees as wind indicator, such as the well-known Fujita Tornado Scale and Saffir-Simpson Hurricane Scale, as well as the Griggs-Putnam and Yoshino tree deformation index to predict wind speed and wind direction in meteorological fields (Cullen, 2002; Hennessey, 1980; Wade *et al.*, 1979; Kasper, 1981). As the main organ of trees, the crown is often used to evaluate the health status of them (Solberg, 1999; Rogers, 2002; Maguire and Kanaskie, 2002). But the less objective crown data made it difficult to establish the relationship to the visually estimated crown transparency in Europe wide investigations of forest health (Mizoue and Masutani, 2003). The big body of tree crown, compared to annual plants, and complex three-dimensional structure make them difficult to be measured. Although many previous studies on typhoon damage to landscape trees involved the ginkgo, the visual scale method was more common in observing the damage characters of ginkgo crowns (Okinaka *et al.*, 1984, 1990). In comparison with sampling method, the digital image analysis is characterized by less labor and less time requirement (Karcher and Richardson, 2003; Richardson *et al.*, 2001). Comparing to visual scale estimation, it is less affected by subjective judgment (Solberg, 1999) and reproducible (Richardson *et al.*, 2001; Geneve and Kester, 2001) with lower observation deviation (Richardson *et al.*, 2001). In contrast with other objective color analysis method, the RGB image analysis is low cost (Kawashima and Nakatani, 1998; Karcher and Richardson, 2003). As a nondestructive and noninvasive method, digital image analysis has ever been used to measure leaf area index and gap fraction of plant canopy (Bréda, 2003), crop coverage (Purcell, 2000), pest damage (Skaloudova *et al.*, 2006) and tree crown transparency (Mizoue and Masutani, 2003) and so on. In the research of wheat senescence, Adamsen *et al.* (1999) held that the relationship between G/R and SPAD value (data read from SPAD-502 chlorophyll meter) was linear over most of the range of G/R values. The G/R value responded to both chlorophyll concentrations in leaves and leaf numbers. Although, the observation conditions, objective plant materials and selected optimal indices from different authors varied, the commonality of them included the utilization of RGB proportional values and color analysis of plant as well as on chlorophyll evaluation of the plant canopy (Cai *et al.*, 2006). Seldom studies have been found on the leaf necrosis by RGB image analysis, especially on the leaf necrotic area and asymmetric crown discoloration induced by typhoons.

As mentioned in Chapter two, the asymmetric crown discoloration and partial leaf necrosis of ginkgo after hit by T0613 is a special characteristic of them. In order to quantitatively estimate the symptoms of damage, the leaf necrotic area percentage (LNAP), crown discoloration area percentage (CDAP) and inflection point (IP) of the threshold response function for asymmetric discolored crowns were determined by image pixel method. The green/luminance (G/L) value was measured by using the RGB images respectively scanned by a flat bed scanner from individual leaves and taken with a CCD digital camera from crowns. Comparing with the sampling method, image analysis has been used to quantitatively evaluate the asymmetric discoloration of both leave and crowns of ginkgo hit by T0613.

5.2 Materials and methods

The RGB images were respectively obtained from both indoor image scanning from leaves and outdoor photo taking from crowns. The individual leaf samples for image analysis were same as that in paragraph 3.2.1. All leaves on the branches were visually divided and counted into five necrotic scales of nil, slight, middle, serious and dead. All of partial necrotic leaves and partial leaves of entirely green and overall brown, in total 153 leaves, were scanned with a flat bed scanner (Canon D125u2). LNAP is measured and calculated with the Equation III2 and the G/R_{leaf} and G/L_{leaf} were measured and calculated with Equation IV1 and IV3 respectively.

The sites for researching asymmetric discolored crowns of ginkgo were same area as mentioned in paragraph of 2.2.1. The sampled ginkgo trees did not include newly planted trees, newly pruned trees and the trees sheltered by houses, buildings and other trees and so on. Most of them were selected in open sites and almost all the data used in result analysis were relative values from the same leaf or crown. The RGB images for calculation of the CDAP and G/L_{crown} values were taken with a CCD digital camera (Canon IXY 6.0). The camera was set to auto white balance, auto ISO sensitivity and the image resolution was 1200×1600 pixels with images stored in the files of JPEG form. It was the vertical profile of sampled tree taken on ground with little elevations 45 days after T0613's hit under natural day light condition (From 900JST to 1600 JST).

The distance of photo taking was determined by fitting the crown to the screen of camera. The position of photo taking was fixed by turning around the sampled tree till the crown can be clearly divided into green part and non-green part so that we can capture the exact sideward (A profile of crown perpendicular to leeward or windward) image. The absolute geographical position of sampled trees was fixed by GPS with Caplio 500SE Ricoh camera.

Firstly, the images were prepared and the part except sampled crown was removed from the image with eraser tool of Photoshop. The removing process was showed in Fig. C5-2. After selected the crown with Magic Wand Tool of Photoshop, the G and L values were also read from the average histogram of Photoshop. The G/L_{crown} value is the proportion of green to luminance value of crown. It was calculated with Equation II1. The G/R_{crown} value was obtained with same image and method, and similarly calculated by using Equation V1 for comparison with the G/L_{crown}.

$$G/R_{crown} = \frac{green\ value\ of\ the\ crown}{red\ value\ of\ the\ crown} \qquad (V1)$$

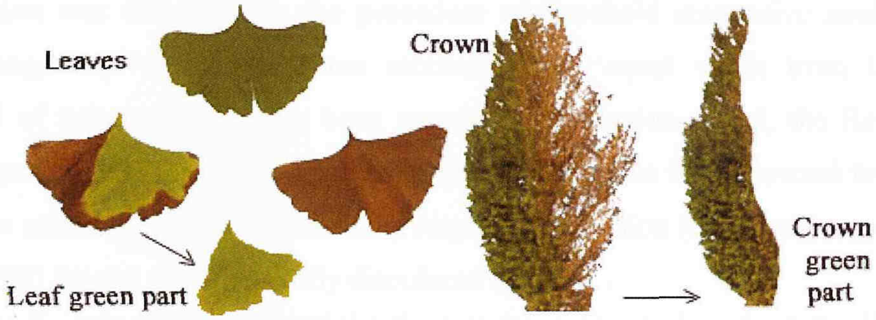


Fig. C5-1 Leaf necrosis and asymmetric crown discoloration of ginkgo tree induced by T0613, and the green parts of both ginkgo leaf and crown

The CDAP, considered as the criterion status of damaged crowns hit by T0613, is the pixel proportion of non-green part to entire profile of the crown. During measurement, the green part of the crown (Fig. C5-1) was visually extracted by transitional color. After getting the pixel numbers of the entire crown and green part, the CDAP was calculated by Equation V2.

$$CDAP = \frac{100^{*}\ (PEC - PGP)}{PEC} \quad (V2)$$

In which, PEC is the pixel numbers of entire crown profile and the PGP is the pixel numbers of green part.

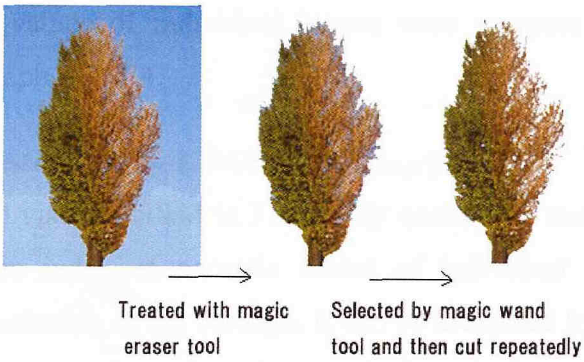


Fig. C5-2 Extracting process of ginkgo crown with Photoshop. Firstly the background was removed by eraser tool, then selected the background interweaving with the crown and cut it out. This process approached repeatedly until the part out of crown was thoroughly removed.

To make a comparison with the CDAP, the inflection point (IP) of crown discoloration was calculated in the procedure of threshold responsive analysis. Each crown image was divided into ten sections with equal width from leeward to windward of the crown. Having been repeatedly regression tested, the Relative G/L (RGL, Equation V3) for crown sections gradually decreases from leeward to windward and can be modeled by logistic threshold responsive function (calculated as same as the Equation II8) for the asymmetrically discolored crowns.

Checked by secondary differential values at the point n>a/r and n<a/r, all IP values existed and were mathematically meaningful except the IP for samples with the crown of overall green or entirely brown. During the measurement, the IP values for crowns of overall green were numbered with the maximum value of 10 and for the crowns of overall brown with the minimum value of 0 in order to digitalize all of the data. The IP can be considered as the estimation value of the threshold between green part and non-green part of discolored crowns and as a reference for the CDAP.

$$RGL_i = \frac{100 \times (G/L_i - G/L_{min})}{(G/L_{max} - G/L_{min})} \quad (V3)$$

Where, G/L_i is the G/L value for i section (i=1,2,3...10), G/L_{min} is the minimum G/L value of all sections in all sampled crowns and G/L_{max} is the maximum G/L value in all sections of all sampled crowns. Based on the study of dogwood leaves, the RGL value could obtain very smaller difference for the same leaf taken into images with big luminance difference (Fig. C7-1).

The distance from coastline (DC) was defined and measured as same as in paragraph 3.2.4. The SPAD values of individual leaves were measure with same method as described in paragraph of 2.2.4.

5.3 Leaf necrosis estimated by LNAP and G/L_{leaf} value

By sampling and visual method in 3.2.1, only qualitative scale estimation results can be obtained. As an index of necrotic extent of individual leaves, the LNAP was determined as the criterion of the damage. It can be measured by many methods such as check counter, leaf area meter, photo image pixel method etc. In this study, the image pixel method was used to determine the LNAP for its high accuracy and low variance (Chen *et al.* 2006, Bai *et al.* 2005). The image pixel analysis method used in leaf area measurement can be remarked as a fine check counter, in which each image pixel can be considered as a check with 5,022 checks per square centimeter for 180 dpi images. However, using visual method is difficult to estimate the exact account of leaf area as the image pixel analysis, especially for variously necrotic leaves and asymmetric discolored crowns.

The total leaf necrotic area and total leaf area of each branch were estimated by using the LNAP and mean leaf area on the basis of necrotic scales (Table 5-1). As the leaf necrosis analysis on ginkgo crowns in paragraph 3.2.3, it also manifested the fact that most leaves on leeward of the sampled crowns were composed of nil and slightly necrotic leaves and most leaves on windward of the sampled crowns were partially necrotic and dead leaves. The total necrotic leaf area of the windward of damaged crowns was more than that of the leeward with the windward and leeward ratio (W/Le) equaling to 7.416. By comparison, the total leaf area showed an inverse tendency with the W/Le equaling to 0.659. It implies that after hit by T0613, not only leaf necrosis and asymmetric crown discoloration occurred, but also the defoliation as well as asymmetric growth took place.

As same as result of bamboo image analysis, an inverse logistic function between the G/L_{leaf} value and LNAP for ginkgo leaves was also obtained by regression analysis, with R^2=0.941 (Fig. C5-3). It indicated that as the LNAP increased the G/L_{leaf} value decreased gradually with a nonlinear pattern. After removing the leaf samples with LNAP <20% and >70%, the relation equation also changed to a linear function, with R^2=0.870 (Fig. C5-4).

Table 5-1 Total necrotic leaf area and total leaf area per branch

		Nil necrosis (mm^2)	Slight Necrosis (mm^2)	Middle necrosis (mm^2)	Serious necrosis (mm^2)	Died leaves (mm^2)	Total (mm^2)	Leaf Number	W/Le
Necrotic Area	Leeward	0	6349	4039	2156	0	12545	152	7.416
	Windward	0	5977	15178	12850	59025	93032	100	
Total Area	Leeward	243972	100736	11805	3148	0	359662	152	0.659
	Windward	43285	69256	41711	23610	59025	236889	100	

† Where W/Le is the ratio between windward and leeward. The data comes from average of three sampled branches.

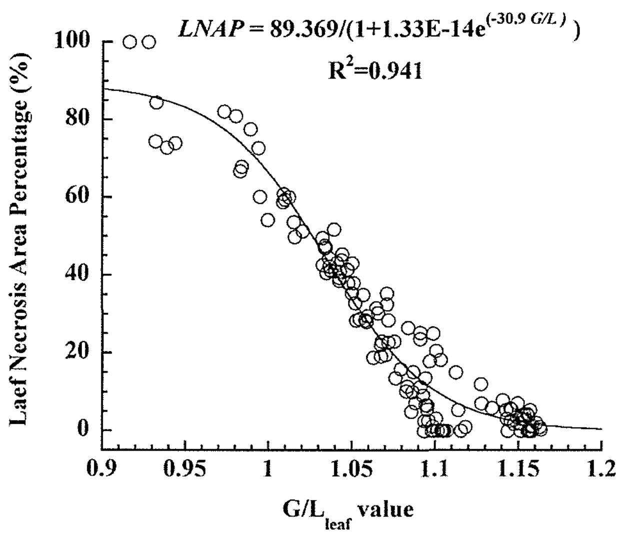


Fig. C5-3 Relation between Leaf Necrotic Area Percentage (LNAP) and G/L_{leaf} value of ginkgo. An inverse logistic function was obtained.

The leaves with LNAP <20% or >70% showed variation in leaf color. By measuring the SPAD value of the non-necrotic part of leaves, it also appeared significant difference among sampled branches (P=2.3637E-12, F=30.735**). It suggested that the G/L_{leaf} was affected by the difference of leaf colors in these ranges. In the range of LNAP >20% and <70%, the G/L_{leaf} value was even much sensitive to the variance of leaf necrotic area than the leaf color difference, according to the near linear relationship. From this perspective, the G/L_{leaf} value of RGB image responds to both chlorosis and necrosis of necrotic leaves. In fact, ginkgo leaves on different crowns showed not only different leaf necrosis but also leaf color variance (chlorosis). Therefore, it has potential to be used in estimating the status of crowns damaged by typhoons like T0613. It also indicated that the leaves with similar color status should be selected to estimate the necrotic area based on G/L_{leaf} value. Fig.C5-5 gives some model ginkgo leaves estimated by LNAP and corresponding G/L_{leaf} values.

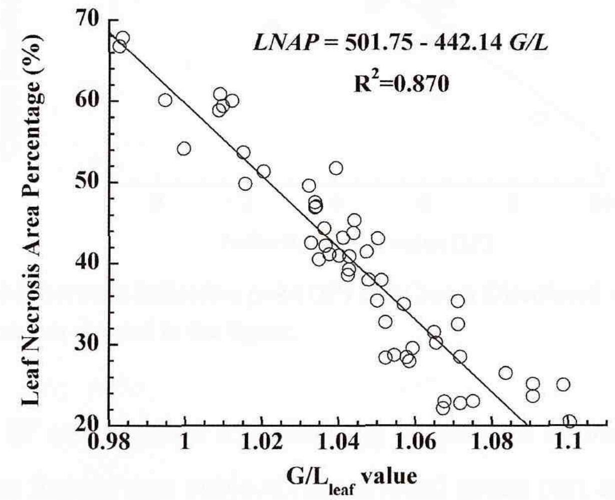


Fig. C5-4 Relation between Leaf Necrotic Area Percentage (LNAP) and G/L_{leaf} value of ginkgo after remove the leaf samples with LNAP <20% and >70%. A linear equation was obtained.

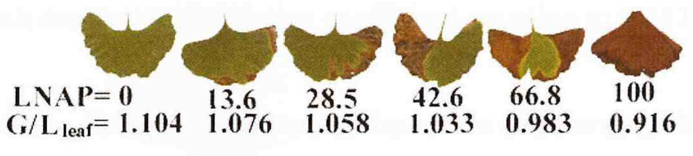


Fig. C5-5 Model leaf samples and the corresponding Leaf Necrotic Area Percentage (LNAP) and G/L_{leaf} value. It is clear that the leaf necrosis of ginkgo showed slight difference to that of bamboos. The fan-like leaflet itself becomes the special characteristics of ginkgo.

5.4 Asymmetric crown discoloration estimated by CDAP, IP and G/L_{crown} values

Compared to bamboos, the asymmetric crown discoloration of ginkgo trees after hit by strong T0613 comprise the main characters of them. Compared between the leaves and crowns of ginkgo trees hit by T0613, almost similar characteristics has been found, which showed partial area of them became brown or red brown. Therefore, as the LNAP was used as the discriminatory standard for leaf necrosis, the CDAP and IP were used to evaluate the asymmetric crown discoloration.

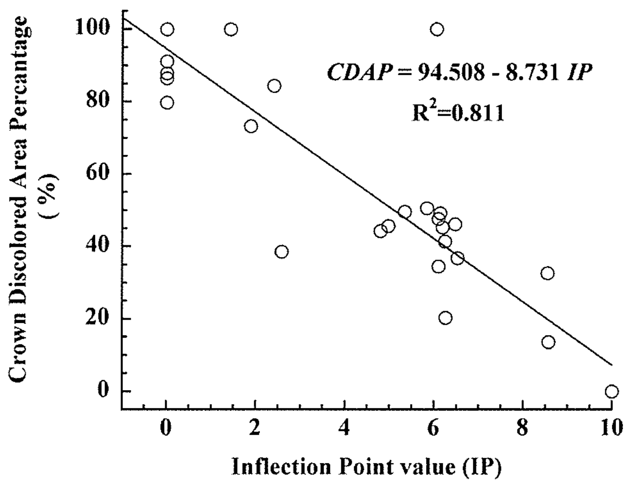


Fig. C5-6 The relationship between Inflection point (IP) and Crown Discolored Area Percentage (CDAP), an inverse linear function was showed in the figure.

Both CDAP and IP can be used to reflect the proportion of the green part to entire crown. However, the former was subjectively divided green part and non-green part by visual method and the later was objectively calculated by parameters from the logistic threshold responsive function. Because of the big contrast between the green part and non-green part of the ginkgo trees injured by T0613, the two indices are consistent with each other with the square correlative coefficient equaling to 0.811(Fig.C5-6).

In comparison to the individual leaves, the crown of trees manifested characteristics of more complex structure, such as leaf orientation variance and difference in gap fraction and light condition. Although it hampered the image taking and RGB image analysis, a significant inverse linear relation between G/L_{crown} value and CDAP for sampled ginkgo crowns was obtained, with R^2=0.826 (Fig.C5-7a). Almost a same level of positive linear relation between G/L_{crown} value and IP for the sampled ginkgo crowns was also acquired, with R^2=0.827 (Fig.C5-7b)

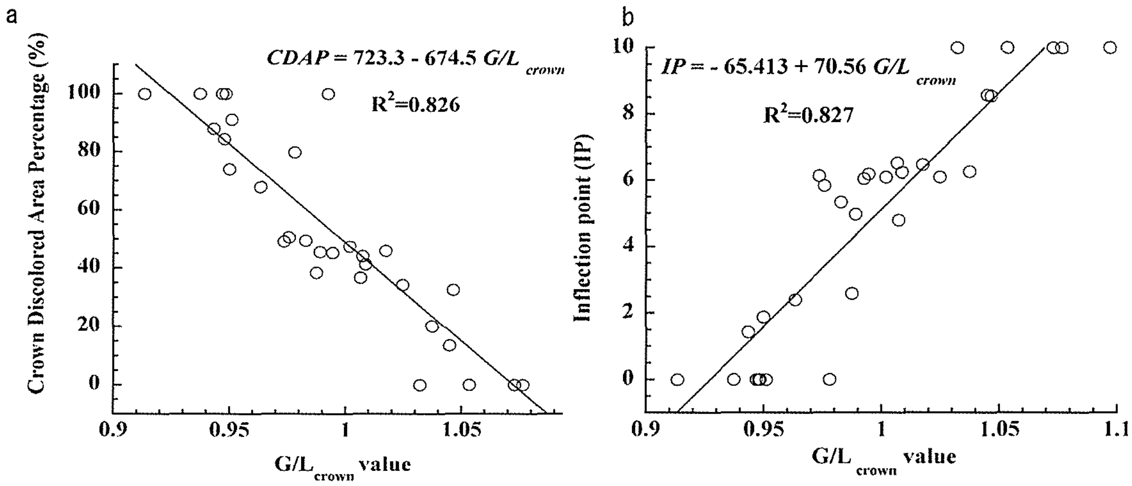
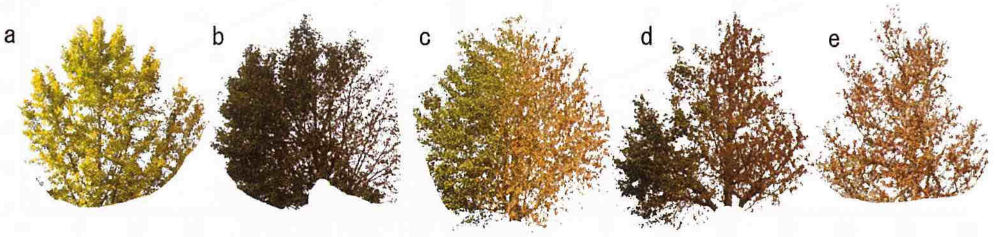


Fig. C5-7 An inverse relationship between Crown Discolored Area Percentage (CDAP) and G/L_{crown} value of ginkgo, and a positive function between Inflection point (IP) and G/L_{crown} value of ginkgo were presented in C5-7a and C5-7b respectively.

Therefore, it suggested that not only leaf necrosis but also asymmetric crown discoloration, induced by strong typhoons like T0613, could be quantitatively estimated by G/L values. Some model crowns (Fig.C5-8a, b, c, d and e) estimated by G/L_{crown} values, CDAP and IP were shown in Fig.C5-8. By comparison, the commonly used visual scale method usually scales the crown healthy status like VS index in the figure. In Fig.C5-8, they were also shown by five figures of threshold responsive function. The logistic curve divided the asymmetrically discolored crowns into green and non-green parts (Fig.C5-8g, h, i). The crown discoloration of injured crowns was clearly described. It indicated that the crown injured by T0613 was more serious on windward than on leeward. It showed responsive equations of level line for the crowns with characteristics of overall green and entirely brown and respectively located on top and bottom of the coordinate (Fig.C5-8f, j). It suggested that the threshold responsive analysis also has a potential to estimate the healthy status of ginkgo trees injured by T0613.

5.5 Relation between DC and both G/R_{crown} and G/L_{crown} values of ginkgo

It was reported that the damage to ginkgo trees by strong typhoons appeared inverse relation to the distance from coastline (Okinaka *et al.*, 1984). A similar result had been obtained in the study at different sites with different distance from coastline with sampling method as in paragraph 3.2.1. Corresponding to the previous research result, the damage to ginkgo trees by strong T0613 also appeared an inverse relation to the distance from coastline according to the result of RGB image analysis (Fig.C5-9).



	a	b	c	d	e
G/L crown	1.073	1.037	0.989	0.963	0.937
IP	10	6.26	4.98	2.587	0
CDAP	0	20.26	45.64	84.391	100
VS	I	II	III	IV	V

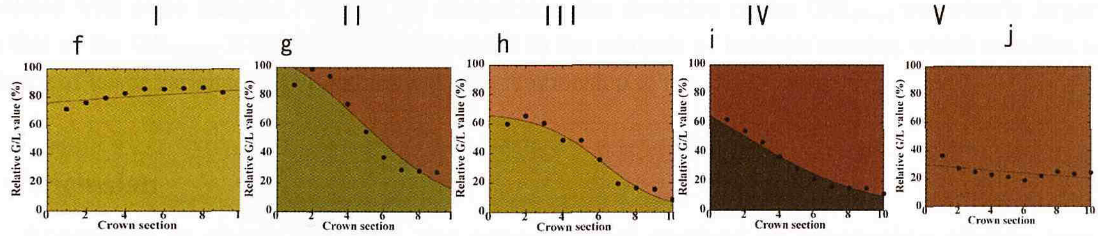


Fig. C5-8 From C5-8a to C5-8e were five model crowns corresponded by G/L_{crown}, Crown Discolored Area Percentage (CDAP) and inflection point (IP) of regression curve and respectively belong to five visual scales (VS). From C5-8f to C5-8j were five figures of threshold responsive function of relative G/L_{crown} (RGL) and showed different logistic curves, which divide the crown into green part and non-green. The C5-8f and C5-8j presented entire green and overall brown respectively and their IP was more than 10 and less than 0 separately. From C5-8f to C5-8j, the vertical coordinate is RGL value and horizontal coordinate is crown section orders from leeward to windward.

By comparison, both G/R_{crown} and G/L_{crown} measured by image pixel method appeared positive relation to the distance from coastline with R^2=0.50 and R^2=0.837 for G/R_{crown} and G/L_{crown} separately (Fig.C5-9a, b). This result is almost the similar as the relation between the DC and both G/R_{canopy} and G/L_{canopy} of bamboo. However, the deviation of G/R_{crown} values was 2.02 times more than that of G/L_{crown} values. It may be the cause of the lower relation between G/R value and DC than that between G/L value and DC. It suggested that the G/L_{crown} was more appropriate to be used analyzed the images taken under the conditions with big lightning difference. By using the method as the visual estimation in paragraph 3.2.1, it showed that the farther is from the coastline, the less damage to ginkgo trees and the larger the G/L_{crown} value. In other word, the nearer is to the coastline, the more is the leaf necrosis and asymmetric crown discoloration, and the more serious damage to ginkgo trees.

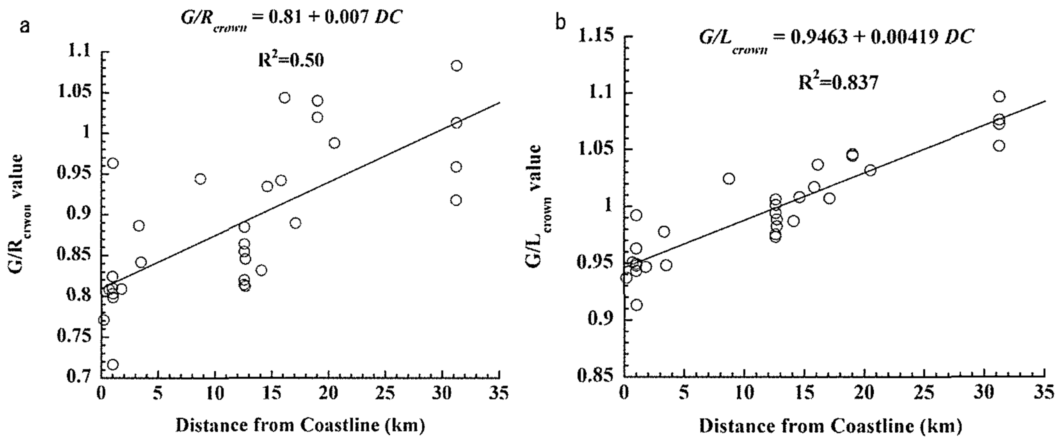


Fig. C5-9 Relation between Distance from Coastline (DC) and G/R_{crown} value of ginkgo calculated with 31 samples (C5-9a), and Relation between Distance from Coastline (DC) and G/L_{crown} of ginkgo calculated with same samples (C5-9b). By comparison, the deviation of the G/R_{crown} was clearly larger than that of the G/L_{crown}. It appeared a similar result to the analysis of bamboo canopy, which manifest a tendency of lower variance of G/L values and high relationship to the DC.

5.6 Conclusion

According to above analysis, the conventional method of measuring ginkgo tree crowns damaged by typhoons is visual estimation, although it is usually affected by subjective judgment with various results from different observers. Labor requirement and time consumption rendered the sampling method unable to be used in studying trees in a large area by fewer researchers. Research about asymmetric crown discoloration has been seldom found recently, especially on measuring the asymmetric discolored crown by RGB image analysis. Comparing to the conventional method, the RGB image analysis can be used to measure the characters of trees quantitatively with characteristics of less labor, less time needs and low cost. The possibility of storage and reusing for digital images made the continuing research possible.

Significant relationship between G/L_{leaf} and LNAP, and between G/L_{crown} and CDAP suggested that both leaf necrosis and asymmetric crown discoloration of ginkgo trees induced by T0613 can be quantitatively estimated by measuring the G/L value from both leaves and crowns. During the study of T0613, the relation between the G/L_{leaf} value and LNAP of ginkgo leaves indicate that not only chlorosis but also necrosis can be quantitatively estimated by using the G/L value of RGB image. Although, the hue of leaf and crown images were affected by different light condition, a significant relation between G/L_{crown} and CDAP or IP had been obtained since the great contrast of the green part and non-green part of ginkgo crowns hit by T0613. It may be an alternative tool to estimate the leaf necrosis status and asymmetric crown discoloration induced by typhoons like T0613, especially by using the relative G/L values.

It was the variation of necrotic leaves that made the crown of damaged ginkgo trees appeared asymmetrically discolored. The logistic function from threshold responsive analysis indicated that more serious injury occurred on the windward of the asymmetric discolored crowns. The proper relationship between IP and CDAP suggested that as an objectively measured parameter the IP has potential to describe the asymmetric discoloration characters of ginkgo trees hit by typhoons like T0613. The relationship between the distance from coastline (DC) and G/L_{crown} value presented that the farther from the coastline, the bigger the G/L_{crown} value of ginkgo crowns. As an index of the image hue of entire crown, the G/L_{crown} value also has a potential to be used to estimate the color change of overall crown originated from leaf necrosis or asymmetric crown discolorations. Based on the logistic threshold analysis, it indicated that the asymmetric crown of ginkgo occurred indeed in the investigated area.

Chapter 6 Quantitatively Estimating Vigor Status of Ginkgo after Hit by T0613 with Image Analysis

6.1 Introduction

Vigor of trees can be thought as one kind of ability to form a perfect individual and healthily grows, which varies with the cultivated conditions, increases with fine nurtures and decreases by serious pest damages, disaster destroys and various kinds of stresses, such as drought, salt, nutrition shortage. Under stressed situations, many low vigorous symptoms may appear like severe wilt, defoliation, discoloration, chlorosis, necrosis and dieback and so on. In some extent, it is a near synonym with tree viability or health. Vigor reduction of landscape trees can be described in many aspects. After hit by T0613, the crown of many ginkgo trees can be clearly divided into green part and non-green part. Leaf discoloration and defoliation were two striking characteristics of ginkgo trees in Yamaguchi City, Japan. It responded the severity of injury from T0613's hit. It is also the indirect manifestation of the vigor status affected by the combination of the previous hit of various extreme environments, especially strong typhoons.

Besides the utilization mentioned above, the ground digital image has also been used in tree measurement and studied on the porosity of shelterbelts (Kenny, 1987; Guan *et al.*, 2002; Wan *et al.*, 2005). Kenny (1987) concluded that the porosity of shelterbelt could be estimated to within 2% at a probability level of 0.05 by silhouette method, and the distance of taking photo has no appreciable effect on estimation of porosity. After improvement of photograph treatment method, Guan *et al.* (2002) considered it was a proper way to measure porosity of shelterbelt with high accuracy.

In this paragraph, by using the indices of crown green area percentage (CGAP), crown coverage (CC), vigor index (VI), and so on, the spatial distribution of different ginkgo tree with varied vigor status were studied and classified into different divisions based on multi-analysis of these indices.

6.2 Materials and methods

6.2.1 Research site and basic meteorological data during T0613's hit

The research site is located in the area from 131°16' to 131°45' east longitude and from 33°55' to 34°25' north latitude in Yamaguchi City. The investigation was practiced in the same area described as in paragraph 2.2.1. It is in a long, narrow area near Yamaguchi Bay, Fushino River and Anno River, which was from seashore via plain to canyon. The meteorological data obtained from AMeDAS and from the nearest observation station of the Hazard Protection Information System in Yamaguchi Prefecture (HPISYP). During hit by T0613, the investigated area just located in the severe right half of the storm field. It is characterized by the max wind speed distributed from the highest of 27 m/s in Ube City to the lowest of 8 m/s around Tokusa Town during the hit by T0613; The precipitation from highest 38mm to the lowest 14 mm and the distance to the nearest coastline is from the shortest of less than 1 km to the longest of more than 40 km (Table 6-1). Photographs were taken 45 days after T0613's hit. It is characterized by horizontally taking photos of the vertical profile of sample trees on the ground and with the same method as in paragraph 2.2.2.

Table 6-1 Basic meteorological data for investigated areas during hit by T0613 on Sep.17.2006

	Daily precipitation (mm)	Average wind speed (m/s)	Maximum wind speed (m/s)	Distance from coastline (km)
Aio	18	No data	No data	0.9
Ube	14	10.8	27	1.0
Ogori	21	No data	No data	3.4
Yamaguchi	24	5.1	20	13.4
Miyano	18	No data	No data	19.5
Mitani	19	No data	No data	31.2
Tokusa	38	2.5	8	40.1

6.2.2 Establishment and measurement of indices

Crown Green Area Percentage (CGAP)

In order to analyze the phenomenon of leaf discoloration of crown and the difference between green part and non-green part on ginkgo trees quantitatively, CGAP was applied, which was an area proportion of the pixels of green part to the pixels of overall profile of the crown. Firstly, the photo image was treated by image editor software of Photoshop CS to remove the parts out of the sampled crown. After obtaining pixels of overall crown, the green part parts were obtained by removing the parts except green with eraser tool (Fig.C6-1). The detail of calculation for CGAP by pixel proportion method is similar as Equation II3.

Overall crown **Green part**

Fig. C6-1 Damaged crown and green part of Ginkgo biloba; Index of Crown Green Area Percentage (CGAP) was calculated by both of them.

Crown Coverage (CC) and Vigor Index (VI)

Another characteristic of ginkgo trees damaged by T0613 is defoliation, which is expressed into increasing of openness of the crown. In the study, the openness induced by defoliation of ginkgo trees hit by T0613 was estimated by CC index. It is the pixel proportion of crown silhouette to crown shadow shown in Fig.C6-2. It was measured by pixel method in reference to researches by others (Kenny 1987; Guan *et al.*, 2002). The detail procedures of measurement include photo image processing and silhouetting by decreasing the color depth to 2-color palette by using Paint Shop Pro X in the pattern of the blue palette component, the nearest color reducing method, and non-palette weight. The pixels of the image shadow were obtained with the threshold algorism manually set gradation to 255 in Photoshop CS. The calculating formula of CC is shown in Equation VI1.

$$Crown\ Coverage(\%) = \frac{pixels\ of\ silhouette}{pixels\ of\ shadow} \times 100 \qquad (VI1)$$

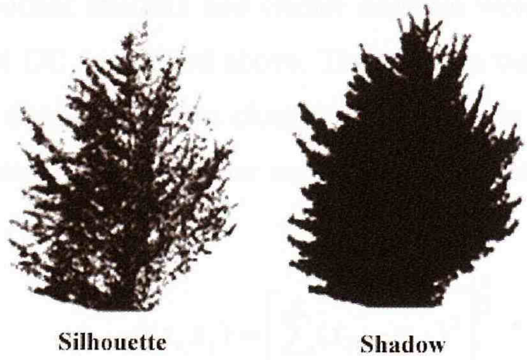


Fig. C6-2 Images of silhouette and shadow for same crown; Crown Coverage (CC) index was calculated by both of them.

The comprehensive index of VI for damaged trees was calculated by the average value of CGAP and CC (Equation VI2), which is a description of both discoloration and defoliation of the crown.

$$VI(\%) = \frac{(CGAP + CC)}{2} \times 100 \qquad (VI2)$$

Windward and Leeward Area Ratio (WLAR)

As a factor of symmetric characteristics of crowns for multi-analysis, WLAR is the proportion of pixels from the shadows of both windward and leeward of crown divided by reference to the main stem. Firstly, the photo image was prepared as above mentioned to remove the parts out of the crown. Then, the crown was divided into windward and leeward from main stem of the tree. After that, both windward and leeward were shadowed respectively and pixels were obtained by using Photoshop CS. The WLAR% was calculated by reference of Equation II2.

Distance from coastline (DC)

As a main analysis factor, the DC is the shortest distance from tree sites to coastline measured with the same method to the paragraph 3.2.4.

6.2.3 Multiple statistic analysis

Principle component analysis and cluster analysis were carried out using CGAP, CC, VI, WLAR, and DC mentioned above. The analysis was conducted by commonly used software. The distance used in cluster analysis is the square Euclidean distance (Equation VI3) for samples and cluster mean (centroid method and refer to Equation VI4) for classes.

$$d(x_i, x_j) = \left[\sum_{k=1}^{p} (x_{ik} - x_{jk})^2 \right]^{\frac{1}{2}} \qquad (VI3)$$

Where $d(x_i, x_j)$ is the Euclidean distance between sample i and sample j, i=1, 2, ……, n, j=1, 2, ……, n and k=1, 2, ……, p. x_{ik} is the data of sample i at point k and x_{jk} is the data of sample j at point k.

$$D_{pq} = d(\bar{x}_p, \bar{x}_q) \qquad (VI4)$$

In which D_{pq} is the centroid distance between class p and class q. $\bar{x}_p$ is the cluster mean value in p class and $\bar{x}_q$ is the cluster mean value in q class.

6.3 Discoloration of ginkgo crown hit by T0613

Based on the calculation, the CGAP distributed from zero or close to zero near the coastline to 100% in the valley far from the coastline around Tokusa Town, corresponding to the overall crown brown and overall crown green. From Fig.C6-3, although the CGAP value for samples at the same site differ from each other for the reason of different site conditions and growth situations, a positive logistic function relationship between CGAP and DC was obtained, with a square correlative coefficient of R^2= 0.913 at 0.01 probability level by screening among the regression equations of logistic, logarithmic, exponential, linear, polynomial etc. The optimal equation determined by maximum correlative coefficient is shown in Equation VI5 and was computed from the regression analysis of 36 sampled trees.

$$CGAP = 101.95/(1 + 8.821e^{-0.183DC}) \qquad R^2 = 0.913 \qquad (VI5)$$

It indicates that the further is from the coastline, the greater the green part of the crown is. In other words, the nearer is to the coastline, the more the green leaf color of ginkgo loses. As the distance from coast to inland increases, the CGAP increases sharply, then smoothly, and then becomes stable. It is calculated that the inflection point of this equation is near 12 km from coastline, where is the location of Yamaguchi with the concentration of a lot of ginkgo trees. Many ginkgo trees of half green and half brown had been observed in this area.

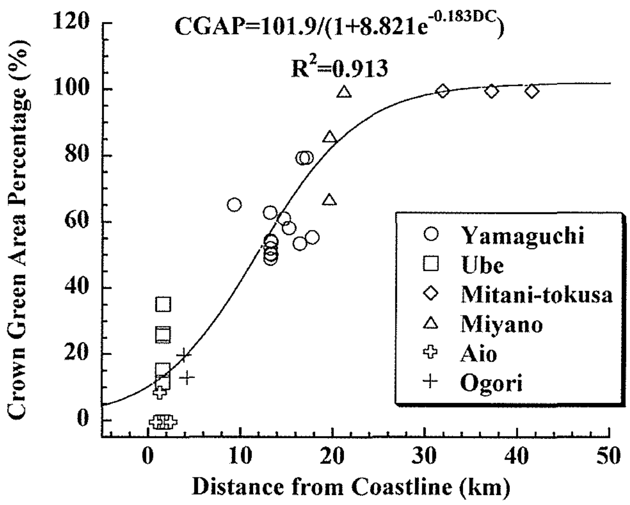


Fig. C6-3 Relationship between Crown Green Area Percentage (CGAP) and Distance from Coastline (DC); It was regressed from 36 ginkgo trees from the sites of Yamaguchi, Ube, Mitani-tokusa, Miyano, Aio and Ogori respectively.

6.4 Defoliation of ginkgo tree hit by T0613

Defoliation is often used as an indicator for the health of forest trees and the damage status in forest investigations (Zierl, 2004). It is observed different defoliation occurred on ginkgo trees in varied site conditions after hit by T0613. From Fig.C6-4, it can be seen that CC ranged from 40% to 90% or so and almost no CC value of ginkgo trees become zero or near zero because there were a lot of dead leaves remained on the damaged trees until next spring. Meanwhile, the result appears that there is a positive relationship between CC and DC, although the correlative coefficient is less than that of the relationship between CGAP and DC. The corresponding equation (Equation VI6) is:

$$CC = 101.34 /(1 + 1.0076 e^{-0.0535 DC}) \quad R^2 = 0.622 \qquad (VI6)$$

The result showed that there is a difference in crown coverage among the sampled trees and the further is from the coastline, the bigger the crown coverage of ginkgo trees is. In other words, defoliation occurred indeed and was more serious near coastline.

The further regression analysis by classifying samples into two groups of dense crowns and sparse crowns showed a positive relationship between CC and DC, and the square correlative coefficient for regressive equations was 0.78 and 0.79 respectively for the dense crown group and sparse crown group. It indicates that the relationship between CC and DC is affected by density of crowns. Therefore, sampled trees with much dense crown were eliminated from the analysis.

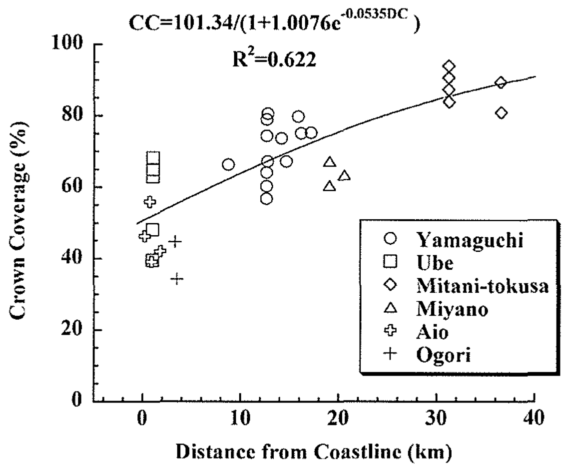


Fig. C6-4 Relationship between Crown Coverage (CC) and Distance from Coastline (DC); It was also regressed from the same ginkgo trees used in figure C6-3.

6.5 Comprehensive vigor status of ginkgo trees hit by T0613

Tree's vigor has been evaluated by various methods, which includes foliage-based indices, volume increment and height growth rate based indices (Robichaud *et al.*, 1991). However, the vigor of ginkgo tree to be estimated in this study is the status after hit by strong T0613, which is characterized by clear discoloration and defoliation of typhoon damaged trees. Therefore, discoloration and defoliation were used to establish the vigor index to response to the vigor status of ginkgo trees hit by T0613. CGAP and CC are two indices respectively response to them in some extents and the VI which integrated with index of CGAP and CC has potential to comprehensively model the vigor status of damaged trees. Fig.C6-5 gave a relation curve between VI and DC and a positive relationship between VI and DC is also obtained, with a square correlative coefficient of R^2=0.882 and regressive Equation VI7. It is nearer to the linear relation according to calculation with a near level of square correlative coefficient of R^2=0.85. Therefore, it has a potential to be used as an index to estimate the vigor status of ginkgo hit by T0613.

$$VI = 99.688/(1+2.5366\, e^{-0.11DC}) \quad R^2 = 0.882 \qquad (VI7)$$

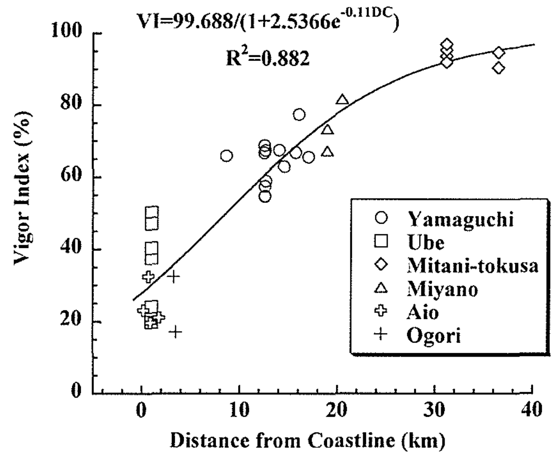


Fig. C6-5 Relationship between Vigor Index (VI) and Distance from Coastline (DC); Ginkgo crowns analyzed in it were also same as figure C6-3.

6.6 Multi analyses and classification of ginkgo vigor status

Based on the principle component analysis by CGAP, CC, VI, WLAR, and DC, samples from different areas were divided into three groups showed in Fig.C6-6. Group 1 consisted of samples from Tokusa and Mitani with DC of more than 30 km, CGAP of 100% or near 100%, average CC of 83.4%, and VI of 95.4%. Group 2 included samples from Miyano and Yamaguchi, with DC from 8 to 20 km, CGAP from 40 to 90%, average CC of 67.3%, and VI of 67.5%. Group 3 came from samples from Ogori, Aio, and Ube with DC from 0.2 to 4 km, CGAP from 0 to 39%, average CC of 54.2%, and VI of 21.1%.

The result of principle component analysis is evidence that the vigor of ginkgo trees were more seriously damaged by T0613 within 4 km from the coastline, and almost no injury occurred in the area further than 20 km from coastline and the ginkgo trees in the area from 4km to 20 km were in the middle position.

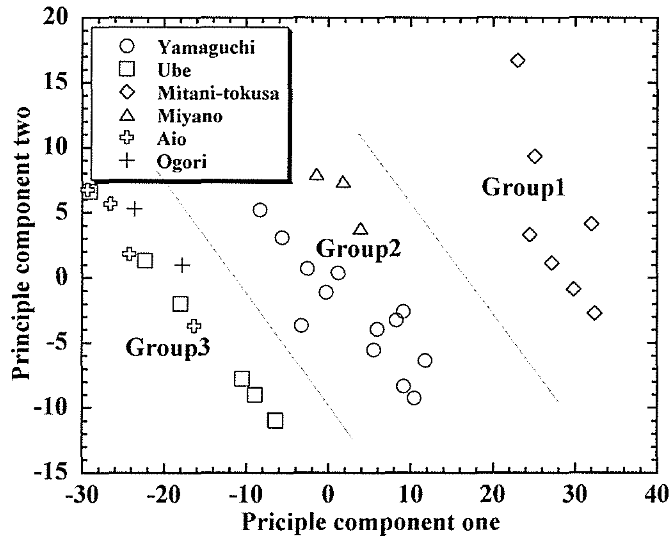


Fig. C6-6 Classification of ginkgo crowns by principle component analysis. 36 crowns collectively distributed in three area of principle coordinate system and were classified into three groups, the first group is concentrated in the first and fourth quadrant at the right side of the x axis, the second group around the datum point, and the third group in second and third quadrant at the left side of the x axis.

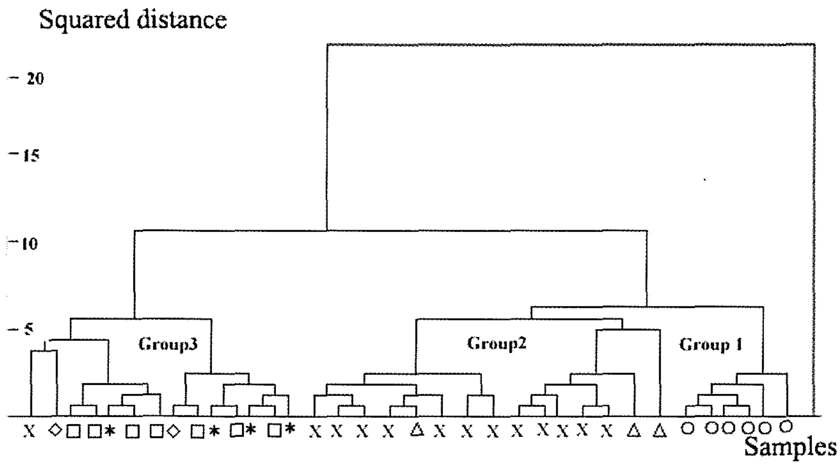


Fig. C6-7 Result of cluster analysis with centroid method, in which the crowns from Mitani-tokusa (○), Miyano (△), Yamaguxhi (X), Ogori (◇), Aio (*) and Ube (□), were also classified into three groups.

Almost the same result has been obtained by Euclidean distance cluster analysis at the point of squared central distance equaling 6.05 with the data of CGAP, CC, VI, WLAR, and DC according to the discriminating standard of the starting point that the squared central distance sharply increases. The samples from different areas also can be divided into three groups as showed in Fig.C6-7. The samples from Group 1 consisted of samples from Tokusa and Mitani, Group 2, from Yamaguchi and Miyano, and Group 3, from Ube, Aio, and Ogori except only one special sample from Yamaguchi.

Fig.C6-8 shows a few of model of ground-based digital image samples for Group 1, Group 2, and Group 3, respectively. A great difference among the groups was shown and they are consistent with the indices used in this research properly.

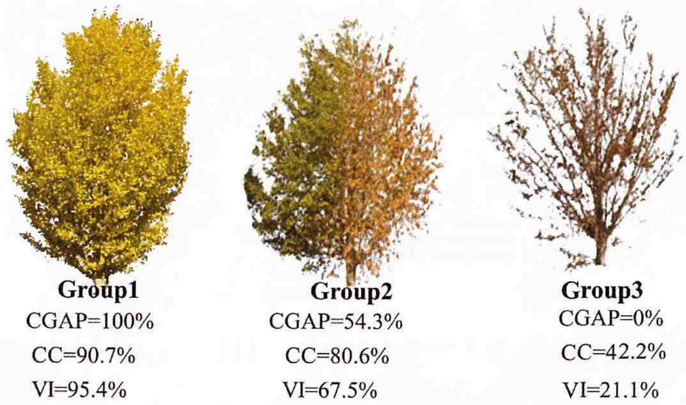


Fig. C6-8 Model samples of ground-based image for group1, group2 and group3 and related CGAP, CC and VI values

An outline of the research area (circled area), meteorological data, CGAP index, and groups of classification was given in Fig.C6-9. In the figure, CGAP was scaled into 5 levels, and respectively represent CGAP of 100, 60-90, 40-59, 1-39, and 0. Every sample, with a consistent scale mark, was located on the map in the figure. It can be observed that the classification result was consistent with the research sites. For the first group, the DC is more than 30 km, the second group is from 4 to 20 km, and the third group is less than 4 km and was in accordance with the gradient of wind and precipitation. It can be seen that the further the sample tree is from the coastline, the slighter the damage by T0613 is according to the indices by ground-based digital image analysis.

From Fig.C6-9, it is easy to see that there is a number gap between scale 100 and scale 69-90 and it is not difficulty to find discontinuous topography between Miyano and Mitani-Tokusa that is located in the canyon. This discontinuous topography formed a natural barrier for the trees, protecting them from strong wind blown by typhoon, so that there was almost no sign of damage to ginkgo trees by T0613 in this area. If there were no effect of this discontinuous topography, the damaged ginkgo trees might spread far inland and the number gap would not exist.

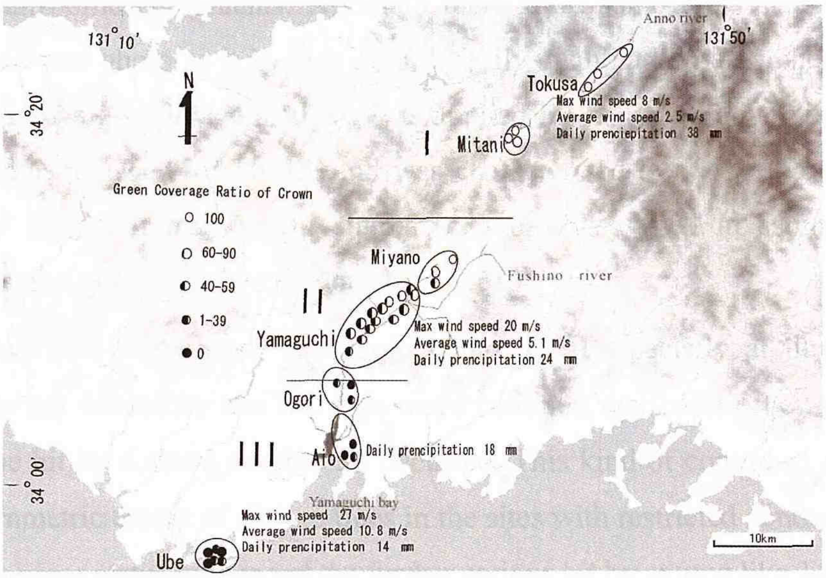


Fig. C6-9 Integrated map of research area, meteorological data and crown green area percentage (CGAP); Sampled crowns were clearly divided into three groups, Group 1 (I), Group 2 (II) and Group 3 (III).

6.7 Conclusion

In summary, typhoons are one kind of disaster that can lead to serious damage to forests, trees, and shrubs. Besides mechanical damage, vigor reduction is another kind of injury by strong typhoons like T0613, characterized by discoloration and defoliation of ginkgo crowns accompanying with not-eye-catching branch or twig dieback. By component analysis, leaves on damaged ginkgo trees are composed of leaves with different scorch areas at the time of investigation. Results show that the further they are from the coastline, the fewer scorched leaves, and the closer they are to the coastline, the more scorched and dried leaves. The relationship between DC and indices of CGAP, CC, and VI show a similar tendency that the further they are from the coastline, the smaller the damage by T0613 is and the bigger the CGAP, CC, and VI are. Based on the multi-analysis of this research, similar tendency has been found. Because of the low land productivity in coastal area, the landscape trees should be affected by more complicated factors, in which the salt injury may be one of the serious damage factors (Boyce, 1954; Griffiths *et al.*, 2003; Okinaka *et al.*, 1990; Munns, 1993).

Since the 1980s, a gradually increasing number of researches on image analysis have been carried out (Wang, 2006). However, fewer researches have been found on typhoon damaged tree crown studies by sideward image, which cannot be detected by space-borne or air-borne equipments. Although there were some reports on typhoon damage with sideward photo as it is, they are not really quantitative researches. In this paper, ground-based digital image analysis was applied in the quantitative research of ginkgo trees' vigor damaged by T0613, and was characterized by analyzing sideward image of entire crown. It may be an alternative tool to be used in estimating or evaluating the degree of damage by typhoons like T0613.

It is observed that lower vigor status of ginkgo trees, especially at limited site condition, seems not caused by one hit. It is more common that before they perfectly recover from one hit by a storm another hit occurred. This kind of continued damages induced the asymmetric crown of ginkgo trees in the sites with restricted conditions and should affect the vigor status to respond the further serious hit by storms like T0613. By the tracing observation, the result of classification showed a tendency of being consistent with the restoring status of these trees two years after the T0613.

Part 3

Quantitatively Evaluating Symptoms of Dogwood Induced by Summer Drought/hot Stresses with RGB Image Analysis, Spectral Reflectance and Thermography

In the year 2007, abnormal weather with uneven rainfall occurred in many areas over the world. Severe drought happened in southeast United States, southeast Australia and northeast China. The weather characteristic during the year 2006 and 2007 in Yamaguchi City, Japan also showed sharp contrast. Plentiful precipitation in Japan rainy season, strong typhoon with less rainfall in mid-September, and higher temperature associated with almost no rainfall in October became the meteorological extreme events in 2006. The less rainfall after strong typhoon 0613's hit almost persisted through the entire 2007 growth season.

The summer drought is another kind of meteorological extreme and often causes plants or trees into dysfunction. Transpiration cooling failure and desiccation usually makes plants or trees into metabolic imbalance of energy, which is lethal to them. In the summer of the years in 2007 and 2008, more than 20 days persistent high temperature and no rain weather during the hottest days in a year seemed the key of meteorological extreme events. They caused many landscape trees into protective responses, especially the kousa dogwoods. Significant leaf necrosis appeared on many crowns of them. During the summer of 2008, some newly planted dogwood trees were observed transplanting shock in Yamaguchi City, Japan. Leaf necrosis and branch dieback occurred on some of them during summer period.

The heterogeneousness of leaf living part and dead part, and leaf color variation from distal to proximal causes them difficult to be directly measured. The flexibility of RGB image analysis makes it suitable to measure the leaves differentially. In the study, leaf images were equally divided into ten sections from proximal to distal and the "Switch-off" type of threshold responsive functions were used to describe the gradually necrotic leaves. Combined the spectral reflectance and water content measurement, the image pixel analysis was used to estimate the necrotic leaves and die-backed branches of kousa dogwood during the abnormal extreme summer drought event in 2007 and 2008 quantitatively. In this part, the segregation of the hydraulic architecture of kousa dogwood had also been descried or estimated by image analysis, spectral reflectance and thermograpny.

Chapter 7 Evaluating Symptoms of Dogwood Induced by Summer Drought/hot Stresses with RGB Image Analysis

7.1 Introduction

Plants usually live in the contradict processes in capturing carbon, receipting energy at expense of losing water. High photosynthesis and carbohydrate production per land area needs additional leaf areas, which implies more water and nutrition consumption. Most of water absorbed from soil is lost by plant transpiration, and less 5% is used in metabolism and growth. Therefore, transpiration has ever been regarded as an unavoidable evil since it causes water deficits and injury by dehydration (Kramer, 1983). It was also considered beneficial because it acts as transpiration cooler to avoid leaf temperature over rise. It causes the ascent of sap and increases the absorption of minerals (Clements, 1934). Plant tissues dissipate heat by three main processes, emission of long-wave radiation, convection of heat, and transpiration of water. Of which transpiration tends to be the most effective process of heat dissipation of plant tissues, particularly at sunny midday. High plant temperatures (>40 ℃) are almost invariably associated with the cessation of transpiring cooling, following stomata closure in response to drought stress (Fitter and Hay, 2002). Therefore, the transpiration cooler failure during the serious drought stress seems lethal to plants. In addition, increase in temperature alone tends to cause an increase in the rate of transpiration through its effect on saturation water vapor density (Fitter and Hay, 2002). During persistent drought and transpiration cooling failure, excessive leaf area usually causes losing balance of energy and water so as to be dangerous to their lives. A lot of plant species respond the unfavorably extremely hot and droughty stresses by transpiring surface reduction (TSR) to maintain the water and energy balance of left parts. TSR has been considered as a hydroecological factor for a long time (Orshan, 1954, 1989) and also thought as an approach of reducing radiation acceptation to maintain the energy balance of plants (Kozlowski, 1973). It can be seen in various patterns, such as leaf or branch shedding for many deciduous trees even evergreens (Addicott, 1982; Rust and Roloff, 2004) and the death of aboveground for most annuals and grasses etc. (Kozlowski, 1973; Bhat *et al.*, 1986). Some tree species trace of scale insect parasite was also found. It suggested that improper site condition made the trees sensitive to environmental changes.

The RGB analysis of leaf necrosis for these dogwood trees was same as Part two. LNAP was calculated with Equation III2, and the G/L_{leaf} and G/L_{crown} were similarly calculated by using Equation IV3 and Equation II1 respectively. To analyze the characteristics of leaf necrosis, the same leaf images for LNAP measurement were used to measure the G/L_{leaf} value of leaf sections (G/L_{ls}). Before getting RGB pixel data, the image was hand prepared by eraser of Photoshop to remove the background and objects except the objective leaf. Then leaf images were equally divided into 10 sections from base to tip. The Luminance (L) and Green (G) values for each section were read from the average histogram value of Photoshop. The G/L_{ls} value for each section was also calculated with the Equation IV3. The relative G/L (RGL, refer to Equation V3) is also consistent with logistic threshold responsive equation (refer to Equation II8) for necrotic leaves.

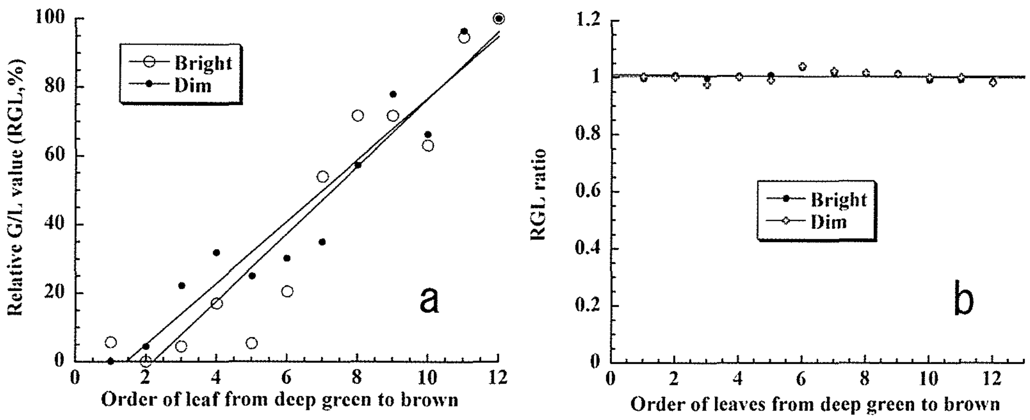


Fig. C7-1 The effect of decreasing luminance variance by relative G/L (RGL) value; 12 leaves from deep green to light brown were taken side by side into a bright image (O—O) and a dim image (●—●) with large luminance difference. One was taken under direct sunshine in field (shutter 1/1250 s) and the other was taken under dim corner in room (shutter 1.6 s). The RGL values among the leaves in one image showed no significant difference from the RGL values in another image (a). The RGL value between left half and right half of same leaf in same image tends to be near 1.0 for both images (b).

Based on the statistical comparison, 12 leaves from deep green to brown were taken into two images with great luminance difference, the RGL value among the leaves in same image appeared much similar to that from another image (Fig. C7-1a). The RGL value between left half to right half of same leaf in same image was almost near 1.0 for both images (Fig. C7-1b). Therefore, it implies that the RGL values from same image are much comparable than that of normal G/L value, which was another reason of the using of RGL values between leaf sections in this study.

The newly planted dogwood trees, transplanted from largely balled saplings, were observed to study the transplanting shock in 2008 in Yamaguchi City, Japan. Leaf necrosis and branch dieback occurred on some of them shocked by desiccation during summer period.

Leaf and branch water relation was also studied by measuring water content. Small twigs were cut from selected trees and then taken back to lab with plastic bags. The water content for single leaves or leaf sections from newly transplanted saplings and normal growing trees were measured by rapid weighing method with 1/10000 g electronic weighing balance in room. The weight of sampled leaves or leaf sections were weighed after sampling from field site without delay. After obtained the dried weight of them, the water content was calculated by reference of Equation II6.

Water contents (WC) of both leaves and branches from newly transplanted saplings were also differentially measured to establish the threshold response equation. During the study, necrotic leaves from transplantation-shocked dogwood trees were cut into seven or eight (according to the leaf size) sections in hoof-shape from proximal to distal, while the die-backed branches were cut into certain sections according to the node numbers. They were measured by rapid weighing method with 1/10000 or 1/100 g Sartorius electronic weighing balance in room. The weight of sampled leaf or branch sections was weighed after sampling from field site without delay. After obtained dry weight, the water content of them was calculated with Equation II6 to study the variant tendency of water content.

In order to check the consistency of leaf necrosis with the extreme drought event, the aridity index of ten days （AD10） was calculated by reference to the Equation I1.

7.3 Characteristics of kousa dogwood leaf necrosis and crown discoloration

After affected by dry and hot summer in 2007, the symptoms of tip and/or edge leaf necrosis appeared on many dogwood trees and made their crowns discoloration in different scale in Yamaguchi City. By RGB image analysis, it was observed that responses of the dogwood varied significantly from trees to trees and among leaves (Fig.C7-2a). The threshold responsive equation for image RGL value of different necrotic leaves (Fig.C7-2a leaf2, leaf3 and leaf4) presented distinct inverse logistic curves (Fig.C7-2b, leaf2, leaf3 and leaf4). It indicated that the injury did not evenly distributed on the leaves and the necrotic area bound from distal to the proximal, which is typical necrotic characters. Carefully observed the necrotic leaf, apparent barrier existed on the leaf surface and the barrier lines also arranged from distal to proximal catastrophically (Refer to Fig.C7-2a). The shape of responsive curve varied from inverse sigmoid shape to rectangular hyperbola shape as the necrosis became severe (Refer to Fig.C7-2c, C7-2d). Meanwhile the leaf area was reduced through necrosing the part outside the barrier.

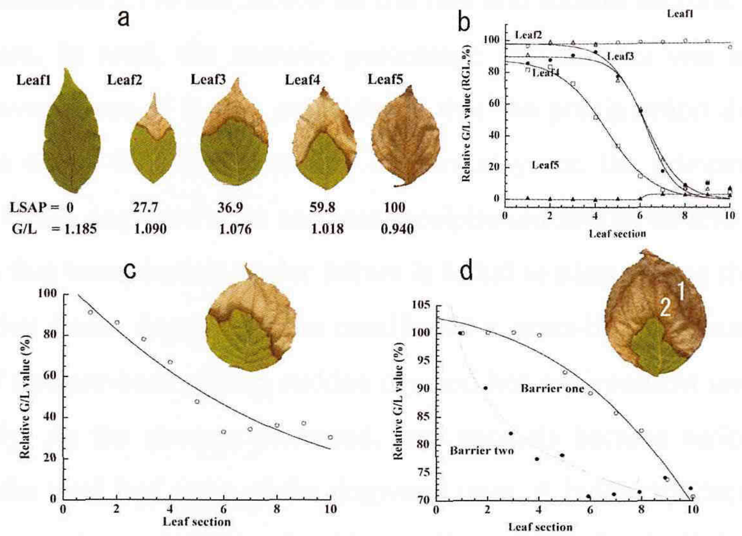


Fig.C7-2 Variant characteristics of kousa dogwood leaf necrosis from proximal to distal and barriers; C7-2a presents five leaves from different trees with different leaf necrotic area percentage (LNAP), LNAP respectively are 0,27.7, 36.9, 59.8 and 100. Image Green/Luminance (G/L) value ranges from maximum 1.185 to minimum 0.940; C7-2b was the responsive curves of relative G/L (RGL) for these leaves, with the characteristics of typical logistic curves for necrotic leaves (Leaf2, Leaf3 and Leaf4), and straight lines for overall green and entire brown leaf (Leaf1 and Leaf5); C7-2c showed a leaf with one barrier and its RGL threshold responsive curve; C7-2d presents a leaf with two barriers (1 and 2) constructed in May and August 2007, and related threshold responsive curve of RGL value.

According to the color analysis of necrotic part, only one major barrier can be observed on most of leaves (Fig.C7-2c). For seriously injured leaves, two (Fig.C7-2d) even three can be seen. It indicated that the barrier withdraw back from distal to proximal gradually until successfully control the necrosis and left a series of unsuccessful defense traces (Fig.C7-2a, Leaf3, Leaf4). The threshold responsive curves for both non-necrotic leaf and entirely necrotic leaf (Fig.C7-2a Leaf1, Leaf5) appeared a tendency of straight lines slightly slanted and laid on top and bottom of the coordinate separately (Fig.C7-2b). It should be the characteristics of the leaves without necrosis and entirely necrosed, separately.

Among the leaves appeared multi defense trace, most of them contained two belts differently colored and separated by two barriers (Fig.C7-2d). It indicated two necrosed periods occurred from leaf sprouting and showed different responsive function curves. Despite the characteristic of the barrier and leaf necrosed area varied significantly among leaves, the total living area of leaves commonly was reduced. By calculating the image LNAP, it presented 2.7% and 38.6% for the first and second necrotic phase for all of the sampled trees. In total, the necrotic percentage of leaf area was about 40% of total sampled leaves. Even if it was coincidence that the precipitation during the first nine months was about 40% less than that of normal years, the relevant between the leaf necrosis of kousa dogwood trees and less precipitation should be less doubt. It supported the opinion that transpiration cooler failure is lethal to plant during the summer drought. It is clear that kousa dogwood trees manifested a grass-like response to it and showed serious leaf necrose-back during sudden dry and hot environment under the insufficient water supply. As the stresses increased, leaf necrosis became serious and resulted in decreasing the total leaf areas of the dogwood trees. It indirectly decreased the water or precipitation requirement and received less radiant energy for the living part of entire tree. The green part of necrotic leaves maintained active status and as the environment became favorable they restored vigorous immediately. By observation, the green part of some necrotic leaves of Japanese blue oak hit by T0613 maintained normal function even after three years in the same city.

During the summer drought period in 2007, 60 differently discolored individual tree crowns of kousa dogwood had been graphed to study the response of these trees to the meteorological extreme event. From each tree, ten typical leaves had been sampled to study the relation of discoloration between sampled leaves and crowns, and the relation between the leaf necrotic area percentage (LNAP) and the discoloration status of the crowns. Although sampling error may be greater, the relation between $LNAP_{leaf}$ and G/L_{crown} (Fig.C7-3b), G/L_{crown} and G/L_{leaf} (Fig.C7-3a), and G/L_{leaf} and $LNAP_{leaf}$ (Fig.C7-3c) has been obtained with significant linear relationship. Among them, G/L_{leaf} and $LNAP_{leaf}$ for same leaves obtained relative higher correlations since there is no significant sampling error. The correlation between $LNAP_{leaf}$ and G/L_{crown}, and G/L_{crown} and G/L_{leaf} were relatively lower because only ten leaves had been sampled each tree.

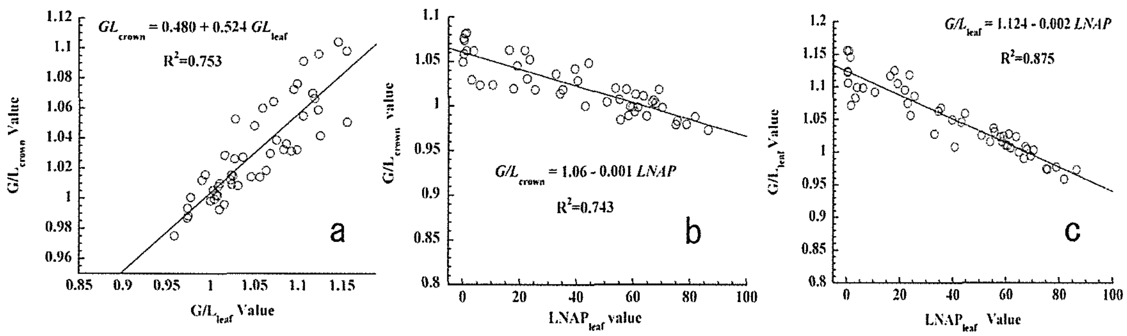


Fig.C7-3 The relation between leaf necrotic area percentage ($LNAP_{leaf}$) and G/L value of crowns (G/L_{crown}) (b, n=48), G/L_{crown} and G/L value of leaves (G/L_{leaf}) (a, n=47), and G/L_{leaf} and $LNAP_{leaf}$(c, n=48).

This suggests that the leaf necrosis status of dogwood can be estimated by RGB image analysis not only with isolated leaves, but also with profiles of tree crown *in situ* since the significant contrast between necrotic part and living part of leaves. This kind of difference can be directly responded into the RGB images. The accuracy of measurement should be increased by improving the instrument, technique and by adding sampling numbers etc. It is one kind of feedback information to respond the meteorological extreme events in Yamaguchi during the summer of 2007. Therefore they not only can be used to estimate the necrotic status of kousa dogwood trees but also may be used to evaluate the injury severity of landscape trees hit by the meteorological extreme events.

By observation, leaf necrosis appeared on dogwood crown during the extremely hot and droughty summer days significantly differ from that induced by T0613. The striking characteristic is the even distribution on the crown and no significant asymmetrical difference between windward and leeward (Fig.C9-10). During the hot and droughty event in 2007, some ginkgo trees near coastal area were also observed leaf necrosis on overall crowns. Similarly no asymmetrical crown discoloration had been found like the ones hit by T0613. This kind of symptoms are also seen and photographed on a large numbers of ginkgo trees newly planted along the street of Jinan, China, in summer of 2007.

7.4 Leaf necrosis of transplantation-shocked kousa dogwood

Transplanting shock usually appeared in planting process of many tree species during the meteorological extreme event of prolonged no rain and sudden temperature ascent, because of the imperfect root system of new transplanted trees and excessive trans-evaporation of water (Kozlowski and Davies, 1975). Leaf necrosis and branch dieback even death of some newly transplanted kousa dogwood trees in Yamaguchi during the summer in 2008 was one case of them. By observation, leaf necrosis of transplanted trees often occurred at a period of AD10 peak and HD10 trough (Fig.C7-4).

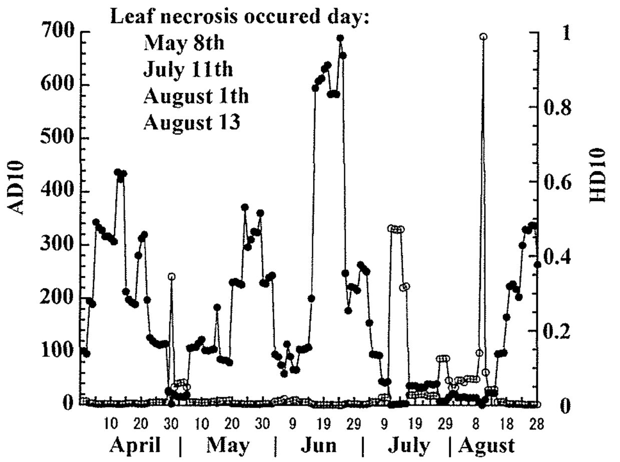


Fig.C7-4 The ten days aridity index (AD10, o–o) and humidity index (HD10, •–•) from April 1 to August 31, 2008 in Yamaguchi; at the peak of AD10, May 8th, July 11th, August first and August 13th, leaf necrosis event occurred on some transplanted kousa dogwood trees; branch dieback emerged on the transplanted trees with serious leaf necrosis at the end of growing season.

In spite of the persistence of these peak periods differ from each other, they all occurred in a prolonged no rain and temperature increasing process. During the highest peak period of AD10 in August (from Jul.22 to Aug.14), 2008, which was the hottest days in a year, only 11mm rainfall was recorded at the Yamaguchi Observatory. The maximum daily temperature of all days during this period maintained higher than 33 °C. High temperature also tended to increase transpiration through its effect on saturation water vapor density (Fitter and Hay, 2002) and raise the water requirement of these trees.

After transplantation, the successful survival of trees mostly depends on rapidly establishing the perfect root system. If not, the newly sprouted leaves may suddenly dried out or necrosis under sudden drought environment for the reason of seriously water imbalance. Sufficient precipitation, 116% of the normal, during the first half year in 2008 caused the normal dogwood trees appearing different responses from that in 2007. Almost no leaf necrotic symptoms occurred during early summer days in 2008 on the same dogwood trees observed in 2007 (Fig.C7-5a-1). Only some newly complementarily planted trees showed the gradually leaf necrosis symptoms on May 8 during the sudden increasing of the temperature and persistent no rain weather (Fig.C7-5a-2, C7-5a-3). It is observed that the leaves from normal growing trees appeared a level responsive curve of RGL value in Fig.C7-5b-1; while under the stress of transplanting shock the leaves desiccated from tip to base and the appearance became unevenly from distal to proximal (Fig.C7-5a-2). A black shade layer, as Whitehead described (1963), between dried and non-dried area was observed and their responsive curve slanted at tail end (C7-5b-2). In this situation, although the leaf tip had dried out, the color of it still remain green, which seems that water loss was too fast to change the chlorophyll. Three days late, the leaf tips became deep gray and a typical RGL responsive function of inverse logistical curve or necrotic symptom occurred (Fig.C7-5b-3). During the shock, a lot of seriously hit leaves dried out after several days temperature increasing and no rain weather at the beginning of the May. Soon after, the coming of the Japanese rainy season and about 350mm monthly precipitation in June promoted the new sprouting of small leaflets with long and narrow tips on the tree. It is calculated by image pixel method that the leaf area of the transplantation-shocked tree was only 38.6% of those before the shock. After the end of the Japanese rainy season in the beginning of July and about ten days persistent drought and hot weather, the remained leaves and small new sprouted leaves necrosed once again (Fig.C7-5b-4). Some of them also presented two barriers on leaflet after two periods of shock (Fig.C7-5b-5, A, B). The RGL responsive lines showed a similar tendency as the first shock during May.

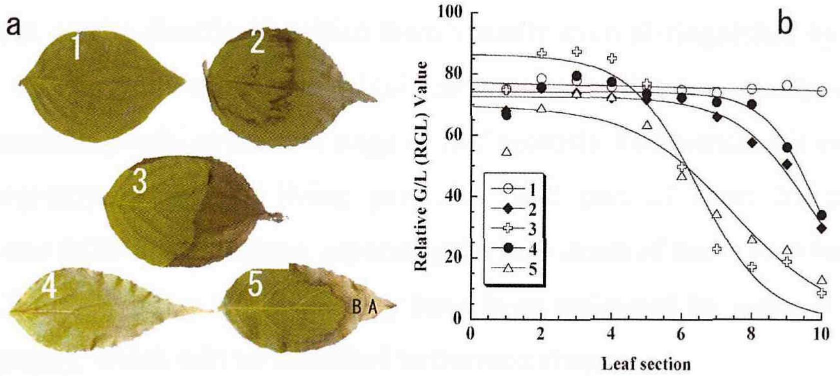


Fig.C7-5 Different leaf necrosis of kousa dogwood during transplanting shock period in 2008; the characteristics of normal leaf (a1), initial necrotic leaf (a2, a4), post necrotic leaf (a3), single necrotic leaf (a4) and dual necrotic leaf (a5). Their threshold responsive curves of relative G/R (RGL) value of normal leaf (b1), initial necrotic leaf (b2), post necrotic leaf (b3), single necrotic leaf (b4) and dual necrotic leaf (b5) with two necrotic parts (A and B). The responsive threshold curves were made by the average values at each point.

However, the leaf necrosis in August 2007 (Fig.C7-2) appeared a significant difference to that in early summer in 2008 by contrast. In summer of 2008, one month persistent no rain and high temperature from July 14 to August 14, the hottest days in a year, not only induce the transplanted dogwood trees to leaf necrosis again, but also lead partial of the normal dogwood trees to leaf necrosis from distal to proximal. The symptoms of leaf necrosis appeared significantly similar to that occurred in the summer of 2007, which also showed light brown necrotic areas. By calculation, the LNAP in 2008 was only 13.2% of the entire leaves and less than 1/3 of that in 2007 for the reason of sufficient rainfall during the first half year. The related precipitation proportion value to normal year of both first nine month and summer three month (7,8,9) in 2008 were respectively 91% and 67%.

The premature response of kousa dogwood to extremely hot and dry event presented leaf gradually necrosed or dried from distal to proximal, which looks like the dieback of branches. In fact, the serious leaf necrosis in overall crown of trees and shrubs often trigger dieback of branches or twigs. The less supplement water supply to the transplanted trees triggered the branch dieback of them in 2008. As above mentioned, the visual symptoms from this kind of acute procedure commonly were partial leaves and branches dried out and can be divided into living (green) part and dead (dried) part. Although the morphologic difference between living part and dead part of leaves was significant that can be directly identified them visually even distinguished by G/L value (Fig.C7-6a, C7-6b) with statistically significant variance, it was usually easy to be neglected morphologically at the first stage of leaf necrosis. For branches it was not easy to morphologically distinguish living part and dead part of them by both visual observation and RGB image indices, especially the new death of the branch tip at leafless stage (Fig.C7-6c, C7-6d). However, they have been estimated by spectral reflectance and thermography, which will be described in the next chapter.

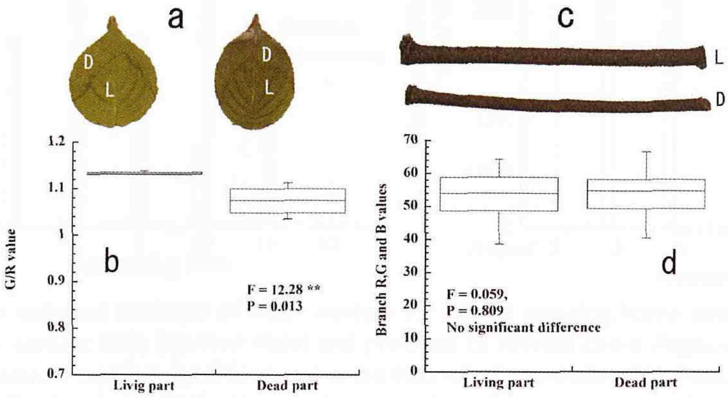


Fig.C7-6 The RGB imaged morphology of the first stage of leaf necrosis (a) and branch dieback (c), and the statistic results of red (R), green (G) and blue (B) values (b, d) of living part (L) and dead part (D) of transplantation-shocked dogwood. The boxplots were constructed by using KaleidaGraph3.6.1.

7.5 Water relation of kousa dogwood during leaf necrosis

It is measured different water content between green part and non-green part of necrosing leaves. It seems that there existed a great resistance between green part and dried part at the barrier position to prevent the further water, nutrient and other resources loss and intrusion of pathogens. This kind of necrosis generally originated from the parts of the leaf that is farthest from the main vascular channel (Yapp, 1912; Günthardt-Goerg and Vollenweider, 2007). During the process of serious drought, the shrinkage of the distal tissue facilitates their separation from proximal tissue (Addicott, 1973).

Leaf necrosis of water stressed kousa dogwood trees seem to extend a prolonged process. During this process, leaves usually appeared different degreed of scrolls for a long time and maintain lower water content than the leaves on normal growing trees

(Fig.C7-7a). Although, there was a tendency of lower distal and proximal ratio of water content as the hot and droughty conditions persisted (Fig.C7-7b), the value of this ratio remained above 1.0 (Fig.C7-7b) until a few leaves began to show significant leaf necrosis on a tree during a sudden hot and dry weather (Fig.C7-8a).

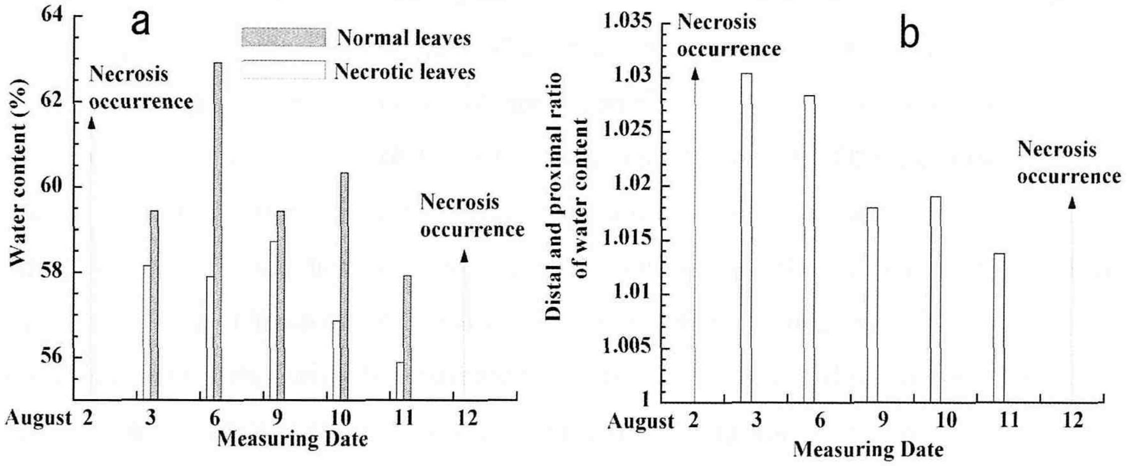


Fig.C7-7 The variation tendency of water content for normal growing leaves and scrolled leaves (C7-7a) and the water content ratio between distal and proximal of normal kousa dogwood trees during seriously hot and dry summer weather conditions and at the interval of two times of leaf necrosis occurrence (C7-7b). In C7-7b the distal and proximal ratio was the proportion of the water content between distal and proximal part of the leaves that were divided into three parts, distal, middle and proximal. The data in C7-7b was the average value from five trees and ten leaves for each tree.

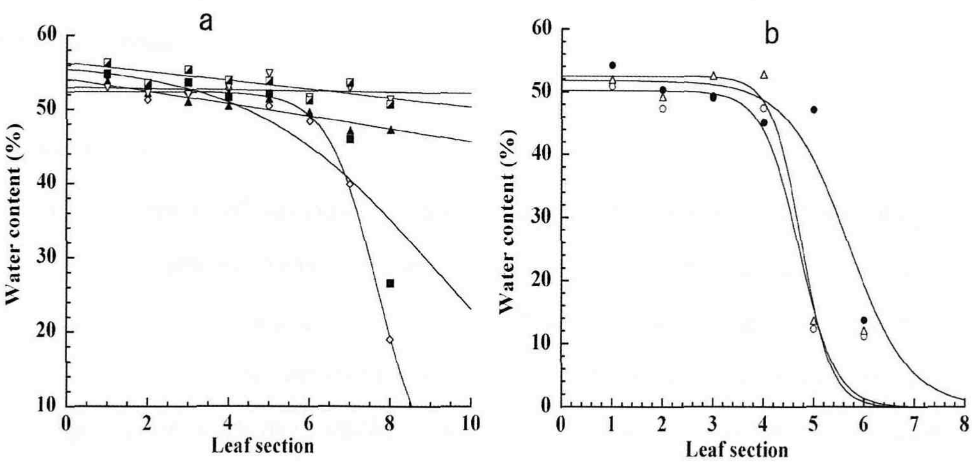


Fig.C7-8 The variation tendency of water content at the threshold status of leaf necrosis during the persistent dry and hot summer days in August 2008. It showed the water content for the leaves before the serious necrosis (C7-8a), in which it contained early stage of necrotic leaves (◊–◊, ■–■), seriously wilted leaf (▲—▲) and wilted leaves (▽—▽, ◪—◪); after the significant necrosis occurred as well as the significant barrier appeared (C7-8b), which contained the leaves with dual barriers (○–○, Δ–Δ) and single barrier (●–●).

At this period of time, some of the leaves appeared evident tendency of water content variance between leaf tip and base with a regression line of water content slightly down slanted from proximal to distal (Fig.C7-8a). But the logistic threshold response curve (Fig.C7-8b) could be seen only on the leaves seriously necrotic symptom occurred.

As mentioned in Chapter 2, kousa dogwood is characterized by higher leaf water loss speed than many other tree species, deciduous or evergreens, in detached condition. However, proper interconnection of leaf venation is sufficient to counteract this shortcoming. It is observed that the main vein cutting from leaf base cannot suffice to result in leaf water imbalance of attached kousa dogwood leaves for months. The local injury to the leaf vascular system does not necessarily cause the water transport obstacle (Kramer, 1983). Therefore, the whole sectional barrier is necessary to interrupt the persistent water loss during the extreme water imbalance. According to observation, the defense barrier usually appeared during night, which suggests it is a response to water stress that cannot be completed without adequate water (Kozlowski, 1976). Some transplanted dogwood trees did not appeared the barrier until a rainy day. In some situations, not only one barrier but also two even more unsuccessful defense traces can be seen on the same leaf. It suggested that under the serious tension of enlarged water gradient leaves responded it by abandon partial tissue or organ to protect them from further water loss.

7.6 Conclusion

Under the impact of serious hot and droughty summer weather events in 2007 and 2008, the apparent responses were the leaf necrosis and branch dieback of kousa dogwood trees, especially the trees during transplanting shock. Apparent barrier lines were observed on leaves and the branch dieback of kousa dogwood almost always ended at the node position. Being synchronous with the aridity peak period suggested that the dogwood leaf necrosis is induced by the temperature ascent under the condition of severe water stress during summer days in 2007 and 2008 in Yamaguchi City. The threshold responsive equation of both necrotic leaves and die-backed branches showed a typical "switch-off" logistic curve. It is this kind of "switch-off" that indicated the protective response characteristic of kousa dogwood trees was also saving the main body at expense of the terminal parts. Although there is an indication that it has something to do with their hydraulic architecture, the detail of its mechanism still need to be further studied. However, it is also this “switch-off” that made them can be detected by using the image and spectral analysis.

Chapter 8 Detecting Leaf Necrosis and Branch Dieback of Dogwood with Spectral Reflectance and Thermography

8.1 Introduction

The emergency of thermography technique made the estimation of plant surface canopy temperature easy and fast and has been used in estimation of plant water content (Grant *et al.*, 2006; Jones, 1999) and water stress (Nakahara and Inoue, 1997; Luquet *et al.*, 2003) etc. There is potential to detect the response under the extreme water stress situation such as leaf necrotic status, especially for pre-symptomic checks (Chaerle *et al.* 1999; Chaerle and Van Der Straeten, 2000) of branch dieback during leafless status of trees. However, some limitations in its measurement (Chaerles *et al.*, 1999), especially in the field, made the noises reduction become the key of imaging temperature measurement. As the manufacturers continually reform their products, researchers too increased their detecting technique by establishing various systems of both software and hardware to maintain stable measuring environment. In the field measurement, the sunlit and shady objects showed large variation in imaging temperature. Some researchers like to detect the imaging temperature at sunlit environment and the others prefer the shady condition (Jones and Leinonen, 2003). Nilsson (1995) manifested that during the process of temperature decreasing with a gust of wind, the rate of recovery varied with the severity of vascular disease. It implied that the dynamics of the imaging temperature was more important for responding to the stress or disease status of plants. Variation of temperature between non-infected and infected leaves even reached 15 °C in the condition of fan blowing wind (Nilsson, 1995). In fact, the active heating technique during thermograph taking procedure has ever been used in some fields (Chaerle and Van Der Straeten, 2000; Yang *et al.*, 2007).

In order to avoid and reduce background noise, the detecting process was mainly conducted at indoor environment in this study. Less difference of indoor-imaging-temperature among various leaves and branches, the background noise and effect of surround temperature and so on made the measurement more complex. It needs special techniques to make a meaningful measurement and obtain comparable data. In the study, necrotic leaves and die-backed branches were heated under incandescent lamp or direct indoor window sunshine to detect the changing procedure of temperature. It was in the process of temperature ascent and descent the amplified temperature variation between plant living part and dead part was found. By monitoring the process of temperature ascent and descent, the instant maximum temperature variation was grasped and used to detect the necrotic part and living part of leaves and branches. It was observed that not only existed amplified variation of imaging temperature but also there was a different distribution curve of response from living part and dead part of transplantation-shocked kousa dogwood trees due to the different specific and latent heat value of the plant parts with varied water content. The imaging temperature noise was minimized under the enlarged temperature range and directly resulted in clearer of the thermo images. Combined with the spectral analysis in near infrared range, the thermography was used in detect the leaf necrosis and branch dieback of kousa dogwood.

8.2 Materials and methods

It was also observed that the spectral reflectance of necrotic part of leaves in both near infrared and thermo infrared ranges significantly differs from that of living part. They were estimated by using a radiometer and a thermo infrared camera. Meanwhile, the branch dieback had also been detected by amplified difference of thermography. The segregation of the hydraulic architecture of kousa dogwood had been clearly observed in the study

A NEC TH7100 thermal infrared (8-14 μm) camera, with the temperature measuring range from –20 to 100 degree centigrade and minimum sensible temperature 0.06 ℃, was mounted on a tripod or hand-held about 50 cm above the objective leaves or branches and then focused to clear. Single thermal infrared images were continually taken after irradiated with 40W incandescent lamp about 10 second at 2-3 cm above the objective leaves, or directly irradiated the objective branches by sunshine, with evenly plastic background. The outdoor sunshine heating and shading process was respectively exposing the attached leaves sheltered by graph taker to sunshine and then shelter them again when their temperature did not increase. The indoor sunshine heating and shading were respectively moving the tray with detached leaves or branches into and out of window sunshine. To obtain the comparable data the living part and dead part from same leaf or branch were always graphed into same thermo image. Images that most respond the difference between the necrotic part and green part of leaves and between living and dead branch sections were selected to analyze the temperature difference of them. Imaging temperatures were read from the software of Viewer version 2.0 equipped with the camera. The relative temperature (T_R) values of thermo image for each branch section were calculated by using Equation VIII1.

$$T_{Ri} = {}^{100\times(T_i - T_{\min})}\!\big/\!{}_{(T_{\max} - T_{\min})} \qquad (VIII1)$$

In which, T_{Ri} is the T_R value for i section, i=1,2... 10. T_{min} is the minimum temperature (T) value of all sections and T_{max} is the maximum T value of all sections. The logistic threshold responsive curve was also calculated by reference to Equation II8.

In the study, spectral reflectance for each scale of necrotic leaves was measured with same method as in Chapter 3 and calculated the NDVI value as Equation III1.

8.3 Kousa dogwood leaf necrosis and branch dieback detected with thermography

8.3.1 Amplified variation of imaging temperature for leaves and branches

During the study, the thermo-images were taken for both attached and detached leaves at outdoor and indoor sunshine environment. The different results between attached and detached measurement was found and it should result from the difference of water status between them.

Although the variation was larger between sunlit and shade leaves, it was observed that at day time the attached leaves indicated higher leaf temperature at necrotic part than living part during both procedure of sunshine heating and shade cooling (Fig.C8-1a). It seems the uninterrupted cooling underground water maintained living part colder than dead part separated by a barrier. The result from Jones and Leinonen (2003) showed similar tendency, which only in occasional situations appeared the temperatures that living leaves exceeded the dried model. For the detached leaves of this study, the necrotic part reached higher temperature than living part during the sunlit heating process, while the temperature of necrotic part soon became lower than that of living part during the shade cooling process (Fig.C8-1b). It implied that at the detached or no continued cooling water supply conditions, leaf temperature changed naturally so that the necrotic part increased and decreased its temperature faster than that of living part because of less water content. This kind of effect of transpiration on leaf temperature had ever described by Lange *et al.* (1976) in their comparison between normal leaf and severed leaf.

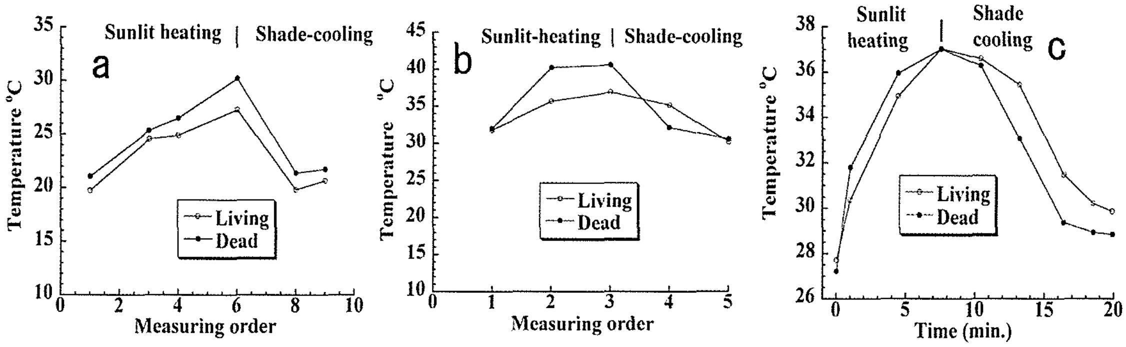


Fig.C8-1 Image temperature of dogwood leaves and branches of living part (○—○) and dead part (●—●); It include the attached (a, JST930; 10/17/2008) and detached (b, 10/18/2008) dogwood leaves during the procedure of sunshine heating and shade cooling; it showed different variation tendency of the necrotic part and living part of attached leaves and detached leaves. The "measuring order" in (a) and (b) is the continually mechanical taking order of thermograph. The imaging temperature of dogwood branches (c, 10/10/2008) appeared a gentler tendency than leaves. It is clear that both ascent and descent process of the imaging temperature for dead part of detached branch or leaf was faster than that of living part at both heating and cooling process.

Since the difference of water content, it was also observed the significantly amplified variation of imaging temperature between living part and dead part of detached branches during the heating and cooling process in lab by window sunshine (Fig.C8-1c). The variation tendency of branches was more significantly obtained since branches changes their temperature more gently than leaves. From Figure C8-1c, it could be seen that the maximum difference of imaging temperature comes from the cooling process, which appears the instant imaging temperature of living part higher than that of dead part of branches. The difference seems originated from the variance of specific heat between the necrotic part and living part. It made the identification of necrotic part from living part become possible.

8.3.2 Detecting necrotic leaves and die-backed branches by thermo imaging

temperature

The living part and dead part of dogwood leaves could be distinguished by both RGB images and thermo-images. The combination of them may be more effective to be used into early detecting stressed plant (Jones and Leinonen, 2003; Leinonen and Jones, 2004), especially to detect the leaf necrosis caused by the variance of water content. Thermo-image may be more proper to be used at the environment of unsuitable for obtaining RGB photo image. The precondition for detecting the leaf necrosis and branch dieback was clearer thermo infrared images. In this study, background noises were reduced artificially by using a plastic tray and provided an even environment for measurement. By amplified variation, the scale of imaging temperature can range from 1 to 70 degree. In the cooling process irradiated by incandescent light mentioned above, the less noise, clear thermo-images were obtained with the area of higher imaging temperature similar to the living part in RGB image (Fig.C8-2a). By measurement, the imaging temperature at necrotic part was almost always lower than that on living part (Fig.C8-2c) during shading cooling procedure, even if there was variation among detached leaves. If attention is taken, two necrotic parts (Fig. C8-2a, noted with 1 and 2) can be seen, the first one lied at leaf tip with brown color and the second, next the first necrotic part with light green color, hard to be identified from RGB image (right one in Fig.C8-2a). However, from thermo image (left one in Fig.C8-2a), the image temperature of second necrotic part seems more similar to the first necrotic part, in a great part, due to the similar water content. Therefore, it is also showed a potential to detect the leaf necrosis with amplified image temperature during transplanting shock.

From Fig.C8-2b, although there is almost no visual difference of living part and dead part of branch in the RGB image, the big difference of image temperature between two parts beside branch node could be seen. The branch node was also significantly different from them, which usually appeared a strong area preventing the dieback of kousa dogwood branches from further proceeding. Among the thermo images obtained at the conditions of natural room temperature, in heating process and cooling process, only the image from cooling process of the kousa dogwood branches showed a typical threshold response curve in the measurement (Fig.C8-2d). It also appeared "Switch-off" threshold response curve and its inflection point was near the node position. Therefore, the cooling process of kousa dogwood branch section may be the proper status to be used to get the maximum difference of imaging temperature.

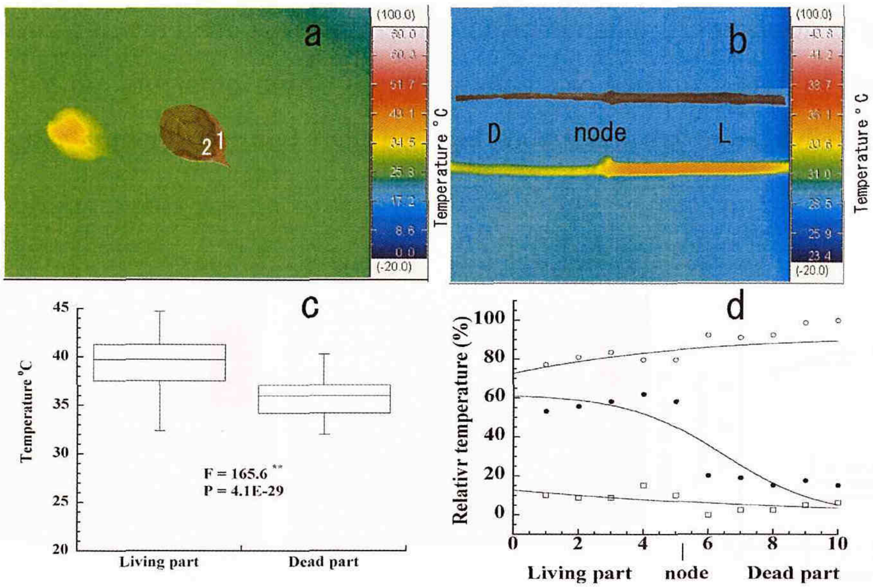


Fig.C8-2 Diagnosing of leaf necrosis of kousa dogwood and branch dieback; RGB image of leaf necrosis at right of Fig.C8-2a and its thermo-image at left of Fig.C8-2a during the cooling process heating by incandescent light; RGB image of branch dieback at up of Fig.C8-2b and its thermo-image at down of Fig.C8-2b during the shade cooling process of sunshine; and the statistical results of imaging-temperature for leaf necrosis (c) and branch dieback (d). Branch dead part (D) and living part (L) was divided by branch node (node). It is clear that the changing tendency of imaging temperature at the condition of natural room temperature (□—□), in heating process (○—○) and cooling process (●—●) was different each other. It suggests that at the cooling process the imaging temperature may obtain the maximum difference value. The number "1" and "2" in the RGB image of dogwood leaf (C8-2a-right) denote the first necrotic part and second necrotic part, respectively.

8.3.3 Detecting die-backed branches by cutting end effect

Transpiring cooling process is an important mechanism of plant to lower the body temperature and maintains the energy balance (Clements, 1934; Gates, 1968; Lange *et al.*, 1976). Thermography provides an advanced method responding the leaf temperature variations. Thermo-images of transplanting shocked dogwood twig sections taken after cutting at each node place manifested a significant phenomenon of lower temperature at the cutting end for living branches (Fig.C8-3b, Fig.C8-3a right five sticks) and twigs with higher water content. The dead part of the branches (Fig.C8-3a, left two sticks) did not show this kind of evaporation cooling effect. It is interesting that the node adjacent to the dead part significantly differs from the other nodes in living part. Its temperature is higher than those in the living part and lower than those in dead part (Fig.C8-3a, the stick with "?"). It is clear that a transition part between dead and living part is inevitable and the water content there also showed the characteristics of transition (Fig. C8-3c). It indicates that the low temperature at cutting ends also become a sign of the living part or high water content part and may be used to discern the branch dieback of kousa dogwood trees.

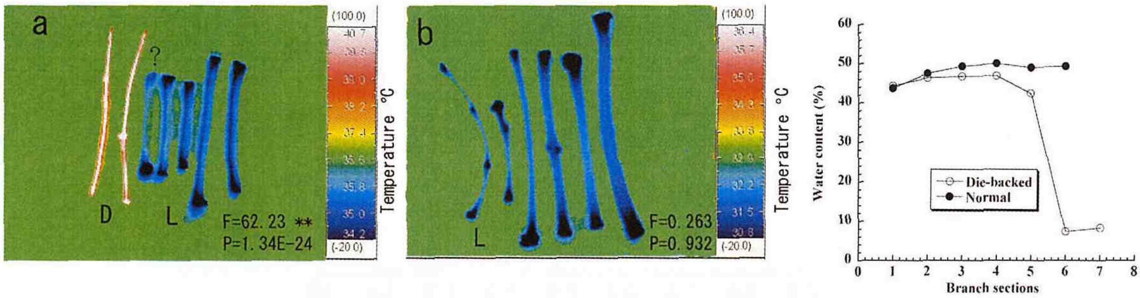


Fig.C8-3 Transpiring cooling effect at branch cutting ends; the living branch (b), die-backed branch (a) during the heating process of sunshine; The living part (L) and dead part (D) appeared different characteristics at cutting ends and nodes. In Fig.C8-3a, a "?" is near the node that adjacent to the dead part of the branch. The water content of normal branch (c, ●—●) and die-backed branch (c, ○—○) showed dissimilar curves from base to tip.

8. 4 Kousa dogwood leaf necrosis detected with spectral reflectance method

As mentioned above, the threshold response characteristics of both color and water content of leaves made the foundation of distinguished them from normal leaves. The spectral reflectance at red edge of visible and near infrared range was usually used to detecting the seasonal variation of vegetation with multi-spectrum-meter. In this study, the leaf necrosis of dogwood trees hit by meteorological extreme event was estimated with a handhold OKI MS720 radiometer in lab. The NDVI values calculated by spectral reflectance data showed a significant inverse relation to the LNAP (Fig.C8-4) that used the same wavelength of 755 and 679nm as the measurement of ginkgo tree in Chapter 3. The result was also similar to that of ginkgo leaves surprisingly.

On the other hand, the significant positive relation between NDVI value and G/L_{leaf} value indicates that spectral reflectance value at red edge can also be used to respond the necrotic leaves and normal green leaves as the image analysis (Fig.C8-5). It was the feedback of the response to meteorological extreme events from the dogwood trees.

From this kind of relations, it is less surprise that the spectral reflectance or NDVI value of deciduous vegetation were often used to detecting the seasonal regeneration of them.

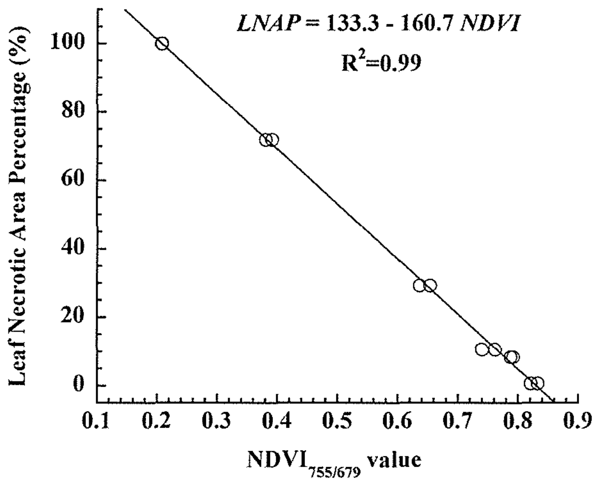


Fig.C8-4 An inverse relation curve between leaf necrotic area percentage (LNAP) and $NDVI_{755/679}$ values. NDVI value was measured with mass leaves filled in a tray and LNAP was the average value of all leaves in the tray measured with image analysis method.

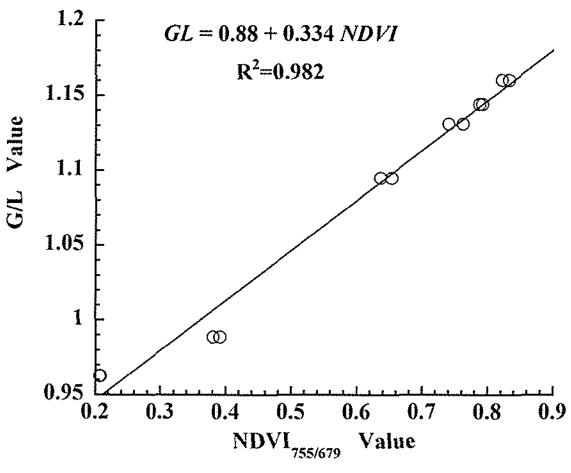


Fig.C8-5 A positive relation curve between G/L value of sampled leaves and $NDVI_{755/679}$ values. NDVI value was also measured with mass leaves filled in a tray and G/R value was the average value of all leaves in the tray measured with image analysis method.

8.5 Conclusion

Leaf necrosis of kousa dogwood can be evaluated by spectral reflectance method and by the thermography. This characteristic has been clearly determined by the amplified image temperatures during the sunlit heating or shade cooling process. It seems being consistent with the changing tendency of water status in them. It is evident that the difference of imaging temperature comes from the variation of the water content of living part and necrotic part of both leaves and branches. The energy capacity and trans-evaporation of water from living part of leaves and branches lead to lower imaging temperature of them in the temperature ascent process. It also becomes an indirect case of effectiveness of transpiring cooler of plants. It can be deduced that it was at the situations of transpiration failure in 2008 that the leaf necrosis and branch dieback of transplanted dogwood trees in Yamaguchi occurred. The meteorological extreme events, especially the persistent no rain accompanying with high temperature, can be considered as the trigger of leaf necrosis and branch dieback of these transplanted kousa dogwood trees under insufficient water supply. During the extreme water imbalance, it is for saving themselves from the lethal damages that separate partial of the tissues or organs from main architecture. The result of this study indicates that the separation can be identified by amplified variation of imaging temperature, especially for the woody plant like kousa dogwood.

General Discussion and Conclusion

By summarizing above measurement, evaluation and analysis, the striking characters of symptoms appeared on landscape trees in Yamaguchi can be described as species specific, temporal delay, asymmetry, heterogeneity and terminal first and so on hit by both metrological extreme events. Considering the relative evenly affected properties of meteorological factors, it can be deduced that the symptoms appeared on landscape trees came from the integration between the effect of these meteorological extreme events and the responses from them. As mentioned above, landscape trees respond the meteorological extreme events in various aspects, such as mechanical, physical, physiological, chemical and so on. It also manifests diverse symptoms of injury that is outlined into Fig. C9-1.

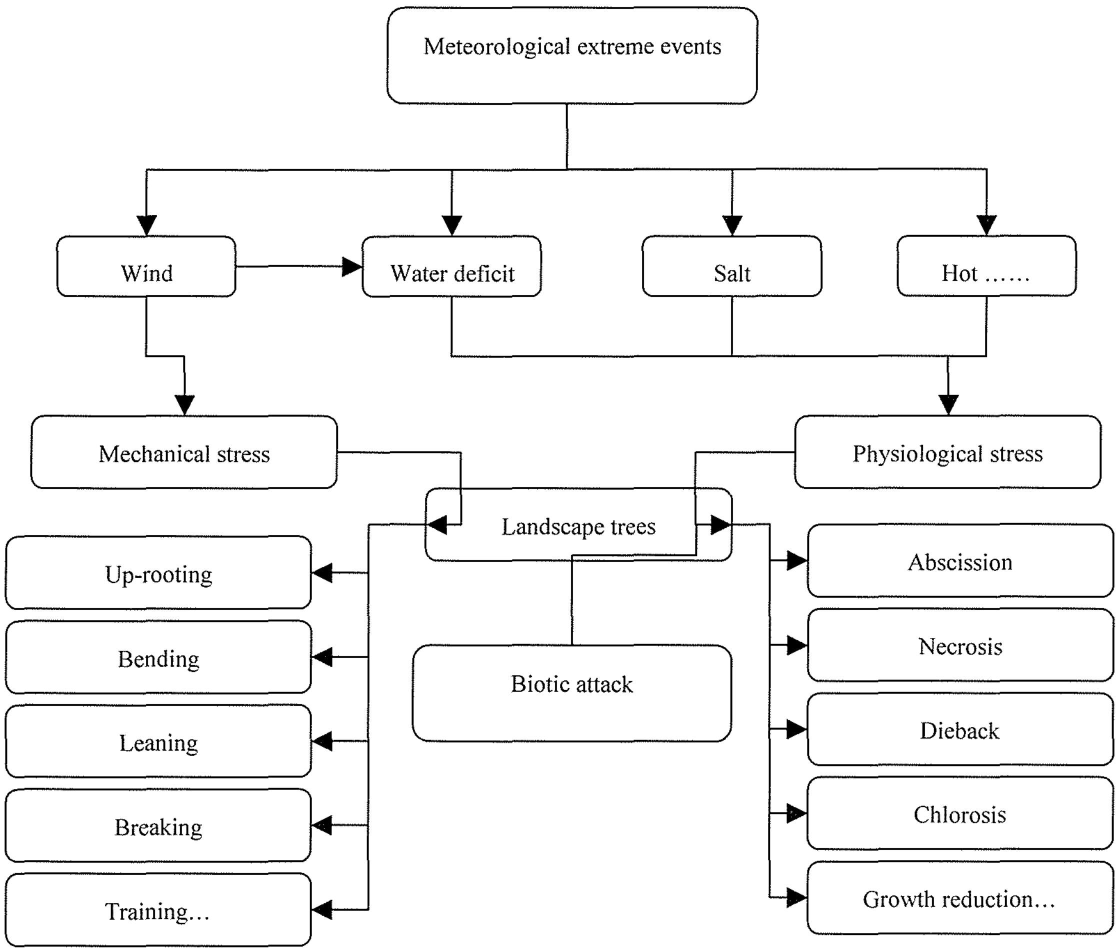


Fig. C9-1 Sketch graph of the extremely environmental impacts and responses from landscape trees. In the graph, only four main environmental factors concerned meteorological extreme events were listed since the space limitation.

Among the above mentioned major factors concerned the meteorological extreme events, the salt stress caused by the salt spray in the coastal area may be the lethal element to many landscape trees, since there are a huge numbers of reports about salt spray damage to the plants including field and indoor experiments (Boyce, 1954; Oosting, 1945; Griffiths and Orians, 2003). However, there is a sharp decline of the airborne salt particles deposited from coast to inland (Malloch, 1997; Rossknecht *et al.*, 1973; Edwards and Claxton, 1964). Combined the results from Boyce (1954), Fujiwara and Umejima (1962), Molloch (1972), Oosting and Bilings (1942), Yaalon and Lomas (1970), Malloch (1997) showed the salt deposition declining from seacoast to inland by a manner of exponential function (Fig C9-2a). Half content of salt appeared at the distance of 100 m from coastline. At the sites of 5 km and 10 km from coastline, the deposited salt accounted for 5% and 2% of that near coastline. It seems consistent with the ginkgo branch dieback after hit by T0613 in this study (Fig.C2-9). The multi analysis of ginkgo crown defoliation and discoloration also clustered the ginkgo trees in the area with high salt spray into serious damaged group (Fig. C6-8). However, there are also some injury facts that cannot be explained by the deposited salt on them. As mentioned above, it is also merged with other meteorological factors (Fig. C3-9). It is a pity I missed the chance to get the salt deposition data on landscape trees hit by T0613.

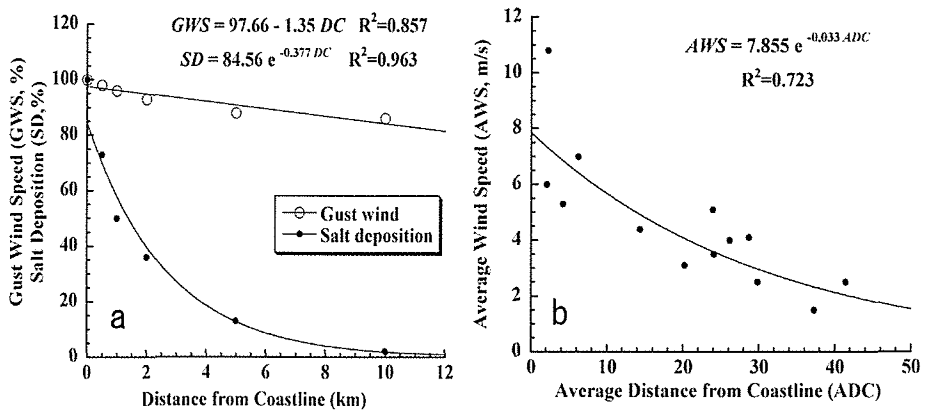


Fig. C9-2 Relationship between gust wind speed (GWS) and distance from coastline (DC) (a, O—O), and between salt deposition (SD) and DC (a, ●—●). The data of salt deposition is cited from Malloch (1997) and the gust wind speed is quoted from Takahashi (1968). The graph-a was the combination of their results. In Yamaguchi Prefecture, the average wind speed during T0613's hit showed similar relation (b) to average distance from AMeDAS stations to the coastlines (ADC) of west, southwest, south and southeast. It is calculated with the following equation $ADC = \frac{west/2 + southwest + south + southeast}{4}$. Where, west/2 was used for the reason that the average width of the west and east is about 2.3 times more than that of south and north in Yamaguchi Prefecture.

In fact, the response from landscape trees is usually to the combination of a series of external environment factors that cannot easily segregate from each other. The salt deposited on trees also carried by serious wind flow. There existed reports that gust wind speed also decline from coast to inland (Takahashi, 1968). However, its declination characteristic is not so sharp as the salt deposition, which showed a linear relation to DC. The wind speed at the position 10 km from coastline still reach a level of 80% of that along coast (Fig. C9-2a, ○—○). During hit by T0613, since the center of T0613 brushed the southwest corner of Yamaguchi Prefecture, there was a tendency of wind speed reduction from southwest to northeast in Yamaguchi Prefecture according to the data from AMeDAS. It also showed an inverse exponential function relationship between average wind speed and average distance from AMeDAS stations to the nearest coastlines (ADC) of west, southwest, south and southeast, with R^2 equaling to 0.723 (Fig.C9-2b). Similar tendency has also been observed in the 30 years normal mean wind speed of Japan (Fig.C9-3). Most of observatories with annual mean wind speed less than 2 m/s (green) are located at inland area and most of observatories with annual mean wind speed more than 6 m/s (red) are located at islands, high elevation and coastal area.

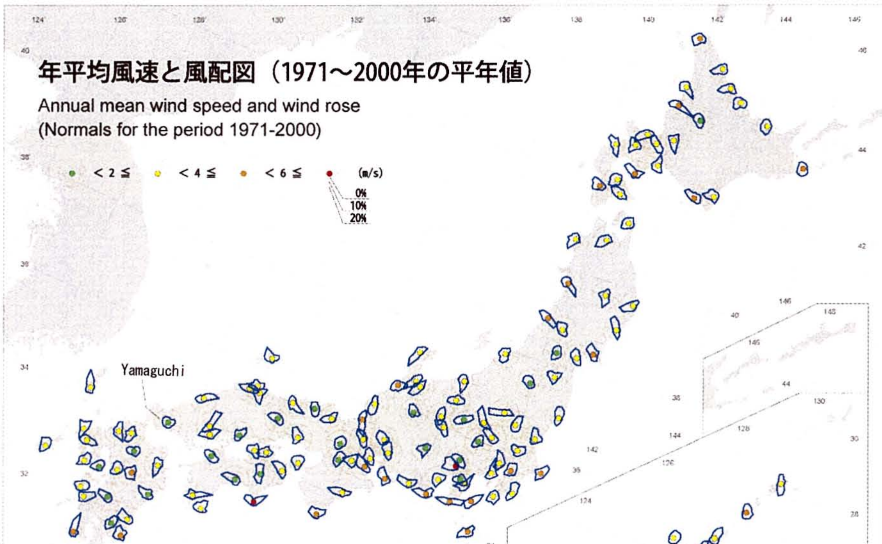


Fig. C9-3 The normal value of annual mean wind speed and wind rose of the major Observatories in Japan. The Yamaguchi Observatory showed a near circle wind rose and lower average annual wind speed. The graph is cited from the Web site of Meteorological Monitory of Japan.

All of these suggested that gust wind is also able to induce the responses from landscape trees where there is less salt deposition. However, wind can cause the physiological damage to the plants or trees commonly integrated with other factors. Salisbury (1805) had noted that great leaf injury occurred when rain was not associated with strong wind, which implied that there were no enough safeguard elements associated. Boyce (1954) has ever criticized Hansen's wind tunnel experiment "injury to leaves only occurred when soil moisture was very low". In this study, it is observed that the bamboo stand with serious necrotic symptoms occurred at the site where is more than 20 km from coastline after hit by T0613 where there is trace salt deposition. Most of severe discolored bamboo canopies were located at mountain sites, whereas it is noticed that many bamboo stands inside riverbank still remain shallow green color. During hit by T0418, almost no such kind of symptoms occurred on landscape trees since the heavy rain associated with the strong wind even higher than that from T0613 in Yamaguchi (Tabale1).

Table 9-1 Related wind and precipitation data in Yamaguchi during T0613 and T0418

	T0613	T0418
Monthly precipitation in Sep (mm)	176.0	401.0
Monthly precipitation in Oct (mm)	5.5	187.5
Precipitation in the day typhoon hit (mm)	24.0 (Sep.17.2006)	111.0 (Sep.7.2004)
Precipitation for 44 days after typhoon hit (mm)	8.5	440.5
Maximum gust wind (m/s)	42.4	50.3

Therefore, the rainless or less rainfall during and after hit by T0613 reveals the leaf necrosis of many landscape trees in Yamaguchi City is just like Salisbury's note. The merge of strong typhoon and persistent no rainfall should be the key of these landscape tree responses. From all of above, there is an indication that serious visible symptoms of leaf necrosis or branch dieback are associated with water stress of them. During the study, more serious necrotic symptoms from the tree species with faster leaf desiccation speed and on transplanting shocked trees well support it (Fig. C2-6). The pruned tree sustained more serious hit by meteorological extreme events provide another positive fact (Fig. C2-4). The effect of root growing constriction often occurred in the wall-flower-bed or tree-pot resulted in the water imbalance of those necrotic leaves. Even the salt in soil is also the origins of water stresses of plants or trees (Munns, 1993, 2002; Pammenter and Smith, 1983). As above mentioned, the one of the important way of summer high temperature affect landscape trees also attributed to promote the transpiration by altering the water vapor pressure in the air.

Under the serious water stress or desiccation beyond the extent of growth or metabolic regulation, most landscape trees often dried from the terminals far from water origin, for example, the leaf tip (Thoday, 1931; Yapp, 1912) and branch top. Based on the study, this kind of tendency has been observed even from the detached leaves of kousa dogwood (Fig.C9-4a), and from the attached leaves on detached branches of some evergreens (Fig.C9-4b). The small detached bamboo branches even appeared a gradually increasing water loss percentage from branch base to tip and then to leaf base and tip (Fig.C9-4c). However, using same method to measure some sasanquas, there was no significant difference between leaf tip and base (Fig.C9-4d), which was consistent with the character of no leaf necrotic symptom and their leaf falling during summer drought. It seems that the frail point of sasanqua is at leaf separation zone. Further study on the detached branches of 15 tree species showed similar results (Fig. C9-5). Under the drought environment, some tree or shrub species showed different color between tip and base of leaves seems has something to do with this kind of end effect of water relations.

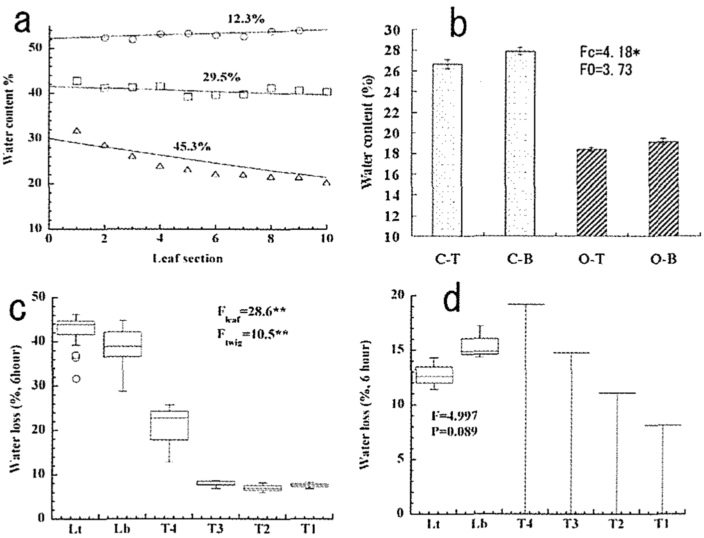


Fig. C9-4 Responsive curves of water content to the leaf sections from proximal to distal for detached leaves with different water loss percentage (a), 12.3% (○–○), 29.5% (□–□) and 45.3%(△–△). It can be seen detached leaves also dried from distal to proximal (line 45.3% water loss). Half-leaf water content of two evergreens (b) after a period of desiccation on the big detached branches in field include camphor tree (C-), Japanese blue oak (O-), which showed higher water content at leaf base (B) than tip (T). Small branches cut from a bamboo main stem (c) further showed an increase of the water loss percentage from branch base (T1, T2, 10cm sections) to tip (T3, T4) and then to the leaf base (Lb) and leaf tip (Lt) after 6-hour room environment dehydration. Dissimilarly, the sasanqua leaves showed relative water loss resistance (d) even harder than twig tips by the measurement same as bamboo.

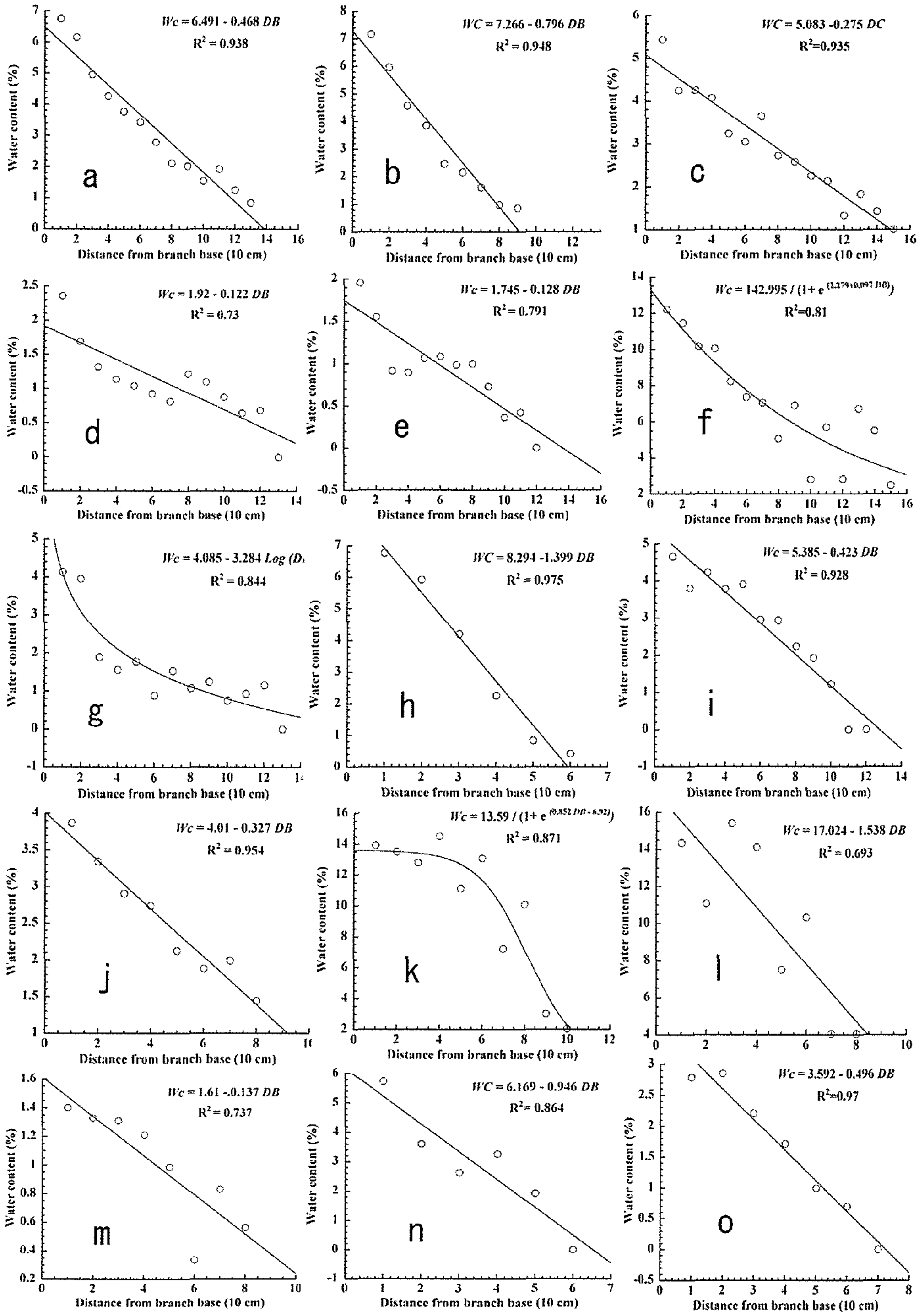


Fig. C9-5 The difference of water loss in different branch sections (10 cm long) from proximal to distal for 15 landscape tree species; they include zelkova (a), kousa dogwood (b), trident maple (c), metasequoia (d), sweet gum (e), ginkgo (f), bamboo (g), camphor tree (h), Japanese blue oak (i), red leaf photinia (j), fragrant olive (k), fortune's osmanthus (l), sasanqua camellia (m), Yedda hawthorne (n) and kaizuka juniper (o). It is the result of water content after 21-hour water loss in oven condition. It can be seen a tendency that all of them appeared the branch tip loss water faster than that of branch base. A big difference among tree species had been observed. Although it appeared hardly losing water from leaves of evergreens, this kind of tendency was not found from their branches. Some of them even loss water from branches easier than deciduous tree species, which seems the weak point of them.

In fact, many tree species can respond the extreme desiccations before the terminal part dried out by starting the protective process, such as leaf color change, leaf or branch abscission, necrosis and branch dieback and so on. The leaf necrosis and branch dieback of new transplanted kousa dogwood trees gave a proper example of it (Fig. C7-6). The direct result of them was the reduction of transpiration surface, exactly the reduction of excessive water resource consuming organs or tissues. Under extreme water stress conditions, many of them can save their lives from lethal desiccation status at expense of partial of them (Orshan, 1954, 1989; Addicott, 1973, 1982; Kramer, 1983; Kozlowski, 1973, 1976; Günthardt-Goerg and Vollenweider, 2007), although it appeared significant plasticity and diversity among tree species.

It is observed that the flower dogwood (*Cornus florida L.*) usually appeared the premature red leaf or red leaf tip during the extreme summer drought in 2007 and 2008. Only fewer of red leaved Florida dogwoods showed leaf necrosis after persistent hot and drought stresses and almost no defense barrier were found on necrotic Florida dogwood leaves. However, the living part of kousa dogwood leaves showed persistent green till late autumn. The annual leaf necrosis on Kumazasa bamboo (*Sasa Veitchii Carr.*) in early winter is characterized with leaf chlorosis from tip to proximal firstly, and then necrosis started from the seriously chlorotic leaf tip. Significant defense barrier usually established on their leaves as same as the kousa dogwood. Fig.C9-6 shows a typical example of protective response process of *Datura meteloides* under the water stress situation of summer drought in a flowerbed. The water content of the leaves just starting necrosis at leaf tip appeared a decreased linear function from leaf proximal to distal (Fig.C9-6a). There is an indication that root growing constriction in the flowerbed and summer drought induced them into serious wilt and scrolling in summer of 2008 (Fig.C9-6b-S). Some of them showed the symptoms of chlorosis also from tip to base (Fig. C9-6b-CH) and tip necrosis (Fig. C9-6b-N). However, the tip necrotic leaves gradually dropped off (Fig. C9-6b-AB). They expressed the different adaptive mechanism from the kousa dogwood and no gradually withdrawing defense barriers were found on their leaves. About one month late (Fig. C9-6c), as rehydration of the plants after the supplementary water supply from precipitation, they recovered to the normal status with fewer and small leaves attached on the top of branches. Some of them began to develop tubular flowers (Fig. C9-6c-FL). It is also a typical example of save their lives from serious desiccation in summer drought through the way of transpiration surface reduction.

Fig. C9-6 Some *Datura meteloides* grown in a flowerbed in Yamaguchi University. It showed a decreases water content line of leaf sections, divided from some leaves just starting leaf necrosis at tip (a); the photo of plants with symptoms of scroll (b, S), chlorosis (b, CH), necrosis (b, N) and abscised leaves (b, AB) on July 27,2008; and the photo image of the same flower bed and the same plants on August 25, 2008 (c).

The abscission of sasanqua leaves during the summer drought in 2007 was another example of this kind of adaptation. With different genetic characters of leaf structure, the sasanqua responded the meteorological extreme event during 2006 and 2007 differently in Yamaguchi. Although, the strong T0613 with less rainfall in 2006 did not lead the evergreen sasanqua appeared significant visible disorder, the dry, hot and windy summer meteorological extreme event in 2007 caused them leaf shedding and less flower bloomed in flower season (Fig.C9-7a, 7b, 7c). This seems having some relations to their water loss resistant leaves and relative faster water loss of branches (Fig.C9-4d). During the severe hot and droughty environment they took the adaptive pattern of segregating leaves from main body to reduce the transpiration surface area.

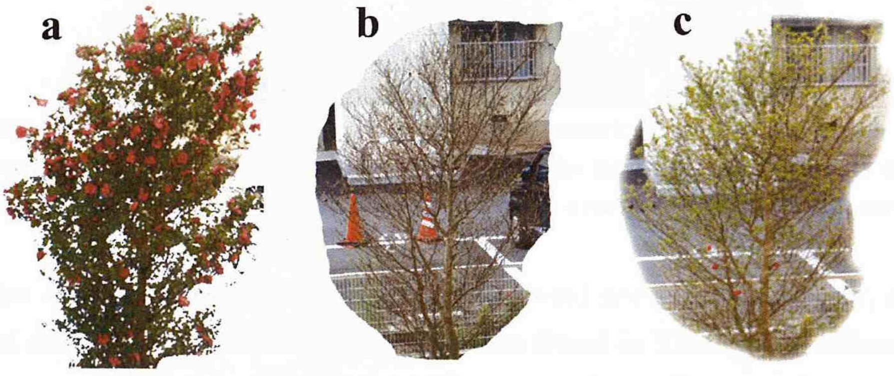


Fig.C9-7 Leaf abscission in 2007 summer days (b, Sep. 2, 2007) and different flower status in 2007-flower-season (c, Jan. 8, 2008) and in 2006- flower-season (a, Jan. 8, 2007) of one sasanqua tree in Yamaguchi

By comparison, the leaf discoloration from upper to the base of the crown for sweet gum tree seems one of the striking adaptive characteristics during the extreme summer drought in 2007 (Fig.C2-2) and the pruned sweet gum tree sustaining it without significant leaf color change indicates the importance of water balance. The supersession of the less vigorous leaves or twigs of some conifer species during the hit by T0613 may be another kind of adaptation to the serious water imbalance.

In some water constricted sites, such as rocky mountain site, coarse sandy soil and the site with root growing limitation etc., it was observed several trees were growing in the status of branch sprouting and dieback cycle (Fig. C9-8).

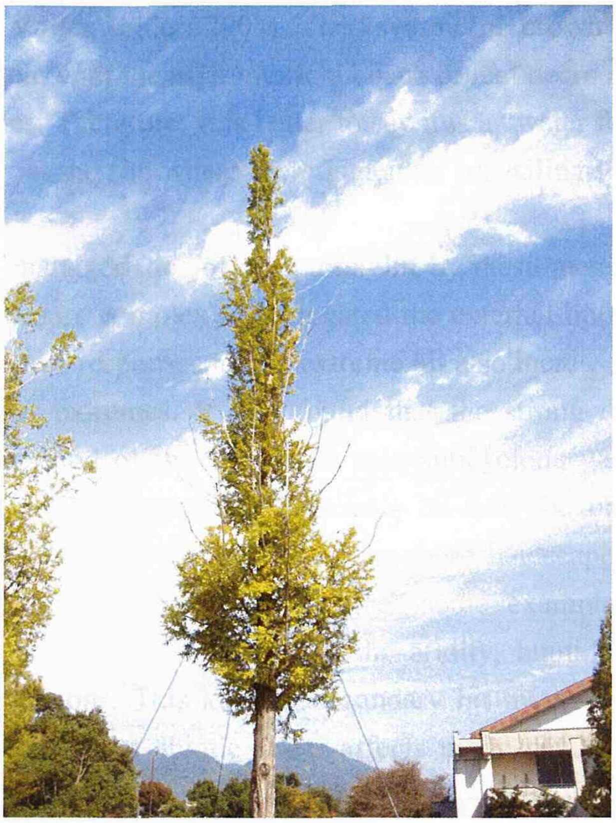


Fig. C9-8 A metasequoia tree, located at a root growing constricted site, is in a branch spouting and dieback cycle in Yamaguchi. It can be seen in the picture the new die-backed branches accompanying with some new spouted branches on the main stem. It remains a narrow crown around the main stem.

At the site where there is neither prevailing wind nor severe salt spray, asymmetric crown of some landscape tree species were also found in Yamaguchi, although no one-side-crown trees had been observed in these areas. It implies that the combination of many kinds of extremely environmental factors could cause many of landscape trees into dysfunction status, especially the strong dry typhoon merged with prolonged droughty period. In reality, they seem hitting by environmental extremes one after another. It is more common that before they perfectly recover from one extreme shock another hit has occurred. Persistent hit at same part of the crown and shelter one part by the others often induce them into asymmetric growth and the formation of asymmetric crowns. Historically, the asymmetric crown of trees had been considered as the trees of "wind form" and "salt form" according the different opinion about the decisive reason caused them (Wells and Shunk, 1937). However, wind and sprayed salt are the external environmental factor, they all induced the trees into apparent visible symptoms through the response of them. The "water" especially the internal water status of them is the direct driving reason of abscission, necrosis and dieback, since the responses from them usually starting at terminal parts that is farthest from central water way (Yapp, 1912; Günthardt-Goerg and Vollenweider, 2007). The asymmetric crown of some landscape trees is usually consistent with the asymmetric dieback or leaf necrosis induced by these meteorological extremes. Therefore, It is better to say it is a "water form" than "wind or salt form", particularly at the site where there is neither prevailing wind nor severe salt spray.

It is the response characteristics of symptoms hit by these meteorological extreme events that make them more complex to segregated the external impacting factors each other. The delay of the tree responses to one extreme hit also increases the possibility of further hit by the other extremes. It was found that the strong dry typhoons often accompanying with a period of the no or less rain anticyclone weather. The sudden temperature ascent after the strong dry typhoon's hit may be one of this kind of secondary hit and induce the severe response from these landscape trees just like the situations during the T0613's hit. Fig.C9-9 gives some examples of this kind of meteorological extreme events, which showed the aridity, humidity and gusty wind index during hit by typhoons. This kind of secondary hit may be more lethal to the shocked trees. In fact, after the abiotic stress affects many plants or trees are easily attacked by biotic pathogens (Kozlowski, 1985). In field condition, many stress factors usually worked together, such as dry and hot wind without rain association and merged with unfavorable site condition, root growing limitation and the improper root/shoot ratio etc. High air temperature often induces higher transpiration and cause trees need more water supply.

On the other hand, high plant temperatures are almost invariably associated with the cessation of transpiration cooling, following stomatal closure in response to drought. Therefore, the combination of them could significantly decrease the threshold of their response especially to the tree species with lower water conservation ability and affect the trees more seriously. The meteorological extreme events occurred from 2004 to 2008 may be the special examples of them. Leaf necrosis and branch dieback of the transplanted dogwood trees, asymmetric defoliation and discoloration as well as the partial branch dieback of ginkgo trees, all showed the desiccation form of above-mentioned symptoms and caused by the integrated environmental extremes.

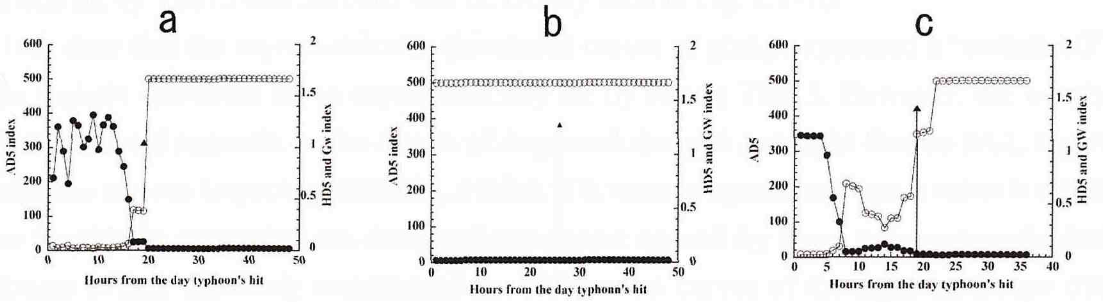


Fig.C9-9 The five-hour aridity index (○—○), five-hour humidity index (●—●)and the gusty wind index (▲) during hit by T8218 (a) for Chiba, T0415 (b) for Aikawa, and T0613 (c) for Yamaguchi Observatorys. They are calculated by refernce with the Equation I1, I2 and I3 respectively. Significant visual sydromes on trees and crops were reported during all of these three typical typhoon's hit, which is characterized by severe typhoon with less or no rain associated and acommpaned with a period of drought weather.

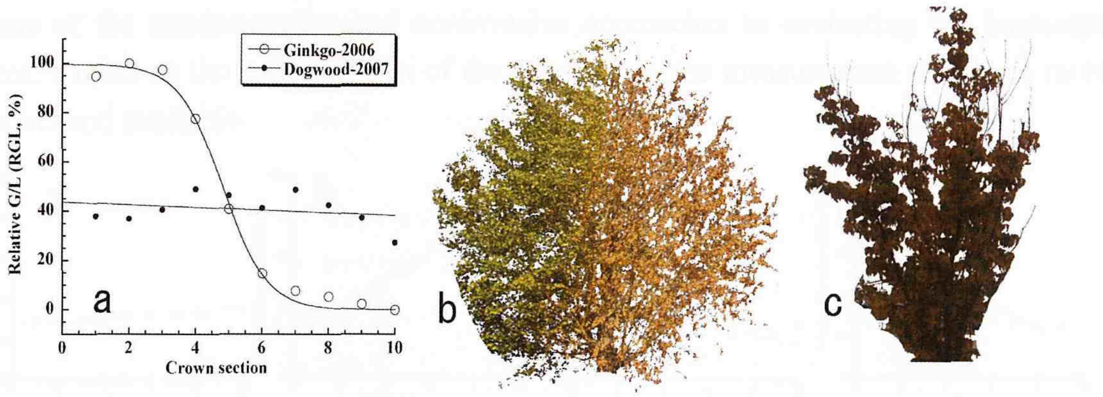


Fig. C9-10 A discolored crown of ginkgo hit by T0613 (b) and a dogwood affected by 2007-summer drought (c) described with threshold curves of RGL value (a).

After the acute effect by these meteorological extremes, striking responses of necrosis or partial organ/tissue death from many landscape trees made them significantly differ from that of normal growing trees. These kinds of differences may be expressed in spectral reflectance, direct visual sense or photo images. The big contrast between living part and dead part of them become the foundation to measure or estimate these kinds of difference. The necrosed part of these landscape trees appeared special leaf color, spectrum and temperature character for their special structure and substance such as water content, tannin and pigments (Vollenweider and Günthardt-Goerg, 2006). They can be clearly differed from the living part of the trees so as to be proportionally measured or estimated by using the relative G/L values of image analysis, threshold response functions and so on. The crown asymmetric discoloration can be also described by the RGL value. By using this approach, the distinguished characteristics of crowns hit by T0613 and SD2007 can be clearly seen in Fig. C9-10.

It is clear that the asymmetrically discolored crown of ginkgo appeared a "switch-off" type logistic threshold curve asymmetrically hit by strong T0613. However, the evenly distributed leaf necrosis on the crown of dogwood showed a straight line on RGL figure under the serious impact by SD2007. I think if it were programmed into a robot it might also be able to recognize the damaged symptoms caused by these two meteorological extreme events. Similarly constructed the differential curves of the eight-landscape tree species hit by T0613 (Fig. C9-11), it appears varied curves of them and is consistent with the visual characters (Fig. C2-6). Therefore, they may be the alternate ways to quantitatively detecting the damage or hurt extent by the meteorological extreme events. By using the thermography the surface image temperature can be clearly detected by amplified difference of the necrotic leaves and die-backed branches. The results of kousa dogwood tree separation were identified with it. It is no doubt that they add some of the nondestructive and noninvasive approaches to evaluating the landscape trees. I think as the accumulation of the experience, the measurement should be more perfect and available.

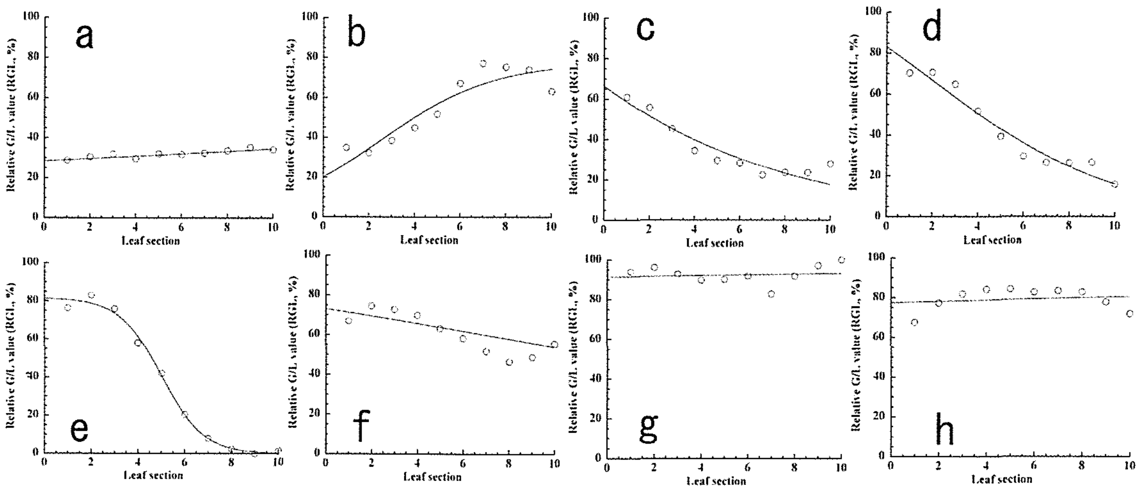


Fig C9-11 Responsive curve of eight landscape tree species showed in Fig. C2-6. They are the curves constructed by RGL value of crown/canopy sections equally divided from leeward to windward (b, c, d, e and f) or from left to right (a, g and h). It is clear that ginkgo (e) showed a typical inverse sigmoid shape logistic response curve for its strongly contrasted leaves between windward and leeward. The positive logistic curve manifested the character of faster sprouted new leaves on windward of zelkova crown (b). Sweet gum (d) and metasequoia (c) expressed distinct inverse rectangular hyperbola shaped logistic curves, respectively. The slight downward slanted linear line of Japanese blue oak (f) indicated its less severe hurt character. Although, the differential of bamboo (a) canopy and the windward image of kaizuka juniper (g) and Himalayan cedar (h) is not as same as the above five species, their almost levelly straight linear line located on the top and bottom of the ordinate showed their severe/superficial damaged and evenly distributed characters separately.

General Conclusion

Strong typhoon and summer high temperature associated with prolonged drought stresses often trigger some landscape trees into serious responses and show significant visible symptoms. The synchronous characteristic of aridity peak period and occurrence of protective responses of many landscape trees suggests that the persistent hot and droughty event is one of the major inducers of injury to them. The combination of them evidently decreased threshold of their responses to the extreme water and hot stresses.

The counteracting effect from precipitation, pruning and self-shelter, the exacerbating effect on trees with light leaf texture or less protection and at the sites with root growing constriction or in the situation of transplantation-shock, and the symptom characters usually staring from far from water resources and so on indicate that the serious responses from landscape trees during hit by meteorological extreme events relate to water stresses of them. Under the water stress, it is the transpiration failures etc. induces the energy metabolic imbalance and trigger the protective responses and reduction of surface area.

By observation and measurement of the sideward profile of crowns, it showed striking difference of the symptom caused by T0613 and extreme summer drought. The symptoms of observed trees hit by T0613 appeared more asymmetric characteristics than that of summer drought in 2007, which can be estimated with differential method or inflection point (IP) value of logistic responsive curves.

Although there is a big difference between the symptoms caused by extremely strong typhoon 0613 and the summer drought during 2007, the commonality of them can be expressed as the partial tissue or organs death or abscission due to desiccation.

Persistent hit by these kinds of meteorological extreme events should affect vigor status of landscape trees to endure the further affect by extreme environment, especially for the individuals in the constricted sites.

This kind of structure and property variance, especially the dehydration bases the detection by image and spectral analysis method. Whatever, the visible image, near infrared and thermo infrared spectrum of dead part and living part vary significantly so that become the foundation of quantitatively estimation of the injury by both meteorological extreme events.

During the extreme water imbalance, it is for saving themselves from the lethal damages that separate partial of the tissues or organs from main architecture, although it showed a tendency of species specific. The result of this study indicates that the separation can be estimated by RGL value, NDVI value and amplified image temperature as well as some other indices.

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Understanding and encourage are one kind of power to capture the knowledge of the nature, although the matter support is as important as them. During the study of myself, I deeply impressed its strength from teachers, classmates, colleges and family. As mentioned above, the interest and hobby are another dynamics that encourage me to trace the route of trees hurt by meteorological extreme events without any hesitation.

The study benefits from the resources of landscape trees in Yamaguchi City, especially the ginkgo that is the symbol tree of Yamaguchi City. We would also like to express our thanks to all members who engaged in planting, managing and maintaining these trees. The view of landscape in Yamaguchi is comprised various trees and shrubs, which is the results of hard working Yamaguchi people. They all are precious resources to study the natural phenomena. The feedback information of landscape tree responses to the meteorological extreme events from 2004 to 2008 is just the sign of the special natural phenomena. As a traveler, I am only the lucky one seen the wonderful scenes. It certainly should and must return to their masters—Yamaguchi people. Here it is just the things what I have seen and offer them back to their masters as possible as it is. It is glories to have the chance to watch these scenes and feel grateful to all of Yamaguchi people who made such a wonderful garden like homeland.

The gratitude will also be expressed to the Time Science Research Institute of Yamaguchi University for providing the chance to research meteorological disaster and their support, and to the Japan Student Services Organization for its support.

As mentioned above, as a foreigner I knew the local natural and social situations a little. Perhaps many of local people observed this kind of phenomena more detail and have more intimate knowledge of it. It is just displaying my slight skill before the experts. Please forgive me if there is something not proper in my ward, expression. I would like to thank all people who give me direct or indirect help in my study and research.

Appendix

1. Instruments

1.1 EKO MS720 radiometer (made by EKO Instruments Co. Ltd)

Wavelength range, 350~1050nm
Resolution, 10 nm
Wavelength interval, 3.3 nm

1.2 PMS 600 Pressure chamber (made by PMS Instrument Co.)

1.3 TH7100 Infrared camera （made by NEC 三栄 Ltd. Co.）

Wavelength range, 8-14 μm
Measuring temperature range, –20 to 100 ℃
Minimum sensible temperature 0.06 ℃

1.4 SPAD-502 chlorophyll meter

Measured area, 2mm × 3mm
Repetition, ±0.3 (in the range of SPAD 0~50)

1.5 Canoscan d125u2 flat bed scanner (made by Canon co.)

1.6 Digital cameras

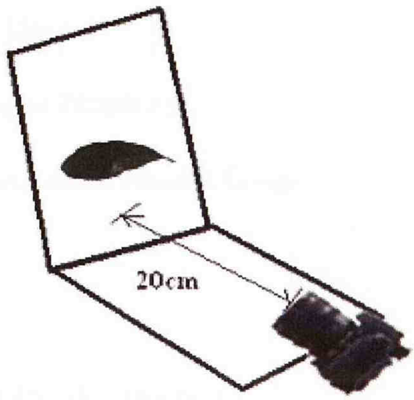
(Ricoh,Caplio 50DSE)

(Nicon D70S)

(Canon IXY 6.0)

1.7 Sartorius CP3202S Balance

1.8 Tool used in equal distance measurement of single leaf area



It is tested that single leaf areas measured with this tool can be highly related to that measured with Canon d125u2 scanner and Aam-8 leaf area meter. The correlation coefficient R^2 reached 0.994 and 0.993 to scanner and Aam-8 leaf area meter respectively.

2. List of the concerned software

Photoshop CS 8.0

KaleidaGraph 3.6J

Adobe Illustrator 9.0

Paint Shop Pro X

Image-tool 300

LIA3.2

AICGIS 9.0

Ms-720 data measuring and analyzing software

Viewer 2.0 for TH7100

3. List of the concerned landscape tree species

Kumazasa bamboo (*Sasa Veitchii Carr.*)

Kousa dogwood (*Cornus kousa Buerg.*)

Sweet gum (*Liquidambar styraciflua L.*)

Japanese blue oak (*Quercus glauca Thunb.*)

Trident maple (*Acer buergerianum Miq.)*

Sasanqua camellia (*Camellia sasanqua Thunb.)*

Metasequoia *(Metasequoia glyptostroboides Hu et Cheng)*

Zelkova *(Zelkov serrata Murr.)*

Ginkgo *(Ginkgo biloba L.)*

Red leaf photinia (*Photinia glabra* (*Thunb.) Maxim.*)

Fragrant olive (*Osmanthus fragrans var. aurantiacus*)

Camphor tree (*Cinnamomum camphora (L.) J. Presl.*)

Fortune's osmanthus (*Osmanthus ×fortunei Carr.*)

Kaizuka juniper (*Juniperus chinensis L. var. kaizuka Hort.*)

Yedda Hawthorne (*Rhaphiolepis indica var. umbellata*)

Japanese red pine (*Pinus thunbergii L.*)

Sacred Datura (*Datura meteloides*)

Convexa Japanese holly (*Ilex crenata 'Convexa'*)

Oriental arborvitae (*Thuja orientalis*)

4. List of figures

5. List of tables

Research on Responses from Some Landscape Trees to T0613 and Summer Drought with Digital Image and Spectral Analysis

Abstract

Morphological expression of landscape trees is usually the equilibrium between endogenous metabolic processes and exogenous metamorphic actions exerted by environment. Landscape trees grow in the unremittingly altering environment and respond it at any time and in varied patterns. Under the favorable conditions they make a response with the characteristic of rapid growth. However, the extremely unfavorable or catastrophic environments occasionally appeared in field. In recent years, many reports indicate that the unfavorable meteorological extreme events have increased as the large-scale climate changed in some area. They often induce many landscape trees into protective response or directly damage to them. Aimed at studying about the meteorological extreme events and responses from landscape trees and by using the methods of image and spectral analysis, the damaged status of some landscape tree species have been researched.

From 2004 to 2008 it appeared a significantly varied and strongly contrasted climate in Yamaguchi, Japan. During this period a lot of meteorological extreme events happened, particularly the exceptional typhoon 0613 (T0613) characterized with strong wind and less rainfall, and the summer drought in 2007 (SD2007) with the precipitation during the first nine months only 60.1% of the normal. Both are the main study content of this thesis.

Among these extremes, the summer hot wave and the strong typhoon associated with elongated less rainfall often trigger significantly visible injuries to them. The leaf color premature change of sweet gum tree during summer drought period in 2007 and 2008 is one of them. Both high temperature and strong wind, associated with less rainfall, easily result in landscape trees into serious water imbalance even desiccation. The combination of them evidently decreases the threshold of landscape tree responses to the extreme stresses. Under this kind of extreme water stress conditions, many of them can save their lives from lethal desiccation status at expense of partial tissues or organs, which comprise the major parts of transpiration surface reduction or damage character. It directly results in leaf abscission, necrosis, branch/twig dieback, crown discoloration and so on. In fact, these terminal parts are the sensitive or frail points in their hydraulic architecture. The characteristics of landscape tree responses to these kinds of extreme events usually show genetic specific diversity and stability. The structure of leaf, branch and cuticle characteristic and so on in a large extent manifest the adaptation pattern of them to severe desiccation. The sensitive landscape tree species often appeared severe injury symptoms after hit by meteorological extremes.

Since the big body of landscape trees, the conventional approach in observing damage characters of them in field is visual scale method. To some extent, it is characterized by observer specific, and probably affected by subjective judgment. As the information technology development, there is a tendency for developing objective methods to determine damages by typhoons and other disasters, especially using imagery analysis nowadays. Leaf or branch necrotic/separated parts usually appear special leaf color, spectrum and temperature character for their special structure and substance content. It becomes the foundation of estimation or evaluation with image and spectral measurement. The apparent symptoms of ginkgo leaves hit by the meteorological extreme event of T0613 were estimated by using the spectral reflectance at red edge under the controlled environment. By using the handhold radiometer of EKOMS720, the optimum wavelength for the calculation of NDVI for necrotic ginkgo leaves is at 679 and 755 nm. The close inverse relationship between $NDVI_{755nm/679nm}$ and LNAP of ginkgo leaves and dogwood leaves indicates that it has potential to evaluate the damaged status and to be an alternative tool to measure the leaf necrosis induced by typhoons like T0613 or SD2007, especially by using the NDVIR value.

Based on the RGB image analysis of both leaves and crowns, the G/L value of bamboo leaves shows lower variance and higher relation to SPAD value comparing to the G/R value at the situation of larger difference of image luminance. Especially, by using the relative G/L value of same leaf/crown in same image, the variance can be significantly lowed so as to make a statistical comparable measurement.

The construction of logistic threshold responsive curves of ginkgo crown discoloration from differential analysis gives a special example of the use of these relative G/L values. By using this kind of logistic threshold curves, the asymmetrically discolored crown of ginkgo hit by T0613 and the evenly distributed leaf necrosis on crown of dogwood under the serious impact by SD2007 can be clearly distinguished from each other. Therefore, they may be the alternative ways to quantitatively estimate the damage or hurt by these meteorological extreme events.

With ground-based digital image, the vigor status of ginkgo damaged by T0613 had been evaluated buy using the characters of defoliation, discoloration and crown symmetry. It is observed that landscape trees seem hit by the environmental extremes one after another, especially the individuals at constricted site condition that are in the situation of high sensitive to the environmental extremes. It is more common that before they perfectly recover from an extreme shock another hit has occurred. Some of them grown at poor site condition are even in the cycle of branch sprout and dieback, and remain a small, narrow or stem alone crown. These kinds of continual damages result in these trees impossible to put up an all-round effective defense against biotic and abiotic intrusion, and induce low vigorousness or abnormal form of them even accelerate the senescence or death. The persistent hit to one direction or part and the self-shelter one part by another as well as the asymmetrical growth during the restoring period often cause asymmetry of some landscape trees. It should affect the vigor status to respond the further meteorological extreme events like Typhoon 0613.

According to image analysis and water content measurement, it is observed a tendency that as stress become serious the desiccation of landscape trees often starts from the terminal part of them such as the leaf or branch tip and crown top and the dogwood leaf necrosis showed a special example. During hit by SD2007, about 40% leaf area had been reduced from investigated kousa dogwood trees. This kind of terminal part separation from main body is the defense response of them to reduce the transpiring surface, although the position of the separation varies with landscape tree species with different properties of water conservation and adaptation to extreme drought conditions. It results in some of them into leaf abscission and necrosis, branch dieback/shedding and so on.

The different variation character of water content and imaging temperature between separated parts and left parts of leaves and branches of dogwood made the thermographic detection of them possible. It manifests the possibility of identification to the reduced parts by amplified variation of imaging temperature, especially for kousa dogwood. Leaf necrosis and branch dieback in 2008 from transplanted dogwood trees in Yamaguchi should be triggered by transpiration cooling weakness.

The visible symptoms of responses from landscape trees often show temporal delay, which manifest the characteristic of the integration between extreme environmental affect and the response of them. It is the response characteristics of symptoms to these meteorological extreme events that make more complex to distinguish the impact of external factors. The delay of the landscape tree responses to one extreme hit also increases the possibility of further hit by other extremes. It is found that the strong dry typhoons often accompany with a period of no or less rain anticyclone weather. The sudden temperature ascent after strong dry typhoon's hit may be one of this kind of secondary hit and induce severe response from landscape trees just like the situations during the T0613's hit.

デジタル画像とスペクトル分析法を用いた台風 0613 号と夏季干ばつに対する緑化樹からの反応に関する研究

摘　　要

緑化樹の外観形態は一般に内在的な代謝と外界環境の影響の均衡状態である。緑化樹は絶えず変化する環境で成長し、常に様々な様式でこの環境に反応している。順調な境遇においては、その反応は迅速な成長で現れる。しかし時折極端な逆境または災害が現地で起こる。近年では多数の報告から不都合な気象の極端イベントの増加が指摘されている。それは一部の地区に大規模な気候変化が生じたためと考えられる。これらは常に一部の緑化樹の保護反応を誘発し、また直接にダメージを与えることもある。本論文では、気象の極端イベントと緑化樹の反応を目的に、デジタル画像とスペクトル分析を用いて一部の緑化樹の被害を研究した。

2004 年から 2008 年まで日本の山口で変動的な大きくコントラストされた気候が現れた。その期間中、多数の気象の極端イベントが生じ、特に強風(最大瞬間風速 42.4m/s)と少雨(日降水量 24mm)の台風 0613 号と、前九ヶ月の降水量が平年の 60.1%しかない 2007 年の夏季干ばつが挙げられる。この両方は研究の内容である。

2007 年と 2008 年の夏季干ばつの期間にアメリカフウの早まった葉変色はこのような保護反応の一つである。それらのイベントの中で長期少雨に伴って表われる夏季熱波と強台風は、しばしばこれらの著しい被害を引き起こす。少雨を伴う高温または強風の天気は、緑化樹の厳重な水分不均衡または脱水を容易に誘発し、極端なストレスへの反応閾値を明らかに低下させる。この種の極端な水分ストレスの状況において、多数の緑化樹は部分的な組織または器官を犠牲にし、致命的な脱水から生命を救うことができる。犠牲した組織または器官は、蒸散表面の縮小部つまり被害の主要部となる。直接の結果としては葉の脱落、ネクロシス、枝枯れ、樹冠変色などが引き起こされる。実際に、これらの先に被害を受ける末端部分は、輸水構造の中での敏感あるいは薄弱なポイントである。緑化樹がこれらの極端イベントに対する反応は、一般に遺伝の多様性と安定性を示している。葉と枝と表皮などの構造が厳重な脱水の適応パターンを明らかにしている。極端な衝撃を受けた後、敏感な樹種にはしばしば厳重な被害症状が表われる。

緑化樹の本体は大きいので、通常に野外で用いる被害の観察法は目視段階法である。この方法はある程度まで観察者によって違うこともあり、主観的な判断によって影響される

可能性もある。情報科学技術の発達により、今は台風などの災害による被害の測定する客観的な方法を開発する傾向があり、特に画像とスペクトル分析法を用いる傾向がある。葉または枝のネクロチック部分は、特別の構造と物質含有量のために、通常特別な色、スペクトルと温度特性がある。これはデジタル画像とスペクトル測定法で評価することの基礎となる。制御条件の中で、レッドエッジスペクトル反射を用いることで、台風 0613 号からイチョウのはっきりした症状を推測することができる。EKO-MS720 手握式放射計を用いて、イチョウの葉の NDVI 値を計算する時に最適波長は 679 と 755 nm である。イチョウとヤマボウシの葉から算出した $NDVI_{755nm/679nm}$ と LNAP の間に高い反相関関係があるために、被害の状態を評価するポテンシャルがあり、台風 0613 号と 2007 年夏季干ばつが誘発した葉ネクロシスの推定の選択方法になりうる。ここでは、特に NDVIR 値を用いることが望ましい。

葉と樹冠のRGB画像分析に基づいて、画像光度差異が大きい条件のもとで、竹の葉または樹冠のG/L値はG/R値より偏差が低く、SPAD値との相関が高いことを示した。特に，同じ画像の中に同一の葉または樹冠からの相対的なG/L値を用いることで、偏差が著しく下がり、統計的に比較できる測定をすることができる。

微分の分析から得た記号論理学の閾反応曲線はイチョウ樹冠の変色を反映し、それは相対的な G/L 値を応用した一実例となる。このような閾反応曲線を用いることで、台風 0613 号から襲撃されたイチョウの非対称樹冠変色と 2007 年夏季干ばつ中に均等に分布するヤマボウシの葉のネクロシスを明確に分けることができる。ゆえに、気象の極端イベントからの被害を定量に検測するために、それは選択可能な方法である。

さらに、落葉、樹冠変色、樹冠対称性などについて地面画像分析を用いて、台風 0613 号からダメージを受けたイチヨウの活力状態を評価した。観察により、緑化樹は極端な環境からの衝撃を次々に受けたことがわかった。特に、制限地に栽培した極端な環境に敏感な個体はそうである。ある極端な衝撃から完全に回復する前に、もう一度衝撃を受けることがよく観察される。やせ地に栽培した一部の緑化樹は枝を出すと部分が枯れるという循環をすることもある。それらは小型で、狭い樹冠或いは幹だけのものが残存しているものである。これらの継続的なダメージは、このような緑化樹の生物または非生物の侵入に対する全面的有効な防御を不可能にし、低活力と異常形態さらに老化と死亡へと加速させる原因の一つとなる。同じ方位からの持続的な衝撃、自己防護と回復期の非対称生長の特徴が非対称樹冠の現象を引き起こすと考えられる。これらはまた台風 0613 号のような気象の極端イベントが再度発生する時に緑化樹の活力状態に影響を及ぼすのである。

画像の分析と水分含有量の測定により次のことが分かる。つまりストレスが過度になるにつれ、緑化樹の脱水は蒸散表面の縮小のため、葉或いは枝の先や樹冠の頂上などの末端部分から始まる傾向がある。画像測定により、2007年の夏季干ばつの期間中、調査されたヤマボウシの木は約40%の葉面積が削られた。この種の末端部分が本体から分離することは、蒸散表面を減少させる防御性反応であり、異なる保水性と干ばつストレスの抗性を持つ緑化樹の種類によって分離の位置が変化する。この反応の結果として、緑化樹からの落葉、ネクロシスと枝枯れまたは脱落などがある。

葉または枝から分離した部分と残された部分の水分含有量と画像温度が違うため、サーモグラフィーを用いる検出ができる。拡大した画像温度差の方法は、分離した部分を識別することができるが、中でも特にヤマボウシの測定で使われている。この方法に基づいて、山口市に移植されたヤマボウシについて検討すると、2008年に現れた葉ネクロシスと枝枯れの現象は、蒸散冷却の不足によるのではないかと考えられる。

緑化樹の反応の可視症状は常に時間的な遅延を表わす。これは極端な環境の衝撃と緑化樹からの反応の共同作用を示す。この反応の特徴は、外部の要因を区別することをより複雑にしてしまう。緑化樹のある極端な要因への反応が遅延することは、またほかの極端な要因からの衝撃を受ける可能性が増加することを意味する。強乾台風後には常に無雨または少雨の高気圧天気を同時に伴うことがある。強乾台風後に突発する昇温現象がいわゆる二次衝撃にあたり、台風0613号来襲時のように緑化樹から厳しい反応を誘発する。

Published papers by Author (ordered by publishing date):

1. Wang F., Yamamoto H., Ibaraki Y., 2008, Measuring leaf necrosis and chlorosis of bamboo induced by typhoon 0613 with RGB image analysis. *J. Forestry Research*, **19**(3): 225-230 (chapter four)

2. Wang, F., Yamamoto H., Iwaya K., 2008, Quantitative research on vigor of ginkgo trees hit by Typhoon 0613 with ground-based digital image analysis. *Journal of Natural Disaster Science*, **30**(1): 45-53 (chapter six)

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

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8. Wang F., Yamamoto H., Ibaraki Y., Transpiration surface reduction of kousa dogwood trees during seriously losing water balance, **Submitted** to *Journal of Forestry Research* (chapter seven)

9. Wang F., 2007, Research on ginkgo leaf necrosis induced by Typhoon 0613. *Agricultural Meteorology of Chugoku and Shikoku,* **20**, 56-59 (chapter one and five)

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