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The Classification of the Leaves and Branches of Sugi (*Cryptomeria japonica*) According to Nitrogen Concentration

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チッ素含有率からみたスギ枝葉の区分

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Summary

Sugi (*Cryptomeria japonica*) branches were divided according to three methods of classification: (1) the diverging part, (2) branch order, and (3) branch age. The relationships between the N(nitrogen)-concentrations and the distance from the top of the branches or the diameter of the branches were examined. N-concentrations in leaves, twigs and branches decreased from the top to the base of the branch. N-concentrations in leaves, twigs and branches were also related to the diameter of the branches in each span. The N-concentration of the third order branch was the highest, and that in the first order branch was the lowest. The N-concentration in the branches changed according to the branch age; that of a one year branch was the highest. The criteria of classification between leaves and branches corresponded to 0.8% in N-concentration and 4 mm in the diameter of the branches.

INTRODUCTION

Generally, trees consist of leaves, branches and a stem above ground. The morphological difference between leaves and branches is very clear in most deciduous and evergreen trees, except for some of needle trees. However, Sugi (*Cryptomeria japonica*) which is one of the main plantation species in Japan has green needle leaves, small green branches and big brown branches, and the differences are not as clear as those of *Abies firma*, *Tsuga Sieboldii*, *Pinus densiflora* etc. Therefore, the leaf biomass of Sugi stands was apt to be over- or under-estimated in previous studies since the criteria for the classification of leaves and branches was not common throughout those studies (9,10,11).

N-concentrations are also clearly different between leaves and branches in most other species (1,2,3,4,5,6,12,13). It is said that nitrogen is an important constituent

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element of chlorophyll which does photosynthesis in a plant. According to Keller (7), there is a very close correlation between the N-concentration and the chlorophyll content of foliage because nitrogen plays a dominant role in chlorophyll formation. Keller (8) also shows that the N-concentration and the photosynthesis rate agree well. Therefore, it should be possible to classify the leaves and branches of Sugi from the difference in N-concentrations.

This study deals with the classification of the leaves and branches of Sugi through the difference between N-concentration in leaves and branches.

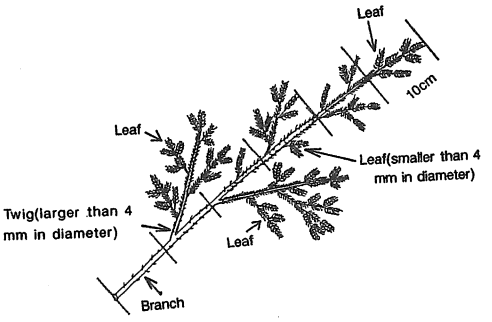
MATERIALS AND METHODS

Branches of Sugi consist mainly of the following four parts : small green needles, green twigs, green branches with twigs, and woody brown branches. Branches and leaves are divided by the color of branches in most studies. Green twigs and small needles fulfill the function of leaves, and green branches with twigs and branches covered with brown bark fulfill the function of branches. However, the green part of a branch is the photosynthetic organ. Since nitrogen is an important constituent of chlorophyll in leaves, the photosynthesis capability of branches and leaves should be dependent on the nitrogen concentrations (7,8).

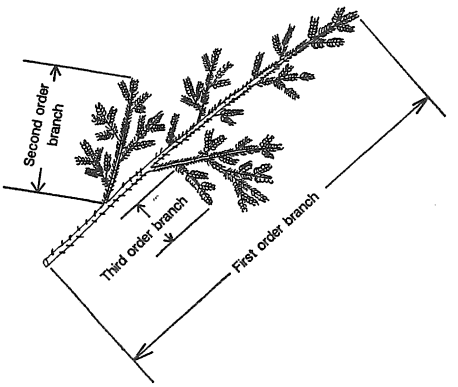
In this study, branches and leaves were divided into the following three classifications.

1. Classification according to the part of leaves and twigs on a branch.

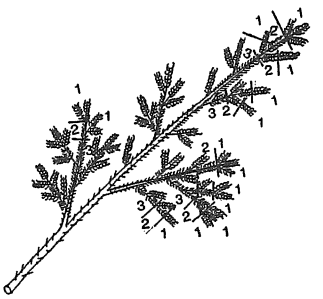
Branches were divided into 10 cm spans starting from the top. In each span, twigs of a base diameter samller than 4 mm were classified as "leaves", and those larger than 4 mm were divided into "twigs", "upper leaves" and "lower leaves" (Fig. 1A). However, the top span of the branch was classified as "branch", though its base diameter was



A) according to the part of branch



B) according to the branch order



C) according to the age of branch

Fig. 1. Classification of leaves and branches

smaller than 4 mm. Eight sample branches were collected from two sample trees in a 29-year-old Sugi stand in the Sanbe Forest of Shimane University in August, 1988.

2. Classification according to the branch order.

Branches and twigs were divided by the order of the branch. The branches that diverged from the tree stem were "first order branches", and those that diverged from the first order branches were "second order branches". The part that diverged from the second order branch was "third order branch". The first order branch was divided into the bark and woody part. The third order branch was divided into new and old parts (Fig. 1B). Twelve sample trees were selected in a 10-year-old Sugi stand in the nursery of Shimane University. Three sample branches were collected at the top, middle, and bottom part of the tree crown in each sample tree.

3. Classification according to the age of twigs.

Branches and twigs were divided into 10 cm spans starting at the top. In each span, the twigs were divided, the elongation in the first year being "the one-year twig", that in next year being "the two-year twig", and the rest being "the three-year twig" (Fig. 1C). A sample branch was collected from the middle part of the tree crown of the same tree according to the classification by the part of the branch.

After dividing the leaves and branches by the above mentioned three methods, the weights of the leaves, twigs and branches were measured. The diameters of twigs and branches were also measured at the base.

N-concentrations were determined by the Kjeldahl method and represented on an oven-dry basis.

RESULTS AND DISCUSSION

1. Changes in the N-concentration in the twigs and leaves within branches.

The N-concentration ranged from 0.7% to 1.5% in leaves smaller than 4 mm in diameter at the base. They were the highest at the top of the branch and lowest at its base. Comparing the mean N-concentration in the lower and upper part of leaves, the upper part showed a higher concentration than that of the lower part. However, the distribution of the N-concentration in both parts were not different, being 0.84-1.46% and 0.86-1.50%, respectively.

The part classified as "twig" appeared 40 cm from the top of the branch. The

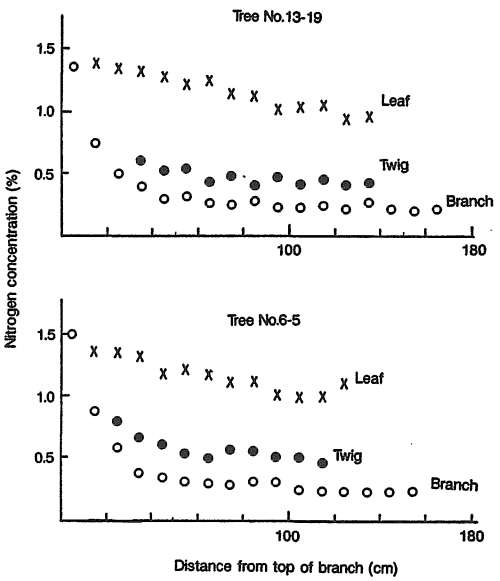


Fig. 2. Relationship between the nitrogen concentrations and the distance from the top of branches

Table 1. Mean nitrogen concentration (%) in branches classified according to branch order

Part of tree crown	1st order woody part	1st order bark	2nd order	3rd order old	3rd order new
Bottom	0.14(0.02)	0.56(0.04)	0.62(0.11)	0.75(0.10)	1.14(0.19)
Middle	0.17(0.03)	0.75(0.06)	0.78(0.07)	0.91(0.07)	1.18(0.16)
Top	0.30(0.03)	1.12(0.15)	1.06(0.14)	0.99(0.08)	1.34(0.18)

Standard deviations are represented in the following parentheses.

N-concentrations in the twigs were 0.30–0.86%, lower than those in the leaves.

The N-concentration in branches changed from 0.19% to 1.74% within a very wide range. The relationship between the N-concentration and the distance from the top of the branch is shown in Fig. 2. This figure shows the mean N-concentration of four sample branches on each sample tree. A tendency to decline from the top to the base of the branch was observed. The N-concentration declined rapidly from the top to 30–40 cm span, and then it decreased gradually to the base of branch. This trend was common in the two sample trees.

These results suggested that the N-concentrations of Sugi branches were higher at the outside than at the inside of the tree crowns.

2. Changes of N-concentration in relationship to branch order.

In dividing branches into five parts by branch order, the ranges of nitrogen concentration were 0.79–1.58% for the third new branch, 0.63–1.15% for the third old branch, 0.47–1.22% for the second branch, 0.50–1.26% for the barks of the first branch, and 0.11–0.34% for the woody part of the first branch.

The N-concentration of each component was different for each part within the tree crowns, as shown in Table 1. The mean N-concentration was higher at the top of the tree crowns than at the bottom. The difference between the lower, middle and upper part was statistically significant in the woody part of the first order branch. However, the difference between the parts of the tree crowns was not significant in the other branches. The difference in the N-concentration among the sample trees, including some different clones, was not significant either.

3. Changes in nitrogen concentration according to twig age.

The nitrogen concentrations in one, two and three year old twigs fluctuated in wide ranges, 0.83–1.57%, 0.86–1.32%, and 0.69–1.03%, respectively. The fluctuation of the

Table 2. Nitrogen concentration (%) in three species of needle leaved trees in Sanbe forest of Shimane University

Species	Leaves		Branches
	New	Old	
Chamaecyparis obtusa	1.12–1.16		0.22–0.23
Pinus densiflora	1.11–1.26		0.29–0.31
Abies firma	0.99–1.07	0.85–0.88	0.33–0.45

N-concentration within one year old twigs was the largest, and that within three year old twigs was the smallest. In each year twig, N-concentrations were higher at the top of the branch and the difference in the twig age was also larger at the top of branch. The difference in the N-concentration was not significant at the base of the branches.

4. Classification of leaves and twigs in relationship to N-concentration.

The green parts of Sugi are usually divided into leaves and twigs. The part called "branches" is also green at the top, and its color changes from green to brown when approaching the base of the branches. The change in color from green to brown seems to correspond to the ability to do photosynthesis. The nitrogen concentration in leaves, twigs and branches also changed from the top to the base of branches as well as with the color. However, it is too difficult to evaluate the change in color and divide branches into parts according to their color change.

On the other hand, in needle-leaved trees, other than Sugi, there are apparent differences between the leaf and branch morphologically (12,11). Table 2 shows the mean N-concentration in the leaves and branches of Hinoki (*Chamaecyparis obtusa*), Japanese red pine (*Pinus densiflora*) and Japanese fir (*Abies firma*) collected in the Sanbe Forest of Shimane University. The N-concentrations in the branches of three species were 0.22-0.45%; Japanese fir had the highest concentration of the three species. The N-concentrations in the leaves were 1.21-1.16% in Hinoki, 1.11-1.26% in Japanese red pine, 0.99-1.07% in new leaves and 0.85-0.88% in old leaves of

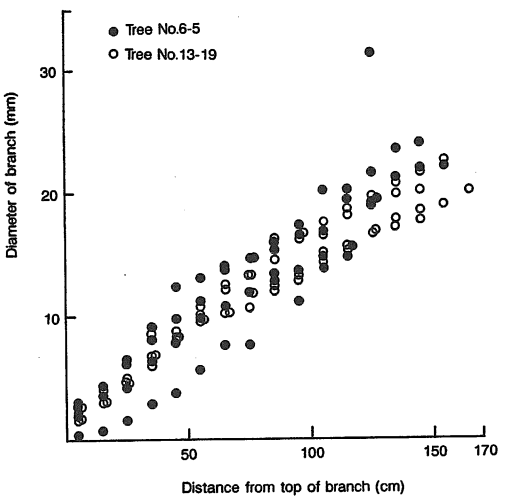


Fig. 3. Relationship between the base diameter and the distance from the top of branches

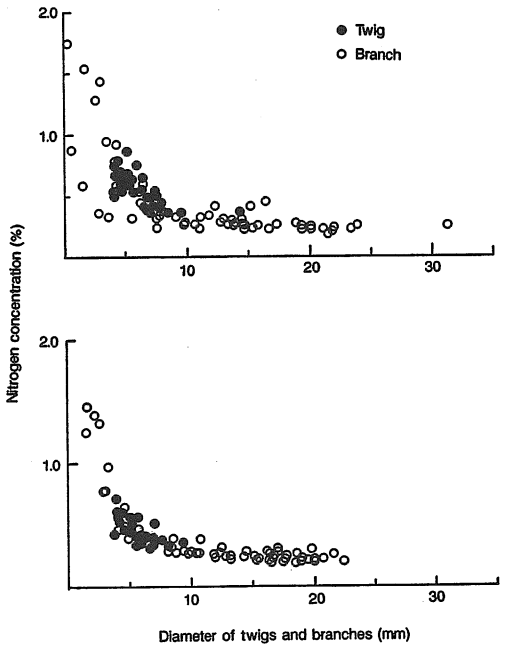


Fig. 4. Relationship between the nitrogen concentration and diameter of twigs and branches

Japanese fir.

These values, especially of leaves, were smaller than the N-concentration in deciduous and evergreen broad-leaved trees (2,3,4,5,6). However, the difference between leaves and branches is apparent. The boundary of the N-concentration in leaves and branches is about 0.8% from these results and the literature.

The diameter of the branches and twigs of Sugi became smaller from the base to the top of the branch, as shown in Fig. 3. The change in diameter corresponded to the change in color. With respect to the classification by the part of twigs and leaves within branches, the diameter of the leaf axis was smaller than 4 mm and corresponded to the diameter of branches 20 cm from the top. The diameters of twigs ranged from 4 mm to 15 mm and were smaller than those of branches which were 16–35 mm. The diameters of the leaf axis, twigs and branches changed continuously, and the N-concentrations also showed the same trend.

Fig. 4 shows the relationship between the diameter and N-concentration in leaves, twigs and branches. The N-concentration in branches decreased remarkably with the increase to a diameter of the branch of about 8 mm, and was constant in the range larger than 15 mm in diameter. Twig N-concentration also decreased in the range of 4–8 mm in diameter. The relationship between the N-concentration and twig diameter was similar to that of branches. Although the diameter of the leaf axis was not measured, leaf N-concentration would correspond to the relationship of branches, because leaf N-concentrations of 0.7–1.5% were equal to branch N-concentration in the range smaller than 4 mm in diameter. Therefore, the relationship between the N-concentration and base diameter showed the entire tendency of leaves, twigs and branches. Nitrogen as well as magnesium are an important constituents of chlorophyll, and the rate of photosynthesis depends on the N-concentration in the leaves. This result suggests that it is possible to divide the Sugi branch into photosynthetic and non-photosynthetic parts according to the change of N-concentrations.

With respect to the branch order, N-concentration increased while approaching the top of the branch or coming up the branch order. Furthermore, the N-concentration of the bark was 3–4 times as high as that of the woody part in the first order branch. That is to say, the N-concentration of Sugi branches is high at the top of the branch which is green and has a low woody part rate, but it is low in the base of the branch which is brown with a large woody part rate. Therefore, the outside branch in trees has the character of the leaf with respect to N-concentration.

However, N-concentration showed a wide fluctuation for all of the first, second and third order branches, and the concentration ranges of each order branch overlapped. This result suggests that a classification of the components into leaves, twigs and branches according to the branch order is difficult from the standpoint of nitrogen concentration.

With respect to branch age, nitrogen concentration decreased in the following order: the one, two and three-year old branches. The N-concentration of each year was higher at the top of the branch than at the base. The one or two-year old branch

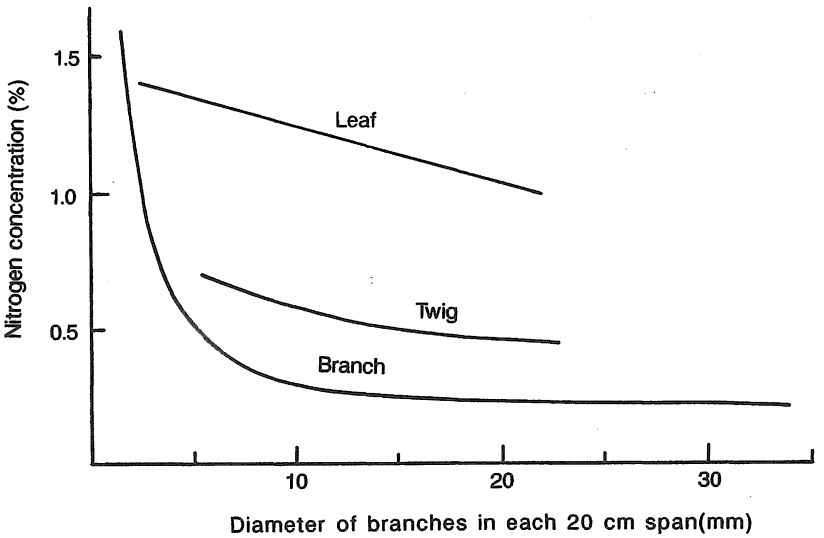


Fig. 5. Diagram of the relationship between the nitrogen concentration in leaves, twigs, and branches and diameter of branches in each 20 cm span

had a high N-concentration, higher than 0.8% at the base. The diameter of the one year old branch ranged from 2.8 mm to 4.7 mm, and it is correspond to the leaves which were classified according to the part of the branch. On the other hand, the N-concentration in the three-year old branch was lower than 0.8% at the base of the branch, and it showed the character of the branch.

The above mentioned value of the boundary of the N-concentration corresponds to that of a branch of 3.5-4 mm in diameter, shown in Fig. 4. The value of diameter corresponded to that at about 20 cm from the top of the branch. Therefore, the criteria of classification that a diameter smaller than 4 mm is "leaves" would be adequate from the point of view of N-concentrations.

Fig. 5 shows a diagram of the relationship between N-concentration and the diameter of the branch in each span. The fluctuation of the N-concentrations in leaves, twigs, and branches, leaves was in the part having an N-concentration higher than 1.0%, and the branches were in the part with an N-concentration lower than 0.8%. The part with an N-concentration between 0.8-1.0% would be regarded as old leaves of other needle-leaved trees. The first order branch could be divided into leaves and branches according to the diameter boundary of 4 mm.

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