皆伐跡地における萌芽更新

地上部現存量および養分量の変化

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論　文

Sprout Shoot Regeneration in a Clear-Cut Deciduous Broadleaved Forest ——The Recovery of Aboveground Biomass and Nutrients——

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KATAGIRI, Shigeo, SHIMA, Kazuto, and KANEKO, Nobuhiro: **Sprout shoot regeneration in a clear-cut deciduous broadleaved forest—The recovery of aboveground biomass and nutrients— J. Jpn. For. Soc. 72 : 388～398, 1990** The recovery of aboveground biomass and nutrients in sprout shoots was studied for two years after clear cutting in the Sanbe Forest of Shimane University. Although the number of sprout shoots decreased in the second year, the mean diameter and length of shoots in the second year increased to about twice of those of the first year. The weight of the nonphotosynthetic organs and leaves in the second year also increased to 1.5～1.8, and 1.1～1.7 times, respectively, of those of the first year. The increases in weights tended to differ depending on the species. The nutrient concentrations of nitrogen, phosphorus, and potassium in both leaves and shoots were greater in the first year than in the second. Calcium and magnesium concentrations in the leaves and shoots increased from the first to the second years. The amounts of nutrient elements that were accumulated in the sprout shoots on four experimental plots were 18～33 for nitrogen, 1.1～2.1 for phosphorus, 12～26 for potassium, 3.2～6.3 for magnesium, and 14～25 kg/ha for calcium. These amounts corresponded to about 10% of the nutrient accumulation in a deciduous broadleaved forest before clear cutting.

片桐成夫・嶋　一徹・金子信博：**皆伐跡地における萌芽更新—地上部現存量および養分量の変化—　日林誌 72：388～398, 1990**　落葉広葉樹二次林の伐採跡地に更新した萌芽の地上部現存量と養分量の変化を2年間にわたって調査した。萌芽本数は伐採後2年目には1年目の約半分に減少した。萌芽の平均直径・平均長は着実に増加し，2年目には1年目の約2倍となった。四つの調査プロットにおいて萌芽の地上部現存量は2年目に同化部で1年目の1.1～1.7倍，非同化部で1年目の1.5～1.8倍となった。地上部現存量の増加の傾向は樹種によって異なった。萌芽の養分含有率の変化は元素によって異なり，チッ素・リン・カリウムは伐採後1年目が最も高く，2年目には低下した。これに対して，マグネシウム・カルシウムは伐採後1年目から2年目にかけて上昇する傾向を示した。4個のプロットの養分量は2年間でチッ素が18～33，リンが1.1～2.1，カリウムが12～26，マグネシウムが3.2～6.3，カルシウムが14～25 kg/haに達した。この量は伐採前の落葉広葉樹二次林の養分量のおおよそ10%に相当し，森林の物質循環系の回復における萌芽更新の高い能率を示唆した。

I. Introduction

Deciduous broadleaved forests dominated by *Quercus serrata* MURRAY are widely distributed in the Chugoku Mountains of Japan. These forests naturally regenerate by sprout shoots coppice rather than by seedlings after a forest cutting. The process of the growth and dynamics of sprout shoots during the early stage of regeneration already has been reported(*13*). There have been many studies on the sprout regeneration of broadleaved forests in Japan(*1,2,8,9*). The proper time of cutting is from winter to early spring while plants stop growing (*1,2*). Differences in the cutting points of trees also influences sprout regenera-

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tion(*1*). The use of chain saws appears to have reduce the number of coppice shoots on a stump somewhat compared with hand-axe cutting(*11*). These factors, in addition to the differences in species, also affect sprouting.

The aboveground biomass and the amounts of nutrient elements rapidly increase after the cutting of a forest(*3*,*4*). On lower slopes, the amounts of grasses are a large proportion of the total amount of regenerative reproduction one or two years after cutting. On upper slopes, the proportion of tree species is very large. This result suggests that the increase in aboveground biomass by sprout regeneration is very important for nutrient cycling on the clear cutting sites because the species which regenerates easily by sprouts, *Q. serrata* is distributed on the upper slopes.

Considered from the viewpoint of nutrient cycling in a forest ecosystem, the nutrient elements included in sprout shoots on a cutting area, as well as their dry weight, are expected to increase rapidly. However, there have been few detailed studies of nutrient cycling on sprout regeneration sites.

This paper deals with the recovery of the above ground biomass and the amounts of nutrient elements created by sprout regeneration over a period of two years after clear cutting of a secondary deciduous broadleaved forest.

II. Study Site and Methods

The study site is located in the Sanbe Forest of Shimane University, in Tonbara, Shimane Prefecture (35°10′N, 132°40′E, elevation 470 m). An experimental plot measuring 20 m × 60 m was established on a southwest slope. The soil type is almost $B_{D(d)}$ on the experimental plot and B_B near the ridge top above the plot. The plot was a secondary deciduous broadleaved forest dominated mainly by *Q. serrata*. The composition of tree species and their densities and sizes are shown in Table 1. *Q. serrata*, *Carpinus Tschonoskii* MAXIM., *C. laxiflora* BL. and *Clethra barvinervis* SIEB. et ZUCC. dominated, with 17.8, 13.1, 18.9, and 7.7, respectively, in their proportions of trees. The mean diameter was rather small, reflecting the stand age. This site seemed to have good conditions for easy regeneration by sprouts.

All trees were felled in March, 1986 to prepare for an examination of sprout regeneration. The plot was divided into 12 subplots measuring 10 m × 10 m. Four subplots (Nos.4, 5, 8, and 11) were selected on which to measure the diameters and lengths of all sprout shoots, and another four subplots (Nos.1, 6, 7, and 10) were selected on which to measure the weights of the sprout shoots (Fig. 1).

Table 1. Outline of experimental plot before cutting

Species	Tree densities (no./ha)	Mean diameters (cm)	Mean tree heights (m)
Quercus serrata MURRAY	834	7.5	7.6
Carpinus Tschonoskii MAXIM.	613	6.5	7.0
Carpinus laxiflora BLUME	885	5.3	6.4
Prunus Jamasakura S. ex KOIDZ.	251	10.2	8.9
Styrax japonica S. et Z.	201	6.6	7.0
Clethra barvinervis S. et Z.	362	5.6	6.6
Fagus crenata BLUME	131	6.0	6.8
Albizzia Julibrissin DORAZZ.	201	9.9	8.4
Lindera umbellata THUNB.	302	3.7	5.2
Other	895	6.2	6.9
All species	4675	6.5	7.0

Fifty-five sample stumps on which sprout shoots occurred were selected on these plots in both the first and second years after cutting. These sample stumps were of the following 11 species, ten stumps each of *Q. serrata* and *C. barvinervis*, five stumps each of *C. Tschonoskii*, *C. laxiflora*,

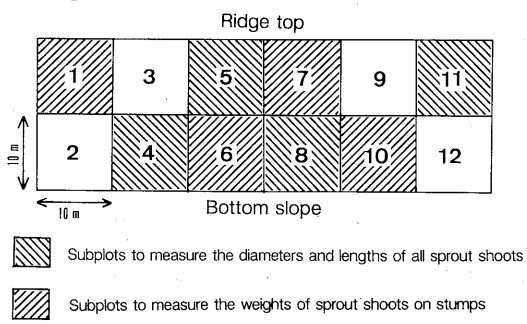

Fig. 1. Distribution of subplots on the experimental plot in the study area

Prunus Jamasakura SIEB. ex KOIDZUMI, and *Lindera umbellata* THUNB., and three stumps each of *Fagus crenata* BL., *Styrax japonica* SIEB.et ZUCC., *Magnolia obovata* THUNB., *Rhus trichocarpa* MIQ. and *Acer Sieboldianum* MIQ.

All sprout shoots were cut in August of both 1986 and 1987, and the base diameters and the shoot lengths were measured. The weights of leaves and shoots were measured individually for only five *Q. serrata* stumps. For the other 50 stumps, the weights were measured of leaves and shoots together for each stump.

The aboveground biomasses of sprout shoots on the four subplots on which diameters and lengths were measured, were estimated by the relationship between total leaves and nonphotosynthetic organ and the sum of D_0^2L for each stump.

The amounts of nutrients accumulated in the aboveground biomasses of sprouts on the four subplots were calculated by multiplying the mean nutrient concentration of each species by its aboveground biomass.

Samples of leaves and shoots for chemical analyses were collected from each stump. Chemical analyses were performed for nitrogen, phosphorus, potassium, calcium, and magnesium. Nitrogen concentration was determined by the KJELDAHL method. Phosphorus concentration was measured by the molybdate blue method by colorimetry. The concentrations of potassium, calcium, and magnesium were determined by atomic absorption spectrophotometry.

III. Results and Discussion

1. *The sizes of sprout shoots*

After cutting a deciduous broadleaved forest, the time that sprout regeneration begins depends upon the characteristics of the species. In a forest dominated by *Q. serrata*, sprout shoots begin to appear abundantly and grow vigorously. The process of appearance and the death of sprouts in an early stage already have been reported(*13*). This section deals with the growth increments of diameters and lengths of sprouts on the sample stumps.

1) The changes in diameters and lengths of sprout shoots

The mean number of sprout shoots per stump, diameters and lengths of sprout shoots for each species in both the first and second years after cutting are shown in Table 2. The number of sprouts of *Q. serrata*, *S. japonica*, *C. barvinervis*, and *A. Sieboldianum*, which were about 30 for each stump in the first year after cutting, decreased to about half of that in the second year. There were four species, which had about ten sprouts in the first year. Two that decreased remarkably were *C. Tschonoskii* and *C. laxiflora*, and two which did not change were *R. trichocarpa* and *M. obovata*.

Table 2. Stand data for first and second years after cutting

Species	Number of sampling stumps	Mean numbers of sprouts per stump		Mean sprout diameters at bases (mm)		Mean sprout lengths (cm)	
		Year after cutting					
		1st	2nd	1st	2nd	1st	2nd
Prunus Jamasakura	5	34.6	19.6	5.2	12.0	64.5	134.5
Styrax japonica	3	33.3	16.0	3.5	9.7	49.7	112.1
Quercus serrata	10	31.1	18.6	4.8	7.9	55.5	81.2
Clethra barvinervis	10	26.9	12.7	4.5	7.7	33.9	66.8
Acer Sieboldianum	3	26.3	12.7	3.4	5.2	34.1	42.2
Carpinus laxiflora	5	11.4	3.0	3.3	6.7	38.7	73.5
Magnolia obovata	3	11.3	7.0	9.4	13.1	55.7	100.1
Rhus trichocarpa	3	9.3	8.7	9.2	10.9	42.5	71.0
Carpinus Tschonoskii	5	7.6	4.2	4.0	6.6	42.5	67.7
Fagus crenata	3	2.3	6.3	5.2	5.3	19.6	37.7
Lindera umbellata	5	1.6	8.8	5.4	5.8	35.0	61.8

The mean diameters at the bases and the mean lengths of the sprouts became larger in the second year. The increments of some species which sprout number decreased remarkably were larger than those of *R. trichocarpa* and *M. obovata* which did not decrease much in terms of sprout numbers. Regarding the average size, sprout regeneration was of two types, one which had many shoots that were small in size, and the other which had a lesser number of shoots but they were large in size. The sizes of sprouts increased in both diameter and length as the year progressed. The growth of sprout shoots for a year from spring to autumn ordinarily was large in the period from mid-May to July but decreased after the summer (*13*).

The relationships between diameters and lengths of sprout shoots are shown in Fig. 2.

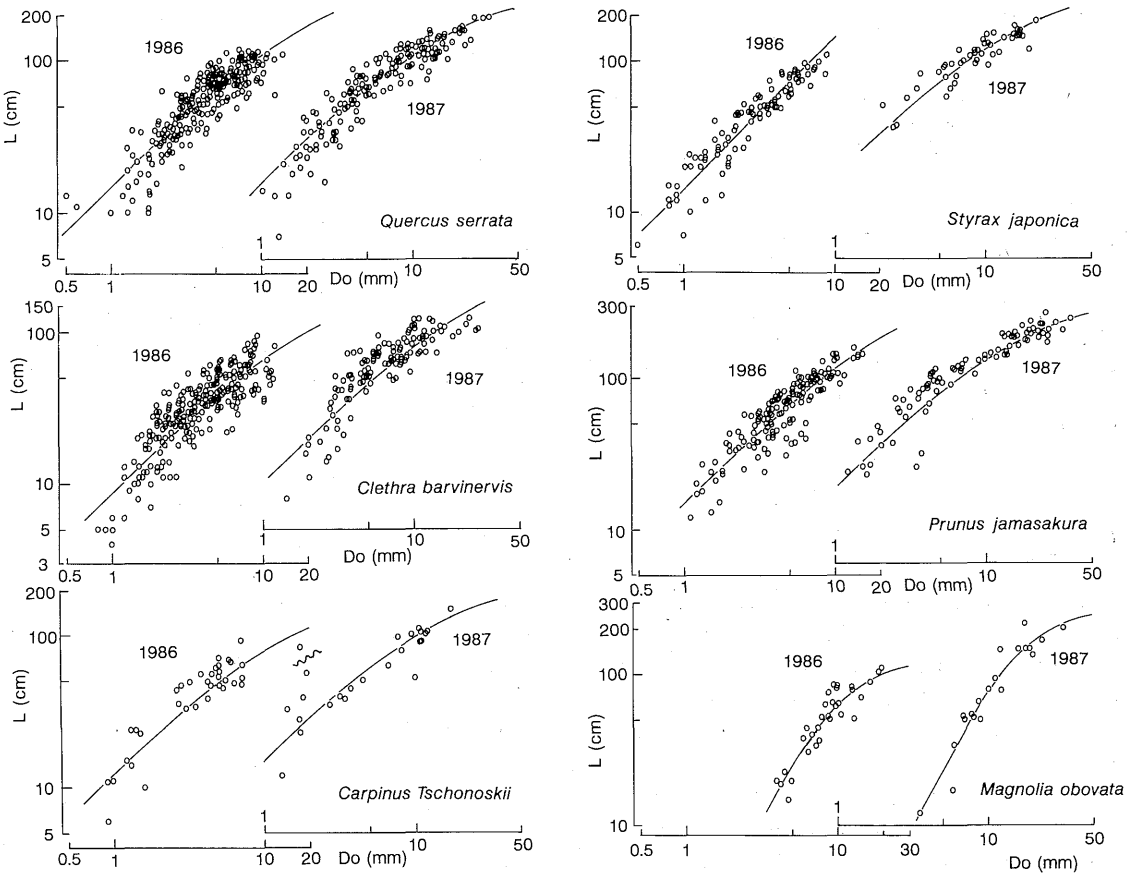

Fig. 2. Relationships between base diameters and shoot lengths in the first and second years after cutting

These relationships could be fitted to the reciprocal equation, $1/L=b/D^h+a$, where L is the length of a shoot, D is the base diameter, and a, b, and h are coefficients. It differed by species and years after cutting. In the first year, the coefficient "h" was 2 for *M. obovata* and *R. trichocarpa* whose growths of diameters were large. For the other species, the coefficient "h" was 1. These relationships moved to the upper-right of the figures, but they did not change from the R-G relationships in which the coefficient "h" was 2 to the C-D relationships of which the coefficient "h" was 1.

According to YAMAKURA (*15*), the relationships between the diameters, and the heights of trees showed the C-D relationship in an early stage of a plantation forest and approached the R-G relationship as the competition became severe. SAITO *et al.* (*12*) also showed that the coefficient "a" changed as time passed for hinoki, *Chamaecyparis obtusa* ENDL. stands. The relationships between diameters and lengths of understory species also is different among some species, and the coefficient "a" becomes larger following the order of increasing shade tolerance (*10*). The differences in the D-L relationships among species appeared clearly in this study. The light intensity was uniform on this experimental site because of clear cutting. The sprout shoots competed within the stumps immediately after cutting. However, the density was not so great, and the shoot sizes were very small. Therefore, the C-D relationship was recognized between shoot diameters and heights of most species in the early stage of regeneration. On the other hand, the R-G relationship was recognized in only the species in which the growth in the early stage was very fast.

Table 3. Dry weights of aboveground parts of sprout shoots

Species	Number of sampling stumps	Nonphotosynthetic parts (g/stump)		Photosynthetic parts (g/stump)	
		Year after cutting			
		1st	2nd	1st	2nd
Prunus Jamasakura	5	186.7	1158.3	143.0	548.7
Quercus serrata	10	135.8	396.8	147.0	313.9
Styrax japonica	3	57.5	384.0	61.5	218.3
Magnolia obovata	3	81.6	264.7	154.8	208.7
Clethra barvinervis	10	51.3	158.0	68.3	125.2
Rhus trichocarpa	3	75.1	113.4	102.7	117.2
Carpinus laxiflora	5	15.1	68.5	24.1	52.1
Carpinus Tschonoskii	5	17.6	59.8	33.4	61.5
Acer Sieboldianum	3	28.8	51.2	31.0	30.7
Lindera umbellata	5	4.2	49.5	5.6	39.4
Fagus crenata	3	2.2	18.2	2.7	11.5

2) Weight changes of sprout shoots

The aboveground weights of sprout shoots increased from the first year to the second year as shown in Table 3. The weights of nonphotosynthetic organs in the second year became 1.5~1.8 times those of the first year. The weights, of the photosynthetic organs in the second year also became 1.1~1.7 times those of the first year. *L. umbellata* and *F. crenata* increased remarkably in the rates of weight increases from the first to the second year. On the other hand, *M. obovata* and *R. trichocarpa* which grew faster than them in the first year, increased less in the second year. The weights of nonphotosynthetic organs would increase after the third year. Because the weights of leaves already had grown greatly in the first year after cutting, the rates of increases from the first year to the second year became small.

Although the aboveground biomass usually is estimated by the equation of relative growth, it would be necessary to examine whether this equation could be applied to the estimation of the aboveground biomass of sprout shoots because the weights of the sprout shoots of all species were measured in a unit, not of individuals but of stumps, in this study.

The weights of *Q. serrata* were measured in a unit of five individual stumps. The relationships between the weights and D_0^2L of individual shoots is shown in Fig. 3. The fluctuations of all of the sprout shoots of the five stumps shown in this figure are rather large. However, these relationships were not for separate stumps but could be expressed by a linear regression. These equations were shown as follows:

For the first year
$$\log W_S = 0.8100 \times \log D_0^2L - 0.4420 \quad (r=0.977)$$
$$\log W_L = 0.7117 \times \log D_0^2L - 0.2450 \quad (r=0.939)$$

For the second year
$$\log W_S = 0.8569 \times \log D_0^2L - 0.3895 \quad (r=0.981)$$
$$\log W_L = 0.7847 \times \log D_0^2L - 0.3372 \quad (r=0.962)$$

where W_S and W_L are the weight of nonphotosynthetic organs and photosynthetic organs, respectively. D_0 is the diameter of a sprout shoot at its base, and L is the length of a sprout shoot.

The relationships between the nonphotosynthetic organs and D_0^2L in which the weights increased separately between the first and second year is translating in the positive direction of the weights. However, these regression lines were not clearly separate for the photosynthetic organs.

The relationships of the 55 sample stumps, including 11 species, between the sum of D_0^2L and the total weights of the nonphotosynthetic parts of the sprouts on a stump, and that between the sum of D_0^2L and the total leaf-weights are shown in Fig. 4 a and b, respectively. These relationships are expressed by one linear regression regardless of the differences in species, although they differed in the year after cutting. The same relationships were recognized between the sum of D_0^2L and the aboveground weights of a unit area in the estimation of the aboveground biomass of a forest understory(5). The equations of this relationship for the nonphotosynthetic and photosynthetic organs are as follows:

For the first year
$$\log(\sum W_S) = 0.9018 \times \log(\sum D_0^2L) - 0.5462 \quad (r=0.984)$$
$$\log(\sum W_L) = 1.0133 \times \log(\sum D_0^2L) - 0.7390 \quad (r=0.966)$$

For the second year
$$\log(\sum W_S) = 0.9206 \times \log(\sum D_0^2L) - 0.5039 \quad (r=0.984)$$
$$\log(\sum W_L) = 0.7944 \times \log(\sum D_0^2L) - 0.2482 \quad (r=0.960)$$

where $\sum W_S$ and $\sum W_L$ are the weights of nonphotosynthetic and photosynthetic organs of the sprouts on stumps, respectively. $\sum D_0^2L$ is the sum of D_0^2L of sprout shoots on the stumps.

From this result, the aboveground biomass of the sprouts could be estimated, and the values of the four

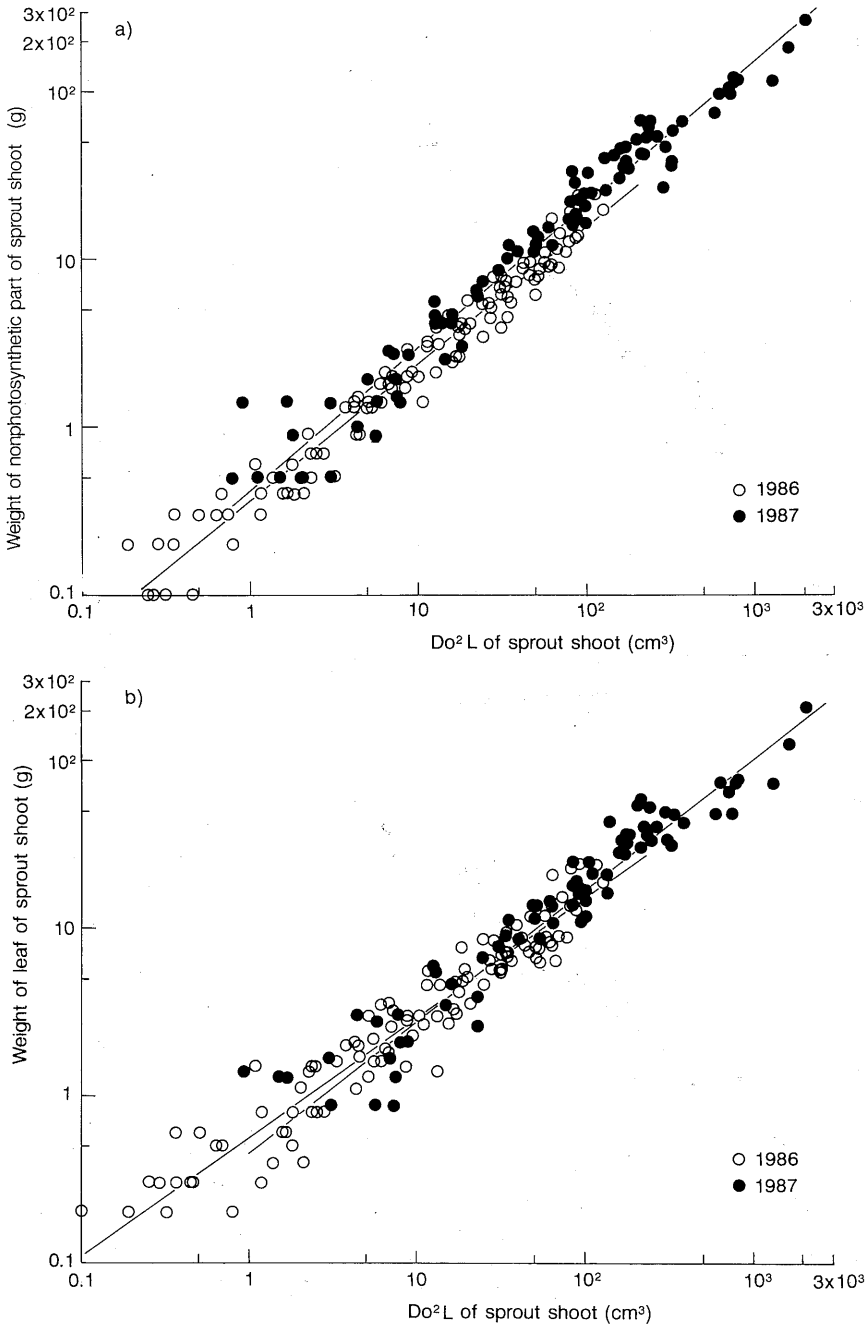

Fig. 3. Relationships between dry weights and D_0^2L of sprout shoots of *Q. serrata* in the first and second years after cutting; a) leaf, b) nonphotosynthetic organs (stem and branches)

subplots of this study area are shown in Table 4. The total aboveground biomasses of nonphotosynthetic and photosynthetic organs on the four subplots was 0.49～1.10 t/ha in the first year and 1.49～2.80 t/ha in the second year. The weights increased steadily during the year. These weights differed somewhat on a slope, and the maximum value attained was about twice that of the minimum value. This difference depended on

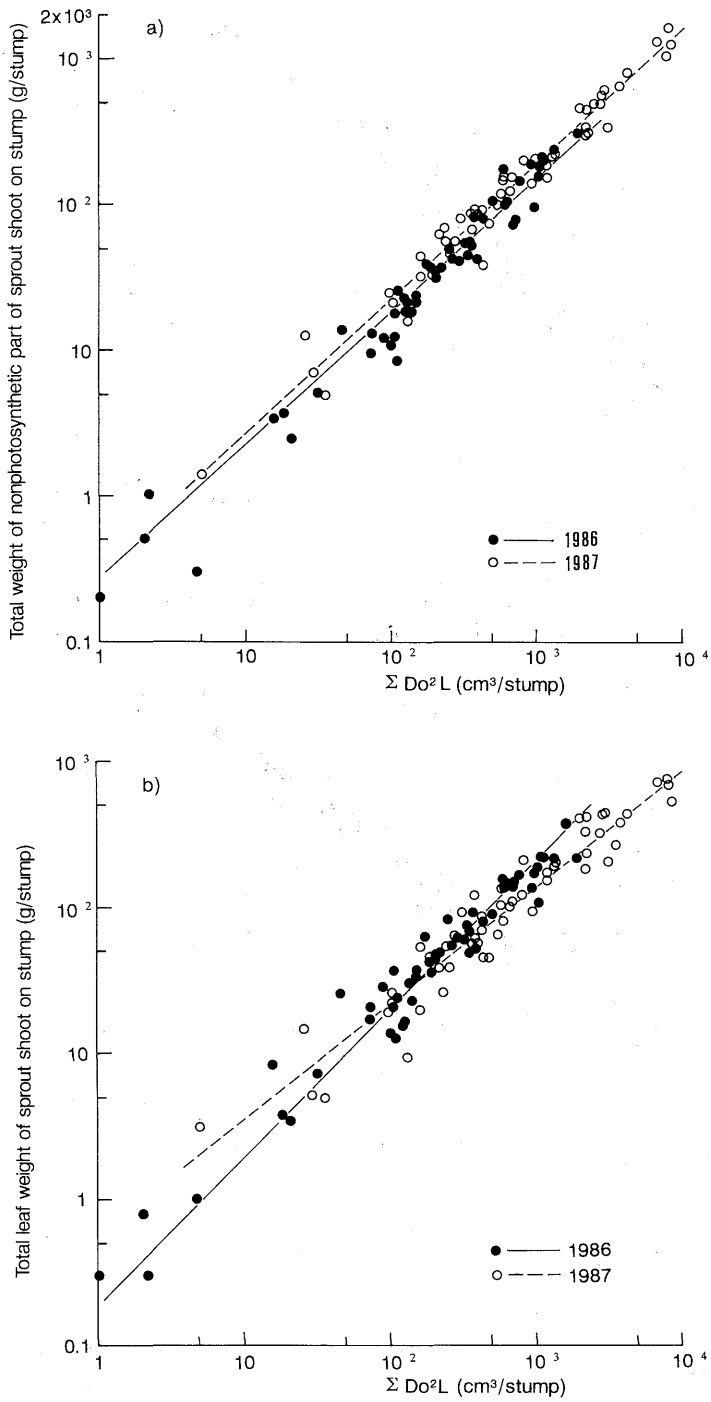

Fig. 4. Relationships of 55 sample stumps, including 11 species, between total dry-weights and sum of D_0^2L of sprout shoots on a stump after cutting; a) total leaves, b) total nonphotosynthetic organs

the difference in the number of stumps and species compositions among the four subplots.

The proportion of the photosynthetic organs in the total biomass of sprouts was 58~61% in the first year, decreasing to 36~37% in the second year. The recovery of leaf biomass was excellent just after cutting, and the increase in the nonphotosynthetic organs became more vigorous than that of leaves in the second year. KATAGIRI, and NAKAO(*4*) reported that the sprout biomass proportion of the total aboveground biomass increased, and that the leaf proportion of the sprouts decreased with time over a period of five years on another clear-cut area of the Sanbe Forest of Shimane University. Leaf-biomass distribution usually accounts for a large part of the total biomass in the early stage of a forest. It becomes smaller as the leaf biomass approaches a constant value. Sprout regeneration on the cutting area also was similar to the change in the leaf distribution.

2. Changes in the nutrient concentrations of sprout shoots

There have been many studies on the seasonal changes in the nutrient elements of trees in mature forests (*6*), and on the relationships between the growth and nutrient contents of planted trees such as *Cryptomeria japonica* D. DON, *Chamaecyparis obtusa* and so forth. However, no study has been made of the nutrient concentrations in grasses, herbs, and trees in cutting areas. KATAGIRI (*3*) showed that the nutrient concentrations of trees and herbs in the cutting areas of deciduous broadleaved forests were large in the first year after cutting. KATO (*7*) also showed that the nitrogen and phosphorus

concentrations of *Rubus* sp. sprouts became larger just after weeding on a plantation area.

The sprout leaf nutrient concentrations of 11 species were analyzed in the 55 sample stumps. The values were as follows on average: 2.42 % for nitrogen, 0.143 % for phosphorus, 1.60 % for potassium, 0.38 % for magnesium, and 1.20 % for calcium in the first year, and 2.10 % for nitrogen, 0.109 % for phosphorus, 1.53 % for potassium, 0.43 % for magnesium, and 1.62 % for calcium in the second year. Those of nonphotosynthetic organs were 0.76 % for nitrogen, 0.077 % for phosphorus, 0.88 % for potassium, 0.12 % for magnesium, and 0.40 % for calcium in the first year, and 0.58 % for nitrogen, 0.056 % for phosphorus, 0.55 % for potassium, 0.11 % for magnesium, and 0.56 % for calcium in the second year. Although these mean concentrations reflected the difference in species and the variances among individuals, the concentrations of nitrogen, phosphorus, and potassium were greater in the first year than in the second.

Figure 5 shows the mean nutrient concentrations of sprouts of each species in the first and second year and those of mature canopy trees which were analyzed on an adjacent site (*6*). The nutrient concentrations of sprouts differed for each species. For example, the leaves of *S. japonica* and *C. Tschonoskii* had large nitrogen concentrations in contrast to the leaves of *F. crenata*, *C. barvinervis*, and *M. obovata* which had rather small nitrogen concentrations. As for the nonphotosynthetic organs, *C. Tschonoskii*, *C. laxiflora*, and *A. Sieboldianum* had large nitrogen concentrations, whereas the nitrogen concentrations in *C. barvinervis*, *P. Jamasakura*, and *R. trichocarpa* were small. These differences in nutrient concentrations, however, were not always common to other nutrient elements.

Moreover, the concentrations of nitrogen, phosphorus, and potassium in the first year were larger in almost all species in comparison with those of overstory and understory trees in the deciduous broadleaved forest at Sanbe. In the second year, these nutrient concentrations decreased, however, they were still greater than the nutrient concentrations in trees in a mature forest. The growth of sprout shoots in the early stage after cutting is very fast. The demand for nutrient elements for growth might differ by the degree of sprouting that occurs. Species which sprout easily would demand the three main elements of nitrogen, phosphorus, and potassium in the early sprouting stage. Therefore, sprout shoots in the first and second years have large nutrient concentrations compared with mature trees, and the differences among species also are large.

On the other hand, magnesium concentrations were not different among sprouts in the first and second years and in the mature overstory trees except for a remarkably large value in *R. trichocarpa* in the first and second years. The change of magnesium concentration is generally stable, because it is the constituent element of chlorophyll and is independent of the difference of early sprout growth. Although the concentration of calcium was not recognized because of wide fluctuations, it increased from the first to the second years in *Q. serrata*.

Table 4. Changes in aboveground biomass of sprouts after cutting

Subplot No.	Organ	1st year (t/ha)	2nd year (t/ha)
4	Photosynthetic	0.67	1.01
	Nonphotosynthetic	0.43	1.76
	Total	1.10	2.77
5	Photosynthetic	0.47	1.07
	Nonphotosynthetic	0.34	1.73
	Total	0.81	2.80
8	Photosynthetic	0.40	0.57
	Nonphotosynthetic	0.27	0.92
	Total	0.67	1.49
11	Photosynthetic	0.28	0.62
	Nonphotosynthetic	0.21	0.98
	Total	0.49	1.60

KATO (*7*) also showed that nitrogen and phosphorus concentrations increased in *Rubus* sp. sprouts regenerated after weeding, and that nitrogen, phosphorus, and potassium were absorbed rapidly from the soil in sprout regeneration and were accumulated in the photosynthetic and nonphotosynthetic parts of sprouts. This tendency was recognized not only in sprouts but also in grasses and trees regenerated after clear cutting. On the other hand, the calcium concentration in regenerated sprouts after weeding was equal to or less than that before weeding. Changes in calcium concentrations were different from those of nitrogen, phosphorus, and potassium, and calcium concentrations gradually increased as the sprouts grew.

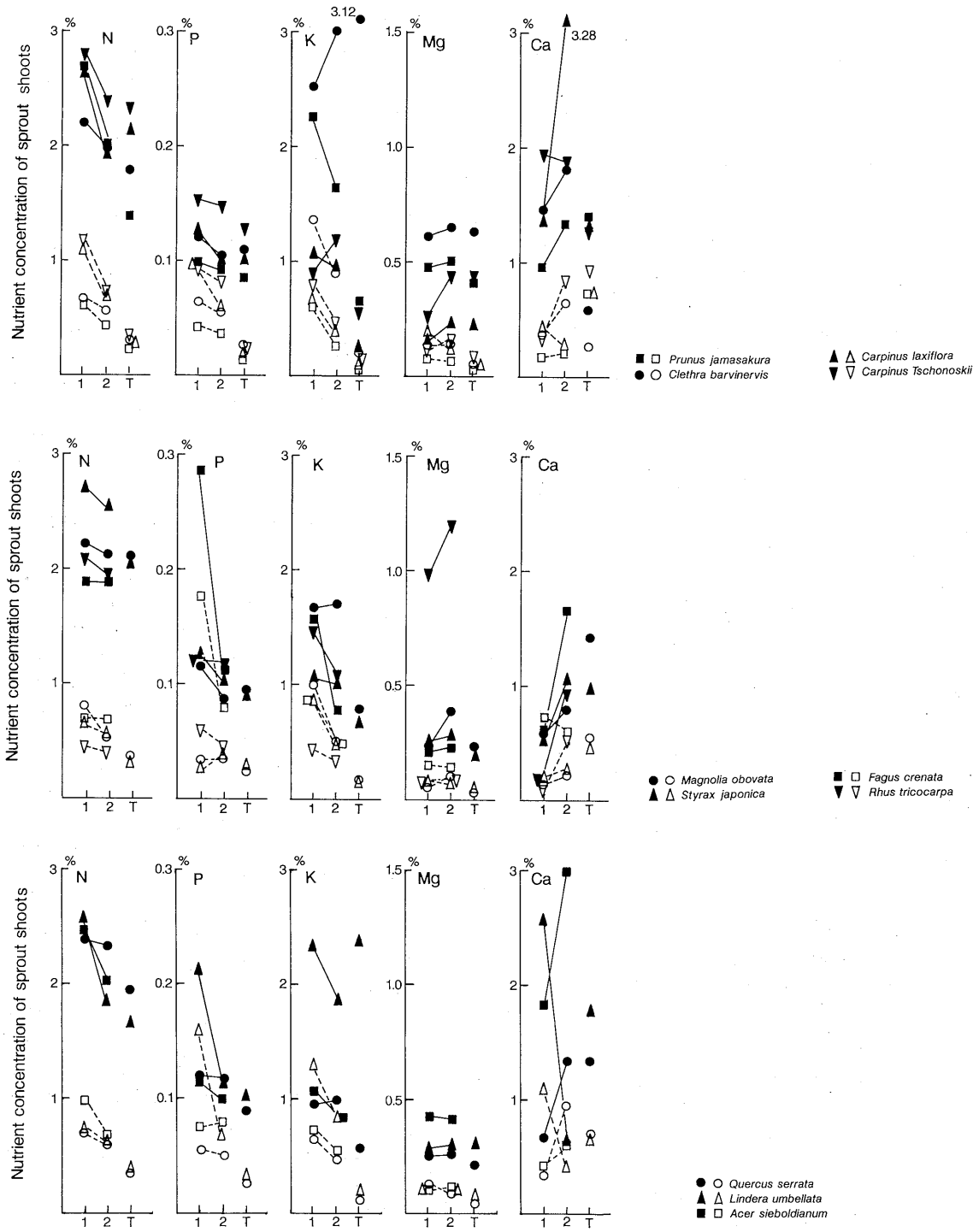

Fig. 5. Nutrient concentrations in leaves and shoots of sprouts of each species one and two years after cutting

Black symbols with solid lines, leaves; white symbols with dashed lines, shoots (branches and stems). 1, One year after; 2, Two years after; T, Mature trees.

Table 5. Amounts of nutrient elements in sprouts after clear cutting

Elements	Subplot No.	Nonphotosynthetic organs (kg/ha) 1st year	Nonphotosynthetic organs (kg/ha) 2nd year	Photosynthetic organs (kg/ha) 1st year	Photosynthetic organs (kg/ha) 2nd year	Totals (kg/ha) 1st year	Totals (kg/ha) 2nd year
N	4	3.27	10.17	16.23	21.41	19.50	31.58
	5	2.35	9.60	11.59	23.79	13.94	33.39
	8	1.91	5.31	9.94	12.24	11.85	17.55
	11	1.47	5.28	6.90	13.28	8.37	18.56
P	4	0.29	0.95	0.93	1.10	1.22	2.05
	5	0.19	0.83	0.61	1.17	0.80	2.00
	8	0.17	0.50	0.56	0.64	0.73	1.14
	11	0.13	0.47	0.38	0.64	0.51	1.11
K	4	3.89	9.74	10.42	16.40	14.31	26.14
	5	2.64	8.24	6.15	13.57	8.79	21.81
	8	1.97	4.38	6.69	7.72	8.66	12.10
	11	1.92	5.51	4.91	10.63	6.83	16.14
Mg	4	0.46	1.99	2.32	4.26	2.78	6.25
	5	0.36	1.72	1.42	3.62	1.78	5.34
	8	0.29	0.99	1.50	2.20	1.79	3.19
	11	0.24	1.06	1.13	2.69	1.37	3.75
Ca	4	1.52	9.18	7.32	14.98	8.84	24.16
	5	1.04	10.81	3.81	14.97	4.85	25.78
	8	0.83	5.49	4.14	9.00	4.97	14.49
	11	0.68	4.37	3.11	9.65	3.79	14.02

3. *Changes in the amounts of nutrient elements in the aboveground biomass of sprouts*

As stated above there was a steady increase in the aboveground biomass of sprouts regenerated after clear cutting. The amounts of nutrient elements accumulated in the aboveground biomass of sprouts on four subplots, both in the first and second year, were calculated by multiplying the mean nutrient concentration of each species by its aboveground biomass. The results are shown in Table 5.

As for all elements, the amounts of nutrients accumulated in leaves were larger than those in nonphotosynthetic parts in both the first and second years. The amounts of all nutrient elements of both leaves and nonphotosynthetic organs increased from the first to the second year. The amounts of nitrogen, phosphorus, and potassium of leaves in the second year were 1.14～2.21 times those in the first year. On the other hand, the amounts of nonphotosynthetic organs in the second year were 2.1～4.4 times those of the first year, and their rates of increase was large compared with those of leaves.

The amounts of magnesium and calcium increased remarkably during the second year, and they were 1.5～3.9 times greater in leaves and 3.4～10.4 times greater in nonphotosynthetic organs than those in the first year. This resulted from the large increases in the weights of nonphotosynthetic parts and the constant or increasing trends of magnesium and calcium concentrations in contrast to the decreases of nitrogen, phosphorus, and potassium concentrations from the first to the second year.

The amounts of nutrient elements in the second year were 18, 19, 32, and 33 kg/ha for P-8, P-11, P-4, and P-5, respectively, for nitrogen, 1.1, 1.1, 2.0, and 2.1 kg/ha for P-11, P-8, P-5, and P-4, respectively, for phosphorus, 12.1, 16.1, 21.8, and 26.1 kg/ha for P-8, P-11, P-5, and P-4, respectively, for potassium, 3.2, 3.8, 5.3, and 6.3 kg/ha for P-8, P-11, P-5, and P-4 for magnesium, and 14, 14, 24, and 25 kg/ha for P-11, P-8, P-4, and P-5 for calcium, on the four subplots. These values were very small and corresponded to about 10 % of the nutrient accumulations aboveground in a mature deciduous broadleaved forest which had developed by sprout regeneration at Sanbe (*6*). Considering that the aboveground biomass of sprouts corresponded to only 2 % of that of the mature deciduous broadleaved forest, however, very large amounts of nutrients had already been accumulated in the second year. According to UHL, and JORDAN (*14*), nutrient percentages were larger than biomass percentages on a 5-year-old forest site following cutting and burning compared to those before such treatment in Amazonia.

According to KATAGIRI (*3*), the nutrient accumulations aboveground, including grasses and trees regenerated by seedlings, were 24～76 kg/ha for nitrogen, 1.2～4.3 kg/ha for phosphorus, 20～66 kg/ha for potassium, 2.9～7.5 kg/ha for magnesium, and 24～57 kg/ha for calcium in the second year after cutting. The nutrient accumulations of sprouts in the second year in this study corresponded to about a third or half of the total accumulation on the cutting area.

Seedling regeneration by grasses was predominant on the lower slope, and regeneration by trees, including sprouts, was superior on the upper slope. The biomass of grasses decreased with increases in tree biomass on the lower slope. Tree biomass on the upper slope increased continuously compared with the

change in the grass biomass on the lower slope. The dry weight of sprout regeneration tended to increase while ascending the slope. Furthermore, the nutrient accumulations in sprout shoots and leaves also were large in the early stage of sprout regeneration. Thus, the recovery of sprout regeneration was very rapid, especially on the upper slope. Therefore, sprout regeneration plays a more important part in the recovery of the nutrient cycling system than does artificial regeneration.

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* The title in parentheses in tentative translation from the original Japanese title by the author.

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