Quantitative Research on Vigor of Ginkgo Trees hit by Typhoon 0613 with Ground-based Digital Image Analysis

Fei WANG[1], Haruhiko YAMAMOTO[2] and Kiyoshi IWAYA[2]
[1] The United Graduate School of Agriculture Science, Tottori University
[2] Faculty of Agriculture, Yamaguchi University

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ABSTRACT

The center of typhoon No.13 (Typhoon 0613) in 2006 passed through the Japan Sea and shaved the southwest corner of Yamaguchi Prefecture with characteristics of strong wind and less rainfall in Yamaguchi City. Many ginkgo (*Ginkgo biloba L.*) trees showed leaf discoloration and defoliation after its hit in Yamaguchi City, Japan. The crown of them can be clearly divided into green part and non-green part so that they were misrecognised as special ornamental trees. In order to quantitatively study this phenomenon, the indices of green coverage ratio of crown (GCRC), crown coverage (CC), vigor index (VI), and so on were used to analyze the vertical sideward profile of ginkgo trees by ground-based digital image analysis. They reflected leaf discoloration and defoliation of the crowns, and positively related to the distance from coastline (DC). Logistic functions between DC and these indices were obtained, with square correlative coefficients being 0.913, 0.622, and 0.882, respectively for GCRC, CC and VI. There is indication that ground-based digital image analysis can be an effective tool used in evaluating the vigor status of ginkgo trees hit by Typhoon 0613. In the paper, combined with analysis of meteorological data, the reason for damage to ginkgo trees was considered as water stress induced by Typhoon 0613. Based on multi-analysis of the research, there were significant differences of vigor status between coast and inland ginkgo trees after hit by Typhoon 0613.

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 unhealthy symptoms may be appeared like severe wilt, defoliation, discoloration, chlorosis, necrosis, dieback and so on. In some extent, it is a near synonym with tree viability or health. Typhoons are one kind of disaster that can seriously damage to forests, trees and shrubs (Hayes, 1999; Yamamoto, 1979; Takahashi *et al.*, 1981). The typhoon No. 13 in 2006 (Typhoon 0613) was characterized by low precipitation and high wind speed when it hit Yamaguchi City on Sep.17.2006. Its maximum wind velocity reached 20 m/s, the daily precipitation was only 24 mm during its hit and this period of less rainfall persisted for more than one month after its hit (refer to Table 2). Although there was no severely mechanical damage to trees, such as uprooting, stem breaking, bending, leaning, and so on in Yamaguchi City, it did lead to reduce the health status of many tree species, especially to some precious landscape trees. Apparent symptoms of leaf discoloration and defoliation appeared on windward of the crowns that made the crown obviously different between the windward and leeward of some deciduous trees, even half green and half brown, such as ginkgo.

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; Robertson, 1987). Recently, most research works on storm damage to trees still use visual scale method (Okinaka *et al.*, 1990; Shimizu *et al.*, 2004; Zhu *et al.*, 2001). Visual assessments of tree crown are also common in forest health investigations (Redfern *et al.*, 2004). To some extent, they are observer specific and probably affected by subjective judgment (Doswell *et al.*, 1988; Solberg, 1999). There is a tendency of transformation to objective methods for determining damage by typhoons and other disasters, especially using imagery analysis nowadays.

Comparing to annual plants, trees have big bodies and complex three-dimensional structure, which makes them difficult to be measured. It is almost impossible to perfectly measure tree crowns in a large-scale area for few researchers with common sampling method. As a repaid, nondestructive, noninvasive method, ground-based digital image analysis has been used to measure leaf area index, gap fraction (Bréda, 2003), crop coverage (Purcell, 2000), pest damage and so on. It has been remarked to be a potential method in coverage research of grasses (Richardson *et al.*, 2001), crops (Iwaya, 2003; Purcell, 2000), and vegetation (Laliberte *et al.*, 2006). Richardson *et al.* (2001) considered that digital image analysis had potential in the study that the amount of green tissue was an indication of health or growth, including injury ratings of

KEY WORDS: Ginkgo, Typhoon 0613, Ground-based digital image analysis, Vigor indices, Water stress

various grasses and diseases or insect injury. It has also been used in tree measurement and researched 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 paper, distinguished from commonly used hemispherical image analysis method, the overall profile of crown was quantitatively measured after hit by Typhoon 0613 by using ground-based, vertical sideward digital images of the profile for ginkgo trees. The vigor status of ginkgo trees hit by Typhoon 0613 was quantitatively studied using indices including the green coverage ratio of crown (GCRC), crown coverage (CC), vigor index (VI) and so on. Combined with analysis of meteorological data, the reason of reducing the vigor status of ginkgo trees has also been studied.

2. MATERIALS AND METHODS

2.1 Research site and basic meteorological data during Typhoon 0613'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. The investigation was practiced in a long, narrow area near Yamaguchi Bay, Fushino River and Anno River, which was from seashore via plain to canyon. It includes the circled sites of Ube, Aio, Ogori, Yamaguchi, Miyano, Mitani and Tokusa, which don't match up the administrated area with same name (see **Fig. 1**), and runs from southwest to northeast.

The meteorological data comes from the Automated Meteorological Data Acquisition System (AMeDAS) and from the nearest observation station of the Hazard Protection Information System in Yamaguchi Prefecture (HPISYP). 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 Typhoon 0613. The distance to the nearest coastline is from the shortest of less than 1 km to the longest of more than 40 km (see **Table 1**).

2.2 Photo image taken method and standard of analysis

Photographs were taken 45 days after typhoon 0613's hit. It is characterized by horizontally taking photos of the vertical profile of sample trees on the ground and by using a CCD digital camera (Canon IXY 6.0). The photo-taking distance was determined according to the size of crown and making crown fit the screen of the camera. The position of photo-taking was fixed by moving around the sample tree until the crown could be clearly classified into green part and non-green part, and the ratio of the green part to the non-green part didn't change, so that we could obtain the exact sideward photo image of sampled individuals. For trees whose crown cannot be clearly divided into green part and non-green part, the position of photo taking was determined by wind direction, local topography or by reference to other tree species etc. The absolute geographical position of sampled trees was fixed by GPS with Ricoh camera (Caplio 500SE). Photographs was taken between 0900JST and 1600JST and at the light-ward.

In order to avoid effects by other trees and take photos easily, most of street ginkgo trees were selected in open sites. Trees exhibiting any of the following characteristics were excluded from use in this study to decrease the primary source of error, such as

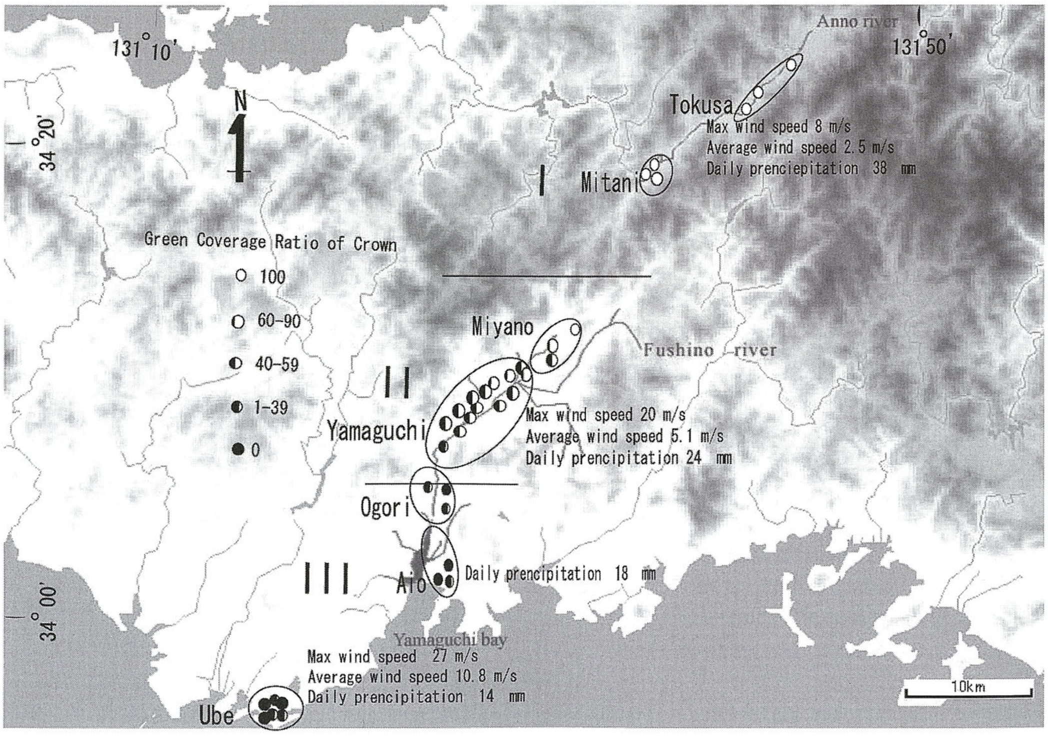

Fig. 1 Integrated map for research area, meteorological data and green coverage ratio of crown (GCRC); Sampled crowns were clearly divided into three groups, Group 1 (I), Group 2 (II) and Group 3 (III).

Table 1 Basic meteorological data for investigated areas during hit by Typhoon 0613 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

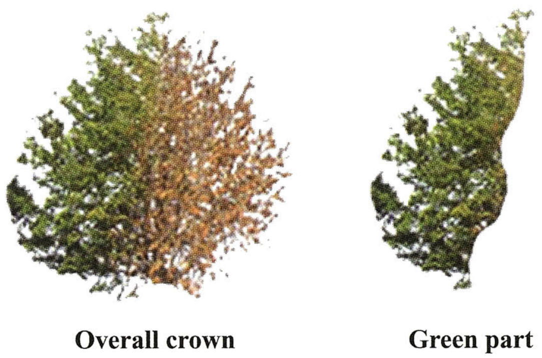

Fig. 2 Damaged crown and green part of Ginkgo biloba; Index of Green Coverage Ratio of Crown (GCRC) was calculated by both of them.

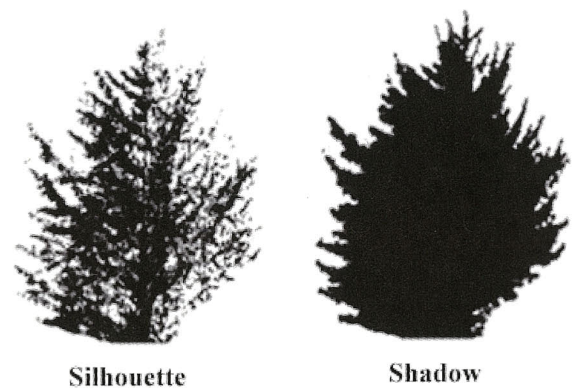

Fig. 3 Images of silhouette and shadow for same crown; Crown Coverage (CC) index was calculated by both of them.

trees sheltered by houses, buildings, and other trees, newly planted trees and newly pruned trees as well as trees with scars on the trunk and so on. To avoid errors in analysis, almost all of data used in the results analysis are relative values from the same crown.

2.3 Establishment and measurement of indices

2.3.1 Green coverage ratio of crown

In order to analyze the phenomenon of leaf discoloration of crown and the difference between green part and non-green part on different trees quantitatively, GCRC was applied, which was a 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 such as Photoshop CS, etc. to remove the parts out of the sampled crown. After obtaining pixels of overall crown, the parts out of green was removed by eraser (see **Fig. 2**) and then pixels of green part of the crown were obtained. The detail of calculation for GCRC by pixel proportion method is presented in Equation 1.

$$GCRC(\%) = \frac{pixels\ of\ green\ part}{pixels\ of\ overall\ crown} \times 100 \qquad (1)$$

2.3.2 Crown coverage and vigor index

Another characteristic of ginkgo trees damaged by Typhoon 0613 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 Typhoon 0613 was estimated by CC index. It is the pixel proportion of crown silhouette to crown shadow shown in **Fig. 3**. 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 from Photoshop CS. The calculating formula of CC is shown in Equation 2.

$$Crown\ Coverage(\%) = \frac{pixels\ of\ silhouette}{pixels\ of\ shadow} \times 100 \qquad (2)$$

The comprehensive index of VI for damaged trees was calculated by the average value of GCRC and CC (see Equation 3).

$$VI(\%) = \frac{(GCRC + CC)}{2} \quad (3)$$

2.3.3 Crown Ratio between Windward and Leeward (CRWL)

As a factor of symmetric characteristics of crowns for multi-analysis, CRWL 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 processed 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 CRWL was calculated as Equation 4.

$$CRWL(\%) = \frac{pixels\ for\ windward}{pixels\ for\ leeward} \times 100 \quad (4)$$

2.4 Distance from coastline (DC) and average distance from meteorological station to the coastlines of west, southwest, south, and southeast (ADC)

As a main analysis factor, the DC is the shortest distance from tree sites to coastline measured by an electronic atlas named Atlas Z Professional5.

The average distance from observation stations for AMeDAS to the coastlines of west, southwest, south, and southeast was measured in Yamaguchi Prefecture to study the relation between wind speed and the distance from coastline. It was also measured by using Atlas Z Professional5 and calculated by Equation 5.

$$ADC = \frac{west/2 + southwest + south + southeast}{4} \quad (5)$$

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 for Yamaguchi Prefecture.

2.5 Multiple statistic analysis

Principle component analysis and cluster analysis were carried out using GCRC, CC, VI, CRWL, and DC mentioned above. The analysis was conducted by commonly used software. The distance used in cluster analysis is the square Euclidean distance (refer to Equation 6) for samples and cluster mean (centroid method and refer to Equation 7) for classes.

$$d(x_i, x_j) = \left[\sum_{k=1}^{p}(x_{ik} - x_{jk})^2\right]^{\frac{1}{2}} \quad (6)$$

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.

$$D_{pq} = d(\bar{x}_p, \bar{x}_q) \quad (7)$$

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.

3. RESULTS AND ANALYSIS

3.1 Discoloration of ginkgo crowns hit by Typhoon 0613

Based on the calculation, the GCRC 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. 4**, although the GCRC value for samples at the same site differ from each other for the reason of different site conditions and growth situations, it was not so great as to significantly effect the relation to DC. A positive logistic function relationship between GCRC 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 8. In addition, the equation was computed from the regression analysis of 36 sampled trees.

$$GCRC = 101.95/(1 + 8.821e^{-0.183DC}) \quad R^2 = 0.913 \quad (8)$$

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 GCRC increases sharply, then smoothly, and then becomes stable.

Further, the leaves on a damaged tree were analyzed by dividing them into groups of non-scorched, scorched, and dried leaves by sampling method in order to analyze the pattern of leaf discol-

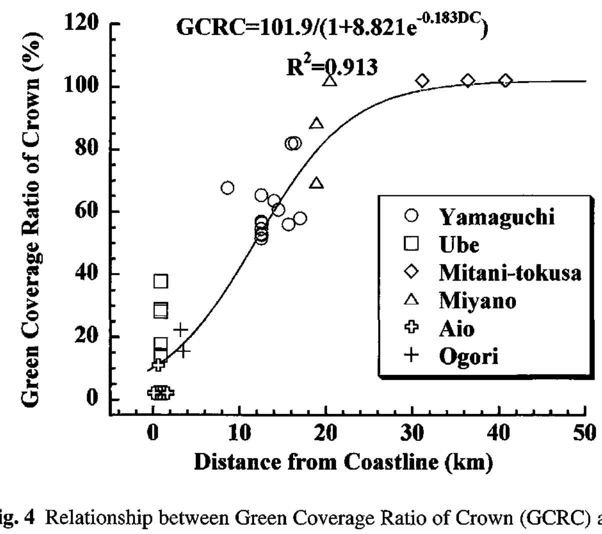

Fig. 4 Relationship between Green Coverage Ratio of Crown (GCRC) and Distance from Coastline (DC); It was regressed from 36 ginkgo trees from the sites of Yamaguchi, Ube, Mitani-tokusa, Miyano, Aio and Ogori respectively.

oration. **Fig. 5** showed the leaf component of samples from trees with different DC. Almost all of the leaf samples from ginkgo trees in Tokusa, with an average DC equaling 35.6 km, were composed of non-scorched leaves, with a non-scorched leaf rate of 93.7%, a scorched leaf rate of 6.3%, and a dried leaf rate of 0%. The scorched leaves showed only scorch spots, which perhaps were not induced by Typhoon 0613 since the scorch spots exist on the leaves at both leeward and windward. Contrarily, the major leaf samples from Ube, with DC equaling 1.7 km, were scorched and dried leaves, with a non-scorched leaf rate of 1.6%, a scorched leaf rate of 49.9%, and a dried leaf rate of 48.5%. The leaf samples from Yamaguchi, with DC equaling 13.5 km, were in the middle position with a non-scorched leaf rate of 39.3%, a scorched leaf rate of 52.3%, and a dried leaf rate of 8.4%. So, it can be said that the difference of crowns in different areas mainly comes from different scorch components of leaves 45 days after Typhoon 0613's hit.

3.2 Defoliation of ginkgo trees hit by Typhoon 0613

Defoliation is widely used as an indicator for the vitality or health of forest trees and the damage status in forest investigations, although it is still debatable (Zierl, 2004). It is observed different defoliation occurred on ginkgo trees in varied site conditions after hit by Typhoon 0613. From **Fig. 6**, it is evident 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 GCRC and DC. The corresponding equation is:

$$CC = 101.34/(1+1.0076\, e^{-0.0535\, DC}) \quad R^2 = 0.622 \qquad (9)$$

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.

3.3 Comprehensive vigor status of ginkgo trees hit by Typhoon 0613

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 Typhoon 0613, 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 Typhoon 0613. GCRC and CC are two indices respectively response to them in some extents and the VI which integrated with index of GCRC and CC has potential to comprehensively model the vigor status of damaged trees. **Fig. 7** gave a relation curve between VI and DC and it shows that there is also a positive relationship between VI and DC, with a square correlative coefficient of R^2=0.882 and regressive Equation 10.

$$VI = 99.688/(1+2.5366e^{-0.11DC}) \quad R^2 = 0.882 \qquad (10)$$

3.4 Multi analysis and classification of ginkgo vigor status

Based on the principle component analysis by GCRC, CC, VI, CRWL, and DC, samples from different areas were divided into three groups showed in **Fig. 8**. Group 1 consisted of samples from Tokusa and Mitani with DC of more than 30 km, GCRC 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

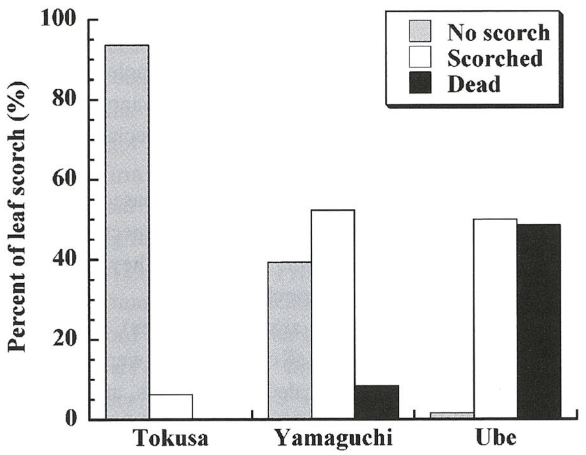

Fig. 5 Percentage of leaf scorch for discolored ginkgo crowns from different sites with different distance from coastline

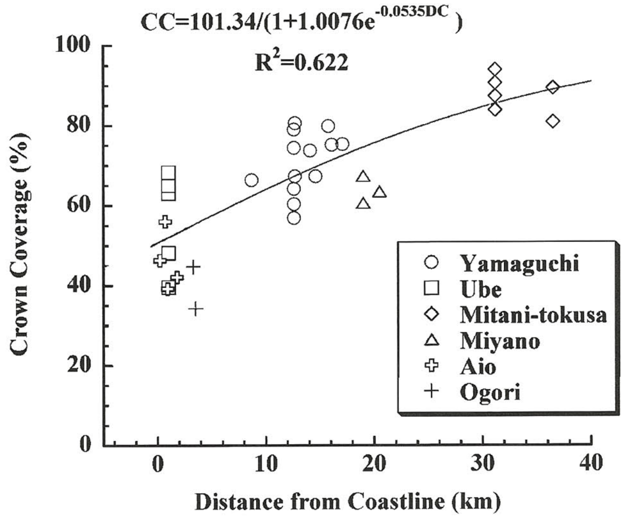

Fig. 6 Relationship between Crown Coverage (CC) and Distance from Coastline (DC); It was also regressed from the same ginkgo trees used in Fig. 4.

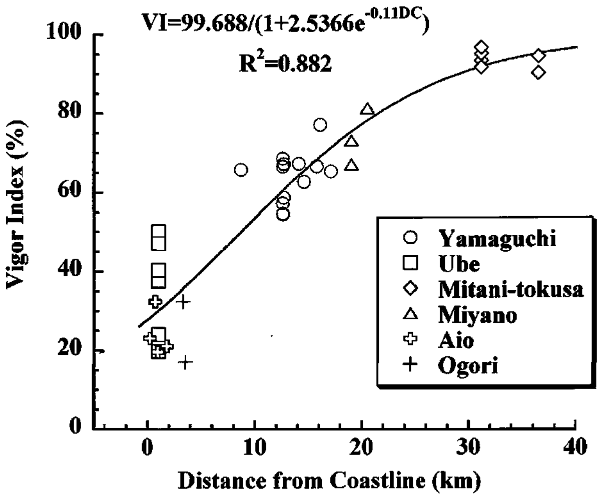

Fig. 7 Relationship between Vigor Index (VI) and Distance from Coastline (DC); Ginkgo crowns analyzed in it were also same as Fig. 4.

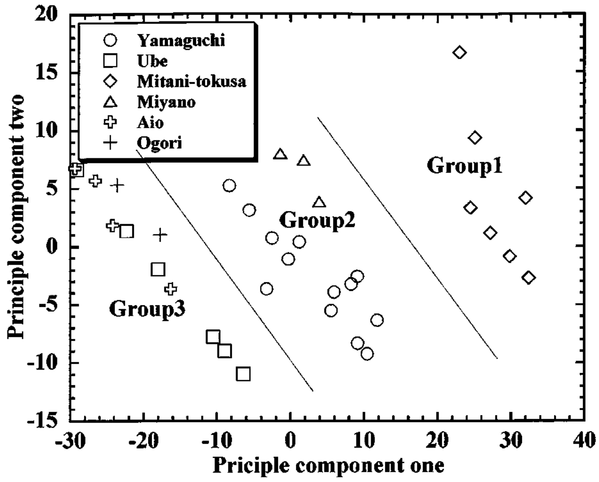

Fig. 8 Classification of ginkgo crowns by principle component analysis. 36 crowns collectively distributed in three area of principle coordinate system and were classified into three groups, the first group is concentrated in the first and fourth quadrant at the right side of the x axis, the second group around the datum point, and the third group in second and third quadrant at the left side of the x axis.

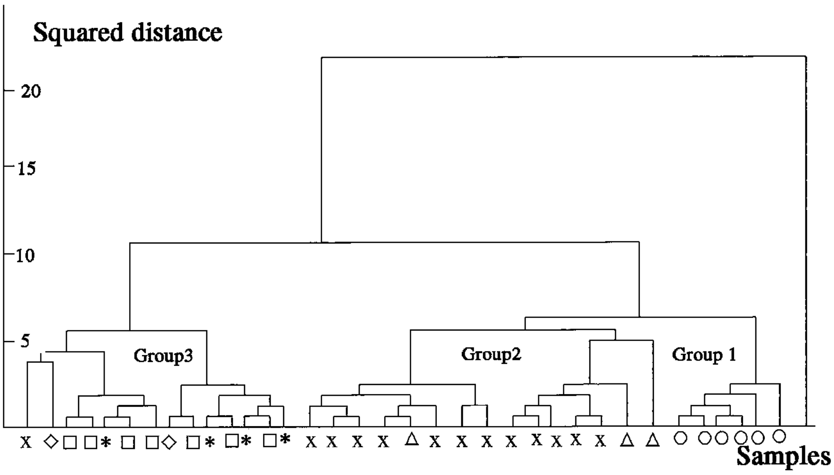

Fig. 9 Result of cluster analysis with centroid method, in which the crowns from Mitani-tokusa (○), Miyano (△), Yamaguxhi (X), Ogori (◇), Aio (*) and Ube (□), were also classified into three groups.

20 km, GCRC 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, GCRC 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 typhoon 0613 within 4 km from the coastline, and almost no injury occurred in the area out of 20 km from coastline and the ginkgo trees in the area from 4km to 20 km were in the middle position.

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 GCRC, CC, VI, CRWL, 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. 9**. 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. 10 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.

An outline of the research area (circled area), meteorological data, GCRC index, and groups of classification were given in **Fig. 1**. In the figure, GCRC was scaled into 5 levels, and respectively represent GCRC 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,

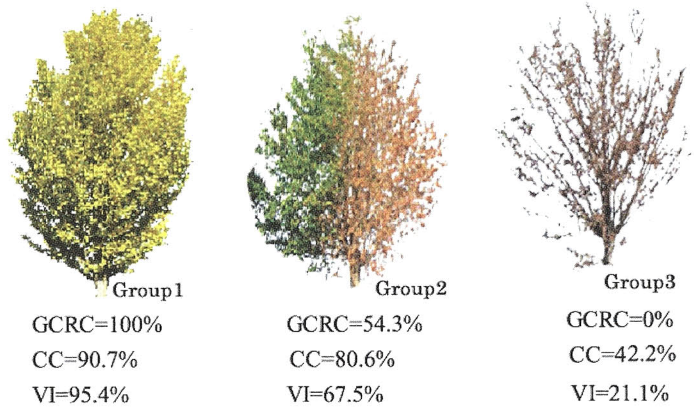

Fig. 10 Model samples of ground-based image for group1, group2 and group3 and related GCRC, CC and VI values

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 Typhoon 0613 is according to the indices by ground-based digital image analysis.

From **Fig. 1**, 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, which 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 Typhoon 0613 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.

3.5 Meteorological data and relation analysis

Since the center of Typhoon 0613 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. **Fig. 11** shows an inverse exponential function relationship between average wind speed and ADC with R^2 equaling 0.723. The investigated area of this research also run from southwest to northeast and had a tendency of decreasing wind speed from Ube in the southwest with a maximum wind speed of 27 m/s to Tokusa in the northeast with a maximum wind speed of 8 m/s (see **Table 1**) during hit by Typhoon 0613. A similar tendency was expressed for the above-mentioned indices for vigor of ginkgo trees in the investigated area. In breif we cannot affirm that there is no relationship between the vigor of ginkgo trees and Typhoon 0613 blowing.

According to data from AMeDAS and HPISYP, the precipitation was only 24 mm during Typhoon 0613's hit in Yamaguchi, and only 8.5 mm from Sep.18.2006 to Oct.31.2006, which is the minimum record of 44 days after hit by strong typhoon (>=15 m/s) for past 40 years (1967-2006). On the other hand, the precipitation during and after Typhoon 0418's hit was so great that it induced regional flooding (see **Table 2**). Meanwhile, almost no such kind of damage to the vigor of ginkgo trees occurred in Yamaguchi after the hit of Typhoon 0418. Evidently, it can be thought that heavy rainfall can counteract damage by typhoons like Typhoon 0613.

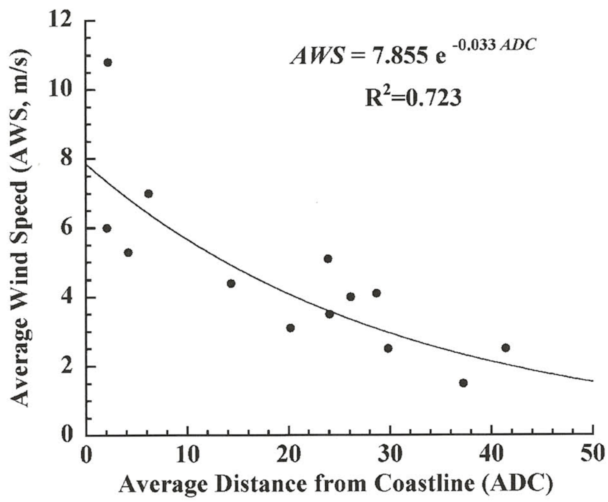

Fig. 11 Relationship between average wind speed (AWS) and average distance from AMeDAS stations to the coastline of west, southwest, south and southeast (ADC) during hit by Typhoon 0613

Ginkgo trees' vigor is damaged by strong wind and lower precipitation together in Yamaguchi City during Typhoon 0613's hit. In other words, it is mainly caused by water stress induced by strong wind from Typhoon 0613.

4. CONCLUSION AND DISCUSSION

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 damage by strong typhoons like Typhoon 0613, which is 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 GCRC, CC, and VI show a similar tendency that the further they are from the coastline, the smaller the

Table 2 Related precipitation data for Yamaguchi during Typhoon 0613 and 0418

	During Typhoon 0613	During Typhoon 0418
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

damage by Typhoon 0613 is and the bigger the GCRC, 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). Most of them were focused on the area of space-borne or air-borne image analysis for vegetation. Ground-based digital image analysis was also mainly limited to the canopy of plants (Bréda, 2003). Almost no research has 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 Typhoon 0613, and was characterized by analyzing sideward image of entire crown. Compared to the common sampling method, it is more effective in application to field measurement of the vigor of trees damaged by severe typhoon with less labor and less time requirement. It may be an alternative tool to be used in estimating or evaluating the degree of damage by typhoons like Typhoon 0613.

As early as 1805, Salisbury noted that great leaf injury occurred when rain was not associated with strong wind. A universal lower rainfall, averaging 21.7 mm in the investigated area during the hit by Typhoon 0613, reveals that the ginkgo tree's vigor reduced by Typhoon 0613 is just like Salisbury's note. That is why almost no such damage was found in Yamaguchi during Typhoon 0418, which is characterized by heavy rainfall accompanied by a high wind speed even greater than that of Typhoon 0613. It can be said that the damage to the crown of ginkgo trees by Typhoon 0613 is caused by water stress induced by strong wind.

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 limited conditions and should affect the vigor status to respond the further serious hit by storms like Typhoon 0613.

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