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論　文

Measurement of Litterfall in a Hinoki (*Chamaecyparis obtusa* S. et Z.) Plantation by the Clothing-Trap Method

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MIYAURA, Tomiyasu & HOZUMI, Kazuo: **Measurement of litterfall in a hinoki (*Chamaecyparis obtusa* S. et Z.) plantation by the clothing-trap method J. Jap. For. Soc. 67: 271～277, 1985** Litterfall-rates were measured monthly from September 1981 to August 1983 in a 25-year-old hinoki, Japanese cypress (*Chamaecyparis obtusa* S. et Z.) stand (as of 1981) planted on the Nagoya University Experimental Forest at Inabu, Aichi Prefecture. The clothing-trap method was adopted to measure litterfall-rates by individual trees. The power-form equation was observed in the relationship between the litterfall-rate of a tree and its size. Based on this relationship, the mean annual stand-litterfall-rate of leaves, branches, and others, and the total during the observation period was estimated to be 1.9, 0.2, 0.1, and 2.2 t(dry wt)/ha·yr, respectively. The seasonal trend of the litterfall-rates was as follows : leaf fall had a distinct peak in autumn and a faint one in February ; branch fall was greater during the winter season ; and fall of others reached a peak in summer. Changes in environmental conditions caused by the cotton net, tree-size dependent litterfall rates, and analytical estimations of the stand-litterfall-rates were measured and are discussed.

宮浦富保・穂積和夫: **単木被覆法によるヒノキ人工林のリターフォール量の測定 日林誌 67: 271～277, 1985** 名古屋大学稲武演習林内に植栽された 25 年生 (1981 年現在) のヒノキ人工林において個体ごとのリター量を単木被覆法を用いて 1981 年 9 月から 1983 年 8 月までほぼ 1 か月ごとに測定した。単木のリター量と個体サイズとの間にはべき乗式関係が成立した。この関係を用いて推定した群落の葉，枝，その他および総リターの年間量はそれぞれ 1.9, 0.2, 0.1 および 2.2 t(dry wt)/ha·yr であった。落葉量は秋に多く，2 月ごろにも若干増加する傾向がみられた。落枝量は冬に，その他のリター量は夏に増加する傾向がみられた。さらに，ネットによる個体の環境条件の変化，個体サイズとリター量との関係，群落リター量の解析的な推定法について測定および考察を行った。

I. Introduction

Litterfall is one of the most important pathways of the nutrient and energy flows in the forest ecosystem. There are many records of the litterfall-rates of forest stands as reviewed by BRAY and GORHAM (1964) and by SAITO (1981 a). However, most of them were conducted by a so-called litter-trap method in which an appropriate number of litter traps or trays with an appropriate mouth area were arranged spatially on the floor of the forest concerned (NEWBOULD, 1967).

Forest trees are in general more variable in size, according to their individual biotic and abiotic environmental conditions. It is inferred that the functional values, such as photosynthetic rate, respiration rate, and litterfall-rate, of a single tree is related closely to its size. Therefore, the measurement of the functional values of individual trees, which constitute a forest, will give us further information on the dynamics of the forest ecosystem.

In regard to the respiration rate, measurements by individual trees were conducted by NINOMIYA and HOZUMI (1981, 1983). These kinds of studies on litterfall have been reported rarely to date. SAITO (1974), and CORMACK and GIMINGHAM (1964) reported the death rate of leaves by individual hinoki (*Chamaecyparis obtusa* S. et Z.) trees and the leaf litterfall-rate by individual heath plants, respectively. However, they dealt with these rates only, and their methods included some problems

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Table 1. The general features of sample trees in October 1982

Feature		Tree No.				
		110	125	81	99	14
DBH	(D [cm])	9.96	7.99	5.38	5.09	4.04
Stem diameter*	(D_B [cm])	5.95	5.92	3.82	2.96	2.74
Clear length	(H_B [m])	6.78	4.23	3.25	4.50	3.32
Height	(H [m])	10.87	8.86	6.34	6.90	5.57
Stem volume	(V_s [dm³])	44.26	25.66	8.07	8.35	4.54

* At clear length

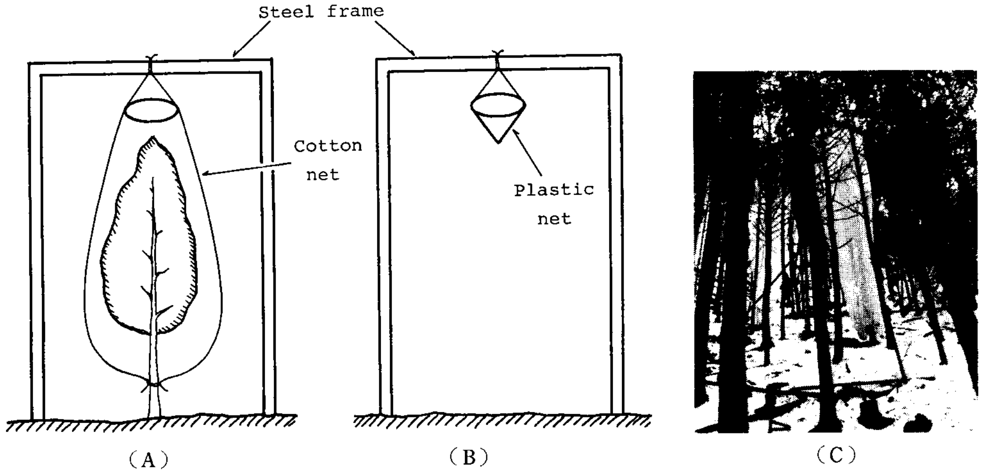

Fig. 1. The clothing-trap method
(A) Main trap, (B) correction trap, (C) the general features of the method

in estimating the annual stand-litterfall-rate and its seasonal fluctuation correctly. SAITO's method could not measure the fall-rate continuously because some destructive measurements were made on the sample trees. The method of CORMACK and GIMINGHAM (1964), using a litter-trap placed under the sample plant canopy, presumably could not catch leaf litter under strong wind conditions.

Considering the present state of research in litter production, we measured the litterfall-rate of hinoki by adopting a clothing-trap method (MIYAURA and HOZUMI, 1983). The present study was designed to clarify the relationship between litterfall-rates of a tree and its size and to measure the litter production of a forest stand.

II. Materials and Method

Measurements were made monthly from September 1981 to August 1983 in a 25-year-old hinoki plantation (as of 1981) of the Nagoya University Forest at Inabu, located about 55 km east of Nagoya, Aichi Prefecture. The study site had an inclination, exposure, altitude, area, density, mean tree-height, and mean stem-diameter at breast height (1.3 m above the ground) of 37°, N 0° W, 1,000 m above sea level, 191 m², 7,274 trees/ha, 8.36 m, and 7.84 cm, respectively, in November 1981. Cultural treatments, such as thinning or pruning, had not been conducted since planting.

Five trees were chosen as sample trees on the study site. The general features of the sample trees in October 1982 are given in Table 1.

Figure 1 shows the clothing-trap method used in this study. The above-ground part of the sample tree was enclosed by a litter-trap made of cotton netting (20 meshes). The litter-trap (A) was supported by a round frame joined to the steel frame by four or five plastic ropes. The mouth of the trap (1 m² in area) was supported horizontally at about 0 m to 2 m above the sample-tree top. The correction trap (B) consisted of a funnel of plastic netting (33 meshes ; 1 m² in mouth area) and was supported at about the same height as the tree-heights growing around it and was used to correct the rate of litter falling into the litter-trap (A) through its mouth. There were two correction traps. The mean fall-rate of the two traps was used to correct the fall-rates of the sample trees by the equation

Table 2. Annual litterfall-rate of the sample trees (l) and annual amount of litter caught by Traps B 1 and B 2 (l_{B1} and l_{B2}) from September 2, 1981 to August 19, 1983

[g(dry wt)/tree·yr]

Component	Fall-rates of sample trees and their numbers					Correction trap	
	110	125	81	99	14	B 1	B 2
Leaves	494.1 (87.5%)	175.3 (82.6%)	91.5 (78.6%)	89.9 (84.7%)	46.0 (79.0%)	2.1	0.8
Branches	52.0 (9.2%)	22.8 (10.7%)	16.7 (14.3%)	11.5 (10.8%)	8.4 (14.4%)	0	0
Others	18.9 (3.3%)	14.2 (6.7%)	8.2 (7.0%)	4.8 (4.5%)	3.8 (6.5%)	0.7	0.6
Total	565.0	212.3	116.4	106.2	58.2	2.8	1.4

Percentage of fall rate of each component of the total litterfall-rate in parentheses. For l, l_{B1}, and l_{B2}, see text.

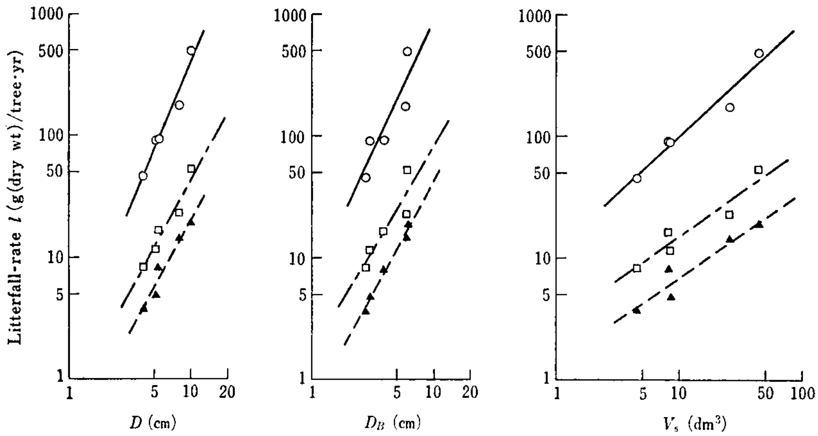

Fig. 2. Relationships between annual litterfall-rates and tree-size
D, diameter at breast height ; D_B, top diameter of clear length; V_s, stem volume
○ Leaves, □ branches, ▲ others

$$l = l_A - (l_{B1} + l_{B2})/2$$

where l, l_A, l_{B1}, and l_{B2} are the litterfall-rate and the fall-rates of litter caught by Traps A, B 1, and B 2, respectively. Figure 1(C) shows the general features of the method.

All organic materials accumulating in the traps were collected monthly, air-dried, and sorted into three fractions ; leaves, branches, and others. Sorted litter samples were oven-dried at 85°C for 24 hours and then weighed.

The annual litterfall-rate of each sample tree was calculated by adding the monthly records of the individual tree, dividing by the observation period (716 days), and multiplying by 365 days.

The stem volume (V_s) of all trees on the study site had been measured annually, together with D, D_B, H_B, and H, by a nondestructive method (TORII and HOZUMI, 1980) from 1977 to date. Of these values, V_s, D, and D_B in October 1982 were used as the measure of tree-size.

In the neighborhood of the study site, five trees were felled, and their leaf and attached dead-branch weights were measured in September 1981 to establish a turnover rate expressed as the ratio of the leaf litterfall-rate to the living-leaf weight and the ratio of the branch litterfall-rate to the attached dead-branch weight. Sample trees were chosen so as to include the range of D found on the study site.

The mean monthly air-temperature in the litter-traps was measured for two sample trees by maximum-minimum thermometers having U-tubes (Nippon Keiryoki Co. Ltd.) from September 1981 to August 1983, at heights of 1.3 m and 4 m above the ground for No. 14 and at 1.3 m and 6 m for No. 125. The air-temperature outside the litter-traps was measured at various heights from 1.3 m to 6 m in the stand.

The light-intensity inside and outside the litter-traps was measured on September 16, 1981 for three sample trees (Nos. 14, 81, and 110) by photometers (LI-188 B ; LI-COR Ltd.) at a height of two meters above the ground in the neighborhood of the litter-traps. For the light measurements, the sensor was kept horizontal. Readings of light intensity were taken five times at the same position for each direction of north, east, south, and west, centered on the stem base. Mean ratios of the light-intensity inside the litter-traps to that outside the traps were calculated.

III. Results

1. *Tree-size-related litterfall-rates*

Annual litterfall-rates of the sample trees are shown in Table 2, together with the annual amount of litter caught by the correction traps. The amount of each litter component of trees increased with the increase in size shown in Table 1. However, the proportions of the three fractions of the total litter were about the same irrespective of tree-size. Leaves, branches, and others accounted for an average of 82, 12, and 6% of the total fall-rate, respectively. The annual amount of the litter fractions caught by Traps B was small compared with that caught by Traps A.

Figure 2 shows the relationships between the litterfall-rates (l [g(dry wt)/tree·yr]) and tree-size (x) such as stem-diameter at breast height (D [cm]), stem-diameter at top of clear length (D_B [cm]), and stem volume (V_s [dm^3]). For each litter component, the relationship between l and the tree-size (x) was approximately linear on the log-log coordinates. Therefore, the following equation was derived:

$$l = a \cdot x^b. \tag{1}$$

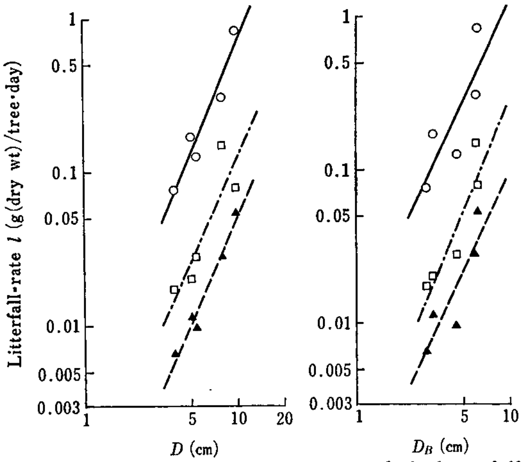

Fig. 3. Relationships between mean daily litterfall-rates and diameter at breast height (D) and top diameter of clear length (D_B) during the period between Feb. 20, 1982 to March 16, 1982
○ Leaves, □ branches, ▲ others

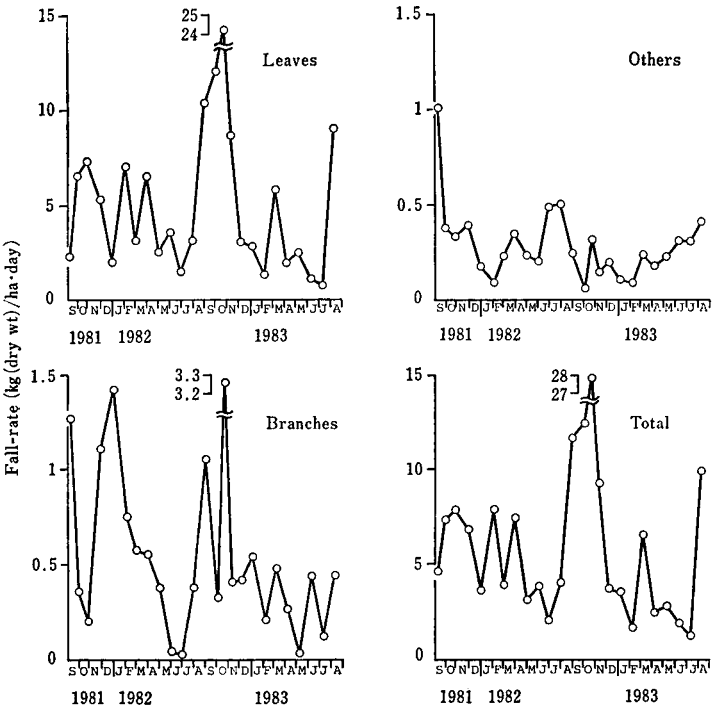

Fig. 4. Seasonal changes in stand-litterfall-rates

Here, a and b are coefficients determined for each litter component. As seen in Figure 2, D and V_s are appropriate parameters of Equation (1). For others litterfall-rate, D_B is superior to D and V_s, and the differences in fitness are not significant.

2. Stand-litterfall-rates

The litterfall-rate of a tree is expressed as a function of the tree-size as stated above. We can estimate the stand litterfall-rates (L [t(dry wt)/ha·yr]) by using the relationship of Equation (1) as follows :

$$L=\sum_{i=1}^{N} a\cdot x_i{}^b\cdot\frac{1}{Q}\cdot 10^{-6}. \qquad (2)$$

Here the subscript i denotes the tree number, N is the number of trees in the stand, being 137 in October 1982, and Q is 0.0191 ha, the area of the stand. D measured in October 1982 was employed as the parameter x_i in Equation (2).

The present estimated mean annual stand-litterfall-rates of leaves, branches, others, and total were 1.880, 0.221, 0.101, and 2.202 t(dry wt)/ha·yr, respectively. Annual litterfall-rates of hinoki stands have been compiled (HAGIHARA *et al.*, 1978 ; SAITO, 1981 a) or reported (KAWAHARA *et al.*, 1979 ; UEDA and TSUTSUMI, 1979 ; SAITO, 1981 b). Generally speaking, litterfall-rates on this study site are somewhat smaller than those of other hinoki stands.

3. Seasonal changes in stand-litterfall-rates

The power-form relationship as expressed by Equation (1) between the size of a tree and its litterfall-rates also was observed in the monthly records as shown in Figure 3. However, the fitness generally was inferior to that of Figure 2 in terms of r^2 values. The monthly amount of litterfall of the stand can be estimated in the same manner as the annual litterfall-rates. Seasonal changes in the monthly fall-rates of leaves, branches, and others, and the total litter are shown in Figure 4.

For the leaf litterfall-rate, the effect of the approaching of a typhoon or a depression on the fall was conspicuous. The peaks in October and November 1981, during August to October 1982, and in August 1983 were linked to typhoons. The peaks in January and March 1982 and in March 1983 reflected the approaches of depressions.

The branch litterfall-rate was higher in the months of September to March, but its seasonal trend was not as clear as that of the leaf litterfall-rate.

The fall rate of others litter was high in the summer months, and was low in the winter months. The trend is affected by the biomass of arboreal arthropods whose dead bodies, together with their feces, are the major component of others litterfall. On this study site, the total biomass of arboreal arthropods reached its maximum in July (HIJII, 1983).

The seasonal trend of the total litterfall-rate is similar to that of the leaf litterfall-rate because leaf litter makes up 80～90 percent of the total litter as shown in Table 2. There is a distinct peak in the late fall and a faint one in the late winter.

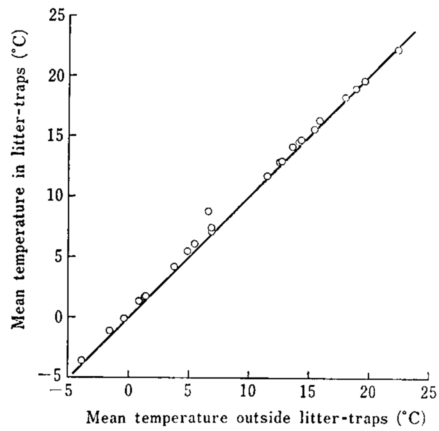

Fig. 5. Comparison of mean temperatures inside and outside the litter-traps

IV. Discussion

1. Changes in environmental conditions caused by cotton netting

The clothing-trap method was adopted to measure the litterfall-rate of a single tree by covering the tree with cotton netting. Thus, the environmental conditions of the sample tree may be modified because of the covering. We examined, therefore, the air temperature and the light intensity inside and outside the litter-traps.

Figure 5 shows the relationship between air temperatures inside and outside the litter-traps. The temperatures in the litter traps are higher than those outside by 0～1°C. Such small differences in temperature seemed to have little influence on sample-tree growth.

Mean proportion of the light intensities inside the litter-traps to that outside were 77.0 percent for No. 110, 60.3 percent for No. 81, and 66.7 percent for No. 14. The grade of decrease in light intensity, being unrelated to the size of the sample tree, is about 20～40 percent. Although we are uncertain about how much the light attenuation by the net affects the functioning of the tree, we think that the sample trees were not stressed

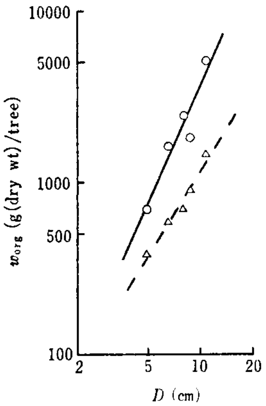

Fig. 6. Relationship between tree-organ weight (w_{org}) and diameter at breast height (D) measured in Sept. 1981
○ Leaves, □ attached dead-branches

Table 3. Coefficients of allometric relationships between fall-rates of leaves and branches of a tree and its diameter at breast height (Eq. (4))

Coefficients	a^*	b	A^{**}	h
Fall-rate of leaf litter	1.62	2.40		
Leaf weight			18.2	2.30
Fall-rate of branch litter	0.614	1.87		
Attached dead-branch weight			25.0	1.67

Units of a^* and A^{**} are [g(dry wt)/tree·cm^b·yr] and [g(dry wt)/tree·cm^h], respectively.

seriously. Since light is an important growth factor, we must clarify the effect of the decrease in light intensity on tree growth and employ netting material with a high transparency instead of the present cotton netting being used.

2. *Size dependency*

The main source of leaf and branch litter is the living-leaves and attached dead-branches, respectively. Therefore, it is important to examine the following : (1) the relationship between the leaf fall-rate and the leaf weight of a tree, (2) the relationship between the branch fall-rate and the attached dead-branch weight of a tree.

The allometric relationship between the diameter at breast height (D) and the leaf weight or the attached dead-branch weight (w_{org}) holds in general for the forest trees exemplified by Figure 6, as

$$w_{org}=A \cdot D^h. \tag{3}$$

Here, A and h are constants determined for each weight. Equations (1) and (3) result in

$$\frac{l}{w_{org}}=\frac{a}{A} \cdot D^{b-h}. \tag{4}$$

If w_{org} is considered as a constant for some years, Equation (4) denotes the relationship between the turnover rate of leaf or attached dead-branch of a tree (l/w_{org}) and its diameter at breast height. Coefficients a, b, A, and h are shown in Table 3. The value of D ranged from about 4 cm to 13 cm in this study. Turnover rates are 0.10～0.12 [1/yr] for the living-leaf weights and 0.032～0.041 [1/yr] for the attached dead-branch weights. These figures suggest that the mean longevities of leaves and attached dead-branches are about 8～10 and 24～31 years, respectively. As shown in Table 3, b and h, the exponents of the leaf fall-rate and the leaf weight, respectively, are nearly equal. The exponent of the branch fall-rate b and that of the attached dead-branch weight h also are nearly equal. Thus we conclude that fall-rates of leaves and branches of a tree in the studied stand are approximately proportional to its weight of living-leaves and attached dead-branches, respectively.

Because there are many factors affecting the abscission of plant organs (ADDICOTT, 1982), the above results should be verified by a long-term investigation.

3. *Analytical estimation of stand-litterfall-rates*

If the frequency-distribution ($\phi(x)$) of the size (x) of individual trees of a stand is known, the stand-litterfall-rate is expressed by the following integration (HOZUMI and SHINOZAKI, 1974) :

$$L(x)=\int_{x_{min}}^{x_{max}} l(x) \cdot \phi(x) dx. \tag{5}$$

Here, x_{max} and x_{min} are the maximum and minimum tree-sizes in the forest concerned. Employing the frequency-distribution of V_s, we estimate the stand-litterfall-rate analytically. As shown in Figure 7, $\phi(V_s)$ is simulated by the beta-distribution (MIYAURA and HOZUMI, 1982) of the form in the equation

$$\phi(V_s)=\frac{\rho}{B(\alpha,\beta)\cdot(V_{smax}-V_{smin})^{\alpha+\beta-1}} \times (V_{smax}-V_s)^{\alpha-1}\cdot(V_s-V_{smin})^{\beta-1}. \tag{6}$$

Here, α and β are coefficients, V_{smax} and V_{smin} are maximum and minimum values of V_s, respectively, ρ is tree density, and $B(\alpha,\beta)$ is the beta function. Values of these parameters in October 1982 were $\alpha=3.757$, $\beta=1.369$, $V_{smax}=93.05$ dm^3, $V_{smin}=3.88$ dm^3, $\rho=7,169$ trees/ha, and $B(\alpha,\beta)=0.136$.

From Equations (1), (5), and (6), the stand-litterfall-rate is given by the equation

$$L(V_s)=\rho \cdot a \cdot V_{smax}{}^b \cdot F(-b, \alpha; \alpha+\beta; 1-V_{smin}/V_{smax}), \tag{7}$$

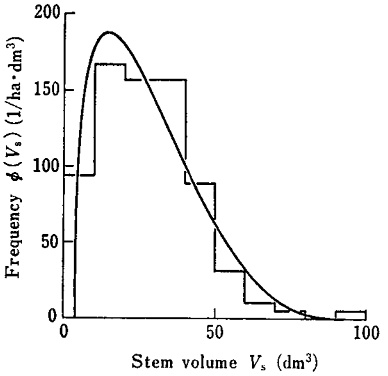

Fig. 7. Frequency-distribution of stem volume of the stand in Oct. 1982
Smooth curve indicates the beta-distribution given by Eq. (6).

where $F(A, B ; C ; z)$ is the hypergeometric function given by the series

$$F(A, B; C; z)$$
$$=1+\frac{A\cdot B}{C\cdot 1}\cdot z+\frac{A\cdot(A+1)\cdot B\cdot(B+1)}{C\cdot(C+1)\cdot 1\cdot 2}\cdot z^2+\cdots.$$

Putting values of a and b on the V_s-base in Table 3 into Equation (7), we have the annual stand-litterfall-rate of 1.847 t(dry wt)/ha·yr for leaves, 0.217 for branches, 0.099 for others, and thus 2.163 for the total. The other calculation procedure, using the same V_s-based a and b values in Table 3 and Equation (2), gives the identical fall rates given above. These estimated values also are nearly equal to those in Table 4. Thus, the analytical method, using the frequency-distribution function of tree-size (V_s), also gives good estimates of stand-litterfall-rates.

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** Only in Japanese
The title in the parentheses is tentative translation from the original Japanese titles by the authors of this paper.

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短　報

蛍光着色粒子による侵食土砂の移動に関する研究（I）
蛍光着色土砂粒子の作成方法と実用化について*

中 島 勇 喜**

I. は じ め に

雨滴や風による土壌の侵食といった表層土砂礫の移動現象については，すでに多くの研究がある。それらでは，移動土砂量を中心にいわば，土砂移動が生じた後の結果論的な研究が行われ，また一方では，侵食の発生機構や土砂粒子の運動機構に関する基礎的な研究が行われている。しかしながら，これら2研究方向の中間に位置する，① 侵食された土砂の平均的な移動距離や方向の測定，および防災上重要である，② どの地点の土砂がどのような割合で防止目的地点に移動しているのか，といった課題についての検討は行われていないようである。

土砂移動そのものの測定については，すでに掃流砂の挙動解析に用いられているように，高速度カメラで写真撮影し，フィルムモーションアナライザーで解析する方法があり，瞬間的な運動機構の解析に有効な方法となっている。ただ，この方法では，個々の土砂粒子の瞬間的な挙動が詳細に解析できる反面，本研究で目的としているような，時間的に長いスケールである①や②についての研究には不向きである。

以上のことから，①，②の課題について実験的に検討するための一方法として，土砂粒子を識別し，発見する方法を採用した。

従来，防災部門で用いられている識別の方法としては，流砂量推定に関し，ラジオ・アイソトープ（RI）を利用したり，礫にペイントで着色した例 (*4, 6*) があるが，RI は取扱いの点から一般的ではなく，また比較的容易な手法であるペイント着色では 2 mm 以上の礫に限られて使用されている。このことは，これより小粒径になると，ペイント着色が困難なことや，また，たとえ着色ができても肉眼では発見が困難なことに起因している。

本研究で対象としている，飛砂や雨滴侵食における土砂の粒径は，大部分が 2 mm 以下のもので構成されている。したがって，ここではペイント着色法が用いられない。そこで，0.1 mm 程度の粒径まで着色可能で，しかも発見を容易にする方法として，土砂粒子を蛍光着色し，紫外線を用いて発見する方法を採用した。

本報では，まず蛍光着色粒子の作成方法を紹介する。つぎに，人工降雨装置による雨滴侵食実験に，これらの蛍光粒子を使用し，これらが移動し，未着色粒子中に混入した場合の発見個数について結果を示し，本方法の実用の可能性について検討する。

II. 蛍光着色土砂粒子の作成方法

蛍光着色した土砂粒子と紫外線とを組み合わせる識別方法は，すでに漂砂関係で用いられている (*1, 5*) が，それらでは，蛍光粒子の作成方法については明示されていない。この点に関して，INGLE (*2*) が各研究者の用いた作成方法をとりまとめている。その中のいずれの方法も，研究対象が，常時，海水中にあって移動し，粒子自体が磨耗する機会の多い漂砂であるため，蛍光の脱落を極力，防がねばならず，接着剤や高速回転器等に特別な配慮がなされており，簡単には蛍光粒子を作成することが困難である。

本研究で対象としている表層土砂の移動現象では，漂砂の場合より蛍光脱落の危険は少ないものと予想され，漂砂の場合ほど脱落防止を厳重にする必要はない。したがって，ここでは特殊な接着剤は用いず，容易に入手できる蛍光着色材料のなかから，不水溶性で，しかも 254, 365 nm の携帯用紫外線ランプが入手容易なことから，これらの光で蛍光を発する材料として，有機蛍光体の一種であるアントラセンと蛍光顔料を溶かした市販の樹脂系蛍光塗料とを用いた。

ほかに，塩基性染料である，オーラミン，ローダミンB，ビクトリアブルーBについても着色実験を行ったが，いずれも着色粒子の蛍光発色が弱く，未着色粒子との識別が困難であった。

以下，蛍光粒子の具体的な作成方法について記す。

1. アントラセン

アントラセン約 17 g を溶剤のクロロホルム 1 *l* に溶

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* Yuhki NAKASHIMA: The movement of eroding soil as observed with fluorescent soil particles (I) A fluorescent-dyeing technique and an example of practical use
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