

壮齡林の肥培に関する研究 XII

スギ・ヒノキ林分の生長および溪流の水質変化に及ぼすヘリコプター施肥の影響

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論 文

Studies on Fertilization in Established Stands (XII)
On Tree Growth and Water Quality in the Stream
after Fertilization by Helicopter in *Sugi*
(*Cryptomeria japonica*) and *Hinoki*
(*Chamaecyparis obtusa*) Stands*

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HAIBARA, Kikuo, KAWANA, Akira & NABESHIMA, Hiroshi : Studies on fertilization in established stands (XII) On tree growth and water quality in the stream after fertilization by helicopter in *Sugi* (*Cryptomeria japonica*) and *Hinoki* (*Chamaecyparis obtusa*) stands J. Jap. For. Soc. 59 : 41~51, 1977
Sugi and *Hinoki* plantation in Sando Forest (property of Mitsui & Co. Ltd.) located in Nabeshima-cho, Kitamuro-gun, Mie prefecture, was fertilized by helicopter. Tree growth, nutrient content in the needles, and concentrations of $\text{NH}_3\text{-N}$, $\text{NO}_3\text{-N}$, P, K, Ca, and Mg in the stream were surveyed after aerial application of fertilizers by helicopter. The results are as follows : (1) Aerial application by helicopter proved to be economically profitable on a large scale. (2) Tree growth increased after the helicopter fertilization in both *Sugi* and *Hinoki* stands. In the case of the 41-year-old *Hinoki* stand, the current annual increment of the stem volume was $5 \text{ m}^3/\text{ha}$ before fertilization, but it increased to $13 \text{ m}^3/\text{ha}$ in three years following the fertilization. (3) Ammonium- and nitrate-nitrogen in the streamflow of watershed increased by 0.01 ppm~0.03 ppm and 0.1 ppm~0.3 ppm, respectively, for a certain period. The amount of ammonium nitrogen discharged from fertilized watershed per ha per year remained at a high level for 5 to 6 months after the application. A high level of nitrate-nitrogen was maintained for a longer period than that of ammonium nitrogen, but the concentration of nitrate-nitrogen decreased at the lower reaches of the stream. As the phosphorus concentration was lower than 0.01 ppm, it is unlikely to have any significant effect on water pollution.

生原喜久雄・川名 明・鍋島 寛 : 壮齡林の肥培に関する研究 (XII) スギ・ヒノキ林分の生長および溪流の水質変化に及ぼすヘリコプター施肥の影響 日林誌 59 : 41~51, 1977
ヘリコプター施肥をスギ, ヒノキ林分に行なった。その結果, 生長増加がみられ, 費用も人為より安い。葉の養分含有率の変化ではヒノキ 20, 21 年生およびスギ 14 年生林分の P の増加が著しい。施肥により溪流の $\text{NH}_3\text{-N}$ および $\text{NO}_3\text{-N}$ 濃度がそれぞれ 0.01~0.03 ppm, 0.1~0.3 ppm 高くなる場合もみられた。また, 採水点に流出する ha 当りの養分量でも, $\text{NH}_3\text{-N}$ および $\text{NO}_3\text{-N}$ の増加が場所によってみられた。 $\text{NH}_3\text{-N}$ の場合は施肥後 5~6 か月後には差はみられなくなるが, $\text{NO}_3\text{-N}$ は $\text{NH}_3\text{-N}$ よりも長期間高い値が続いているようである。しかし, その増加量の絶対値はそれほど大きくない。下流になると $\text{NO}_3\text{-N}$ 濃度は低くなるようである。P 濃度は 0.01 ppm 以下なので, P の汚染については問題ないと思われる。

I. Introduction

Aerial fertilization of established forests is a common practice in Northern Europe, the U.S.A.

and Canada. In Oceanian countries and in Europe, small airplanes are used, whereas in the U.S.A. and Canada, helicopters are mainly used for fertilization (6, 20). In Japan, several reports were

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made of helicopter application of fertilizers on the fields after land slips around the year 1963, but a more commonly accepted initial date for aerial fertilization in general stands is 1967. Now there are detailed reports on application methods and results, such as spreading methods, dropping of fertilizers, distribution, and burn damage to trees after fertilization (26, 27, 29, 30, 31). However, only a limited amount of information is available on the rate of tree growth following fertilization (25).

WERNER (35) pointed out the need for prompt investigation of various influences aerial fertilization might have on the ecosystem of rivers, streams, and lakes. BREZONIK (5) reported a few examples in which the amount of nutrients leached out from forest land was increased by either fertilization or clear cutting. Unfortunately, research pertaining to the change of water quality of forest streams after aerial fertilization has not been actively taken up in foreign countries, nor in Japan (3, 13).

In this study, helicopter fertilization of *Sugi* and *Hinoki* stands was carried out, and subsequent investigation were made on the stand growth, the nutrient contents in the needles of standard trees, and the change of concentration of nutrients in the streams. A few notable results were obtained, and are reported in this paper.

II. Outline of Experiment Plots and Method of Research

The research was carried out in the Sando Forest owned by Mitsui & Co. Ltd. and located in Nagashima town, Mie prefecture. The base rock in this region is sandstone and the annual average temperature is 14°C. Annual precipitation is 3,500 ~4,000 mm. The region is characterized by steep slopes and is also known for its large amount of

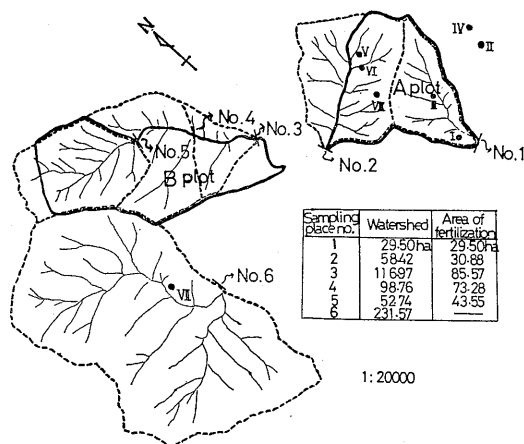


Fig. 1. Rough sketch of area fertilized by helicopter

Solid line: fertilized area, broken line: watershed, No.1~No.6: sampling place of water, A plot: fertilized twice in 2 years consecutively, B plot: fertilized only once, I~VIII: experimental plot for measurement

precipitation. So, clearly this region has the greatest possibility of nutrients being leached out from forest land into the streams after fertilization.

A rough sketch of the plots is shown in Fig. 1. The fertilizer was applied at two places, plots A and B. Application was made twice at plot A, once in March, 1971, and again in March, 1972. At plot B, application was done only once, in March, 1972. A urea compound (20:10:10) fertilizer was used since previous research in other experiment plots in this region demonstrated the higher efficiency of urea compounds for *Sugi* and *Hinoki* forests (8, 21). The amounts of fertilizer used were N: 100 kg/ha/year for 12 to 19-year-old stands and N: 113 kg/ha/year for 41-year-old stands.

Table 1. Outline of the experimental fields, height and D.B.H. of two standard trees (needles used for nutrient analysis) and chemical properties in soil before fertilization (Feb. 1971)

Plot No.	Treatment	Species and stand age	Density (No./ha)	Soil type	Inclination (degree)	Elevation (m)	Height (m)	D.B.H. (cm)	pH (H ₂ O)	pH (KCl)	C%	N%	C-N ratio	Exchangeable acid (Y)
I	Fertilization	<i>Sugi</i> 14	3,430	B _E	15	160	6.6 6.3	7.9 7.8	4.82	4.14	11.38	0.77	14.8	17.4
II	Unfertilization	<i>Sugi</i> 12	3,940	B _E	13	170	5.6 4.8	5.6 5.5	4.56	3.92	5.78	0.37	15.6	26.1
III	Fertilization	<i>Hinoki</i> 14	4,360	B _D	15	200	3.9 3.7	4.1 4.2	4.62	3.94	9.52	0.33	28.9	28.8
IV	Unfertilization	<i>Hinoki</i> 14	3,850	B _D	20	230	6.0 6.2	7.2 7.0	4.80	4.02	7.94	0.50	15.9	17.5
V	Fertilization	<i>Hinoki</i> 20	3,690	B _D	35	384	6.8 7.2	8.0 7.9	4.80	4.00	5.39	0.46	11.7	28.4
VI	Fertilization	<i>Hinoki</i> 21	3,960	B _D	33	330	7.4 8.0	8.8 8.8	4.72	4.12	10.84	0.63	17.2	17.0
VII	Unfertilization	<i>Hinoki</i> 21	4,230	B _D	40	260	6.8 6.9	7.5 7.6	4.82	4.04	4.82	0.31	15.6	24.4
VIII	Fertilization	<i>Hinoki</i> 40	1,770	B _D	30	260	10.8 10.2	12.6 12.7	4.48	3.77	6.99	0.33	21.2	43.5

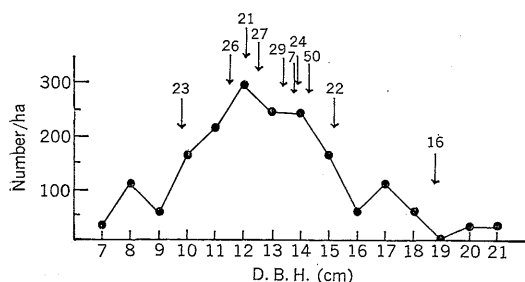


Fig. 2. Frequency distribution of D.B.H. and tree No. for stem analysis in 1974

Arrow: cutting tree for stem analysis, No.: tree No. of stand

Water was sampled once a month from 5 places in the stream along which the fertilized plots were located, and from one location by the unfertilized plots. Concentrations of $\text{NH}_3\text{-N}$, $\text{NO}_3\text{-N}$, P, K, Ca, and Mg in the water were determined. The sampled spots, the catchment area of the sampled spots, and the fertilized area within the catchment area, are shown in Fig. 1. There are two sampling places in A plot (No. 1, No. 2) and three in B plot (No. 3, No. 4, and No. 5). We can see that No. 3, No. 4, and No. 5 are located in the same stream. Stream quantity (m^3/sec) was measured (300 ha catchment area) at Miyagawa Dai-ichi Electric Power Station, approximately 200 meters away from the experiment plots. From the data thus obtained, the amount of catchment water per month per ha was calculated and this was multiplied for the catchment area of each sampling place in order to estimate its rate of flow.

The helicopter used for the application was a 47 G 3 B-KH 4, Kawasaki Bell. Its velocity was 60 km/

hr, and it flew 30 to 50 meters above crown canopy. The effective width of spread was 30 m. The application was done by criss-crossing over the region several times.

In February, 1971, 8 investigation plots (approximately $15\text{ m} \times 15\text{ m}$) were set up within *Hinoki* and *Sugi* stands. These experiment plots (I to VIII plots) are outlined in Table. 1. The soil is appreciably acidic and the C-N ratio is high, so the site quality is not good. A timber cruise survey of the plots before and 3 years after fertilization, and an analysis of changes in the nutrient content of the needles on the southern-upper part of two standard tree canopies in each plot were made. Samples used for needle analysis of *Sugi* were current year needles, and for *Hinoki*, roughly current to one year needles. Three years after fertilization, the growth rate of 41-year-old *Hinoki* stands was measured by stem analysis of 10 trees of different diameter classes, based on D.B.H. distribution. The frequency distribution of D.B.H. in 41-year-old *Hinoki* stand is shown in Fig. 2.

Figure 3 shows monthly precipitation and amount of effluent water/ha. There was a wide discrepancy between the precipitation and effluent water in June and July, 1972, but the two quantities were more or less the same at other study periods.

The analysis of nitrogen in the needles was done by the KJELDAHL method. After wet-ashing (1), phosphorus was analyzed colorometrically by the molybdenum blue method, potassium was analyzed by a flame photometer, calcium and magnesium were done by atomic spectroanalysis. Water analysis was carried out as follows: $\text{NH}_3\text{-N}$ by WINKLER method using NESSLER's reagent, $\text{NO}_3\text{-N}$ by GRIESS-ROMIJIN method using spectrophotometer, P by

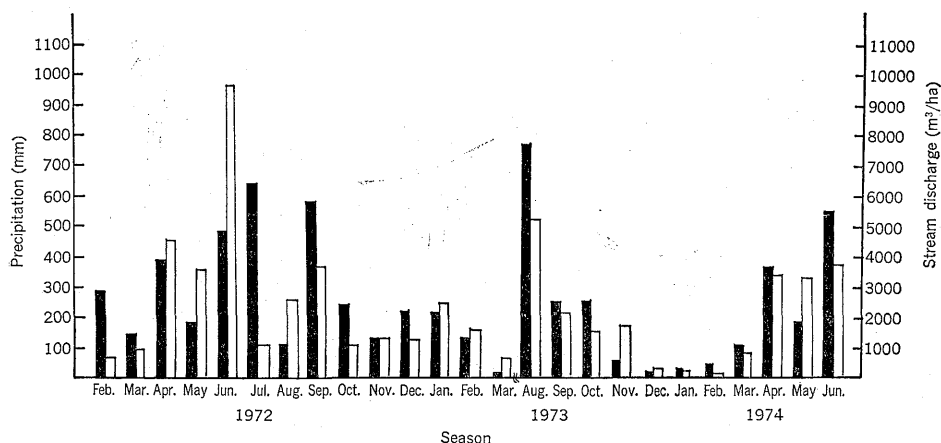


Fig. 3. Monthly precipitation and amount of discharged water per ha from the watershed
Solid slim bar: precipitation, open bar: amount of discharged water

Table 2. Fertilization cost in aerial application (actual) and manual application (trial)

Area of fertilization	Amount of fertilizer	Treatment	Application cost (yen/ha)			Ground cost (yen/ha)			Total* (yen/ha)
			Cost of spreading	Cost of air transport	Cost of confirmative flight	Loading cost	Cost of construction of heliport	Miscellaneous cost	
60.38 ha	28,600	Aerial application	16,560	331	346	2,146	1,402	661	21,446
	(kg)	Manual** application	22,848	—	—	2,146	—	3,296	28,290

* Except of the cost of fertilizer

** Daily allowance is 2,500 yen a day per one person.

Table 3. Three years increment on basal area (m²/ha) after fertilization

Treatment	Species and stand age	Basal area (m ² /ha)		Growth increment	Growth percentage and efficiency index*
		Feb. 1971	Mar. 1974		
Fertilization	<i>Sugi</i> 14	16.39	29.91	13.52	82.5 (117)
Unfertilization	<i>Sugi</i> 12	12.17	20.73	8.56	70.3 (100)
Fertilization	<i>Hinoki</i> 14	6.74	14.82	8.08	119.9 (146)
Unfertilization	<i>Hinoki</i> 14	15.69	28.57	12.88	82.1 (100)
Fertilization	<i>Hinoki</i> 20	18.54	23.73	5.19	28.0 (120)
Fertilization	<i>Hinoki</i> 21	24.08	31.15	7.07	29.4 (131)
Unfertilization	<i>Hinoki</i> 21	21.03	25.76	4.73	22.5 (100)
Fertilization	<i>Hinoki</i> 41	17.76	20.55	2.79	15.7

* Efficiency index : ratio of fertilized plot to 100 of growth percentage of the unfertilized plot

molybdenum blue method (concentrated to 1/5 volume) using the colorometrical method, K by flame photometer, Mg and Ca by atomic spectro-analysis (14, 23).

III. Results

Although it was assumed that the fertilizer was evenly spread by helicopter, sufficient data could not be obtained to verify this assumption. Due to the considerable velocity at which the fertilizer was spread and the nature of its granular shape, a large portion of it escaped the needles and branches of the trees, and there was hardly a trace of it left on the Japanese pampass grass and shrubs. Most of it fell directly onto the ground.

The expenditures for aerial fertilization (actual cost) of approximate 60 ha in A plot and for manual fertilization (trial calculation) are given in Table 2. The expenses excluding that of the fertilizer, was 21,000 yen per ha for helicopter application and 28,000 yen per ha for manual application. This indicates that about 7,000 yen per ha was saved through helicopter application.

The rate and the amount of growth of basal area per ha are shown in Table 3. Although there was a two year difference between the fertilized and the unfertilized *Sugi*, the data shows that the efficiency index (ratio of fertilized plot to 100 of growth percentage of the unfertilized plot) of fertilized *Sugi* was 117 as compared to 100 of the unfertilized. In the case of the 14-year-old *Hinoki* stand, the

difference of basal area before fertilization (Feb. 1971) was too large to compare between fertilized and unfertilized plots. Twenty and 21-year-old *Hinoki* stands indicated a growth of 120, and 131 in the fertilized plots as compared to 100 of the unfertilized plots. The efficiency of fertilization can be seen in the basal area growth per ha.

The changes in the nutrient content in the needles of the two standard trees are shown in Fig. 4. There was no increase by fertilization of the nutrient in 14-year-old *Hinoki* stands. However, 20 and 21-year-old *Hinoki* stands indicated a tendency for nitrogen, phosphorus and potassium to increase in the needles after fertilization. The rate of increase was greatest in phosphorus and not so much in potassium. Calcium and magnesium content, on the other hand, decreased somewhat in the fertilized plots. Nitrogen and phosphorus showed an increase in 14-year-old *Sugi* after fertilization. In particular, phosphorus increased considerably. But there was no difference in potassium, calcium and magnesium contents between the fertilized and the unfertilized *Sugi*.

The annual height growth, based on the stem analysis of 41-year-old *Hinoki* stands at the time of fertilization, is shown in Fig. 5. Most of the trees showed an increased rate of growth from the year of the first fertilization, reaching maximum growth in the second year after the first fertilization. However, the rate began to fall from the third year. Although there were a few exceptions, the efficiency

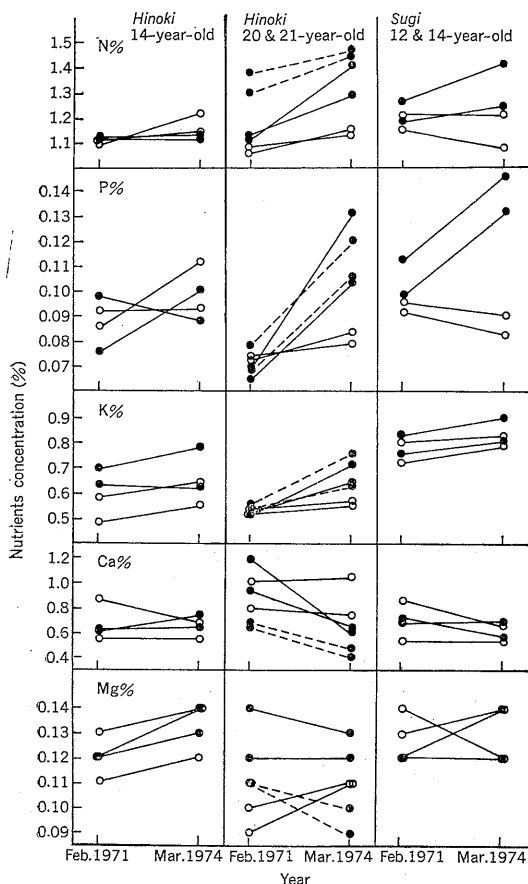


Fig. 4. Nutrient concentrations in the needles for February 1971 and March 1974

○—○: unfertilized tree (20-year-old), ●—●: fertilized tree (20-year-old), ●—●: *Hinoki* fertilized tree (21-year-old)

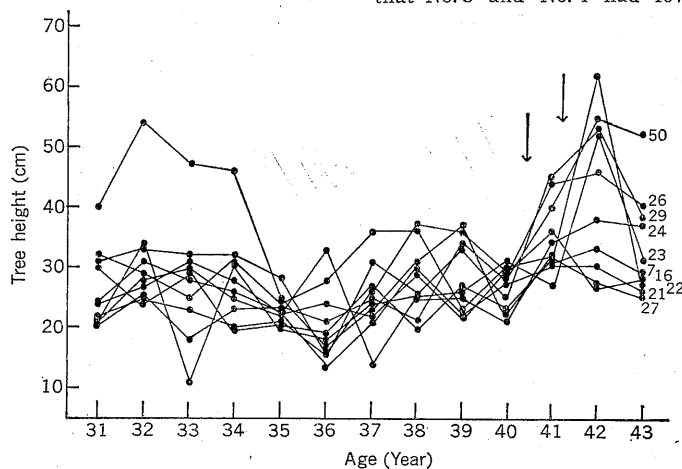


Fig. 5. Annual height growth by stem analysis of 41-year-old *Hinoki* stand at the time of fertilization (plot No. VIII)

Arrow: fertilization date, No.: tree No. (see Fig. 2)

of fertilizer seemed to be greatest for larger trees.

The annual volume growth is shown in Fig. 6. Volume began to increase in the year of fertilization and continued at a considerable rate. Although the rate of height growth began to fall in the third year, the volume growth remained positive and even showed a tendency to increase after 3 years. The fertilizer did not seem to be effective on the smaller trees.

The annual volume growth per ha is shown in Fig. 7. The final data, based on the D.B.H., are calculated from the values obtained by the stem analysis of ten standard trees. Seven to 8 years prior to fertilization, the annual volume growth was only about 5.2 m³/ha/year, but the rate of growth rose rapidly after fertilization until it reached approximately 12 m³/ha/year in the third year. Thus, in comparison with the period before fertilization, there was an increase of approximately 13 m³ in the three years following fertilization.

The changes in phosphorus, NH₃-N, and NO₃-N concentrations in the streams are shown in Fig. 8. NH₃-N ranged between 0 and 0.05 ppm. Periodic analysis showed that the concentration became low from November through January. Depending on the location, however, it increased temporarily by 0.01 to 0.03 ppm on the year of fertilization. NO₃-N ranged between 0 and 0.5 ppm, which was ten times that of NH₃-N concentration. In 1972 it was found that No. 4 and No. 5 of B plot, which were fertilized only once, gave higher values than the other plots. Number 1 which was fertilized twice in two years gave results not substantially different from the unfertilized plot. The sampling water collected from the same stream (No. 3, No. 4, No. 5) showed that No. 3 and No. 4 had lower concentrations of

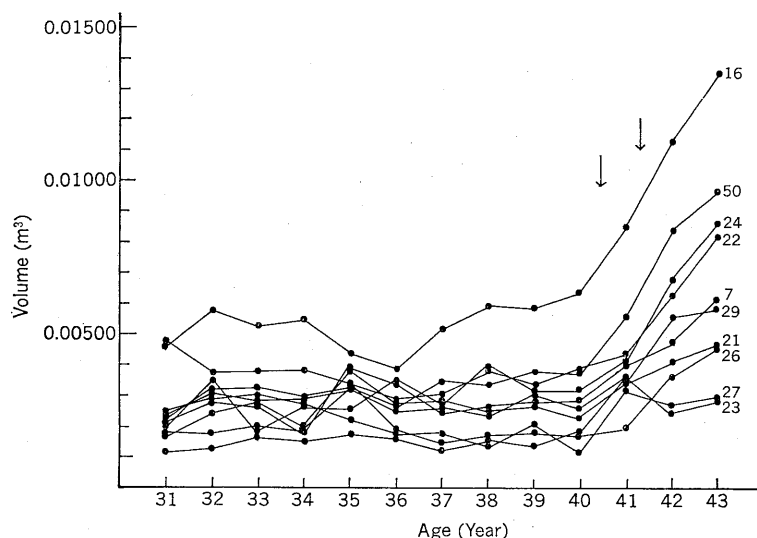


Fig. 6. Annual volume growth by stem analysis of 41-year-old *Hinoki* stand at the time of fertilization (plot No. VIII)
Arrow : fertilization date, No. : tree No. (see Fig. 2)

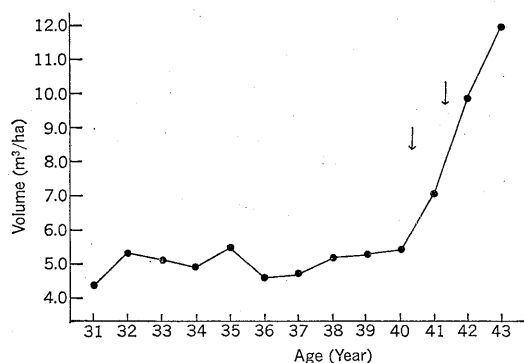


Fig. 7. Annual volume growth per ha of 41-year-old *Hinoki* stand at the time of fertilization (plot No. VIII)
Arrow : fertilization date

$\text{NO}_3\text{-N}$ in comparison with No. 5, which was located on the upper stream.

As the catchment area of No. 4 and No. 5 was 1/2 and 1/4 of the unfertilized plot respectively, one could not simply conclude that the higher concentration of $\text{NO}_3\text{-N}$ was solely due to fertilization. By comparing the values obtained 2 years after the fertilization, in 1974, however, it was observed that the concentration went up 0.1 to 0.2 ppm at certain periods. But as stated above, $\text{NO}_3\text{-N}$ maintained a lower concentration at No. 3 than at No. 4 or No. 5. From December, 1972 to March, 1973, phosphorus concentrations became slightly higher, but there was no difference with respect to collected plots or seasons. The concentration ranged from 0 to 0.01 ppm, which was comparatively lower

than the other nutrients.

The changes in potassium, calcium, and magnesium contents are shown in Fig. 9. There was no difference in the potassium concentration with respect to the collection points. The concentration ranged between 0.2 and 0.6 ppm. Seasonal differences in concentration showed a greater deviation, but there was no set pattern in seasonal fluctuations. Calcium concentration varied from 1 to 6 ppm which was comparatively higher than the other nutrients concentrations. Moreover, it varied from one plot to another, from highest to lowest in the order of No. 6, No. 5, No. 3, No. 4, No. 1 and No. 2. Seasonal differences show the concentration up in relatively rainless periods, the months of December through April. This observation falls in line with the reports of IWATSUBO (17). The concentration range of magnesium was 0.3 to 1.2 ppm and although the level was lower than that of calcium, only slight variation was seen at different plots.

The monthly outgo of nutrients per ha at each of the collection points is shown in Fig. 10. As the concentration of phosphorus was extremely low, no calculation was done to measure the amount per ha. The flow-out amount of nutrients and the flow-out amount of water had the same tendency. A similar report is also given by IWATSUBO (17). In a few fertilized plots, the amount of $\text{NH}_3\text{-N}$ was greater than in the unfertilized plots during the first 6 months following fertilization. The difference in the amount was greater when the flow-out amount of water was greater. Since the $\text{NO}_3\text{-N}$ concentration in the unfertilized plots was low even before

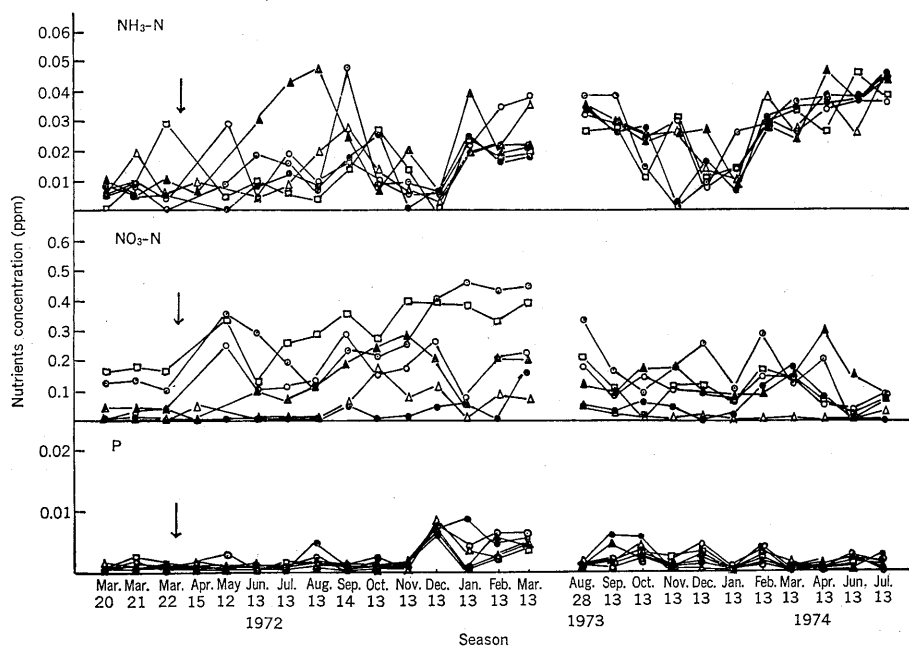


Fig. 8. The changes in $\text{NH}_3\text{-N}$, $\text{NO}_3\text{-N}$ and P concentration in the stream

Arrow: fertilization date, $\triangle$: No.1, $\blacktriangle$: No.2, $\circ$: No.3, $\odot$: No.4, $\square$: No.5, $\bullet$: No.6, No.1 to No.6: see Fig.1

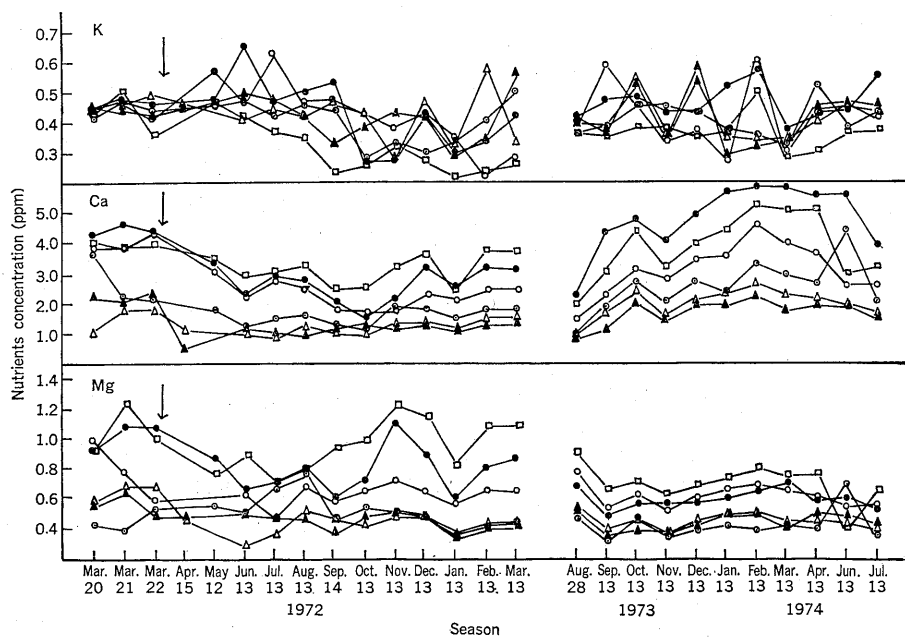


Fig. 9. The changes in K, Ca and Mg concentration in the stream

Arrow: fertilization date, $\triangle$: No.1, $\blacktriangle$: No.2, $\circ$: No.3, $\odot$: No.4, $\square$: No.5, $\bullet$: No.6, No.1 to No.6: see Fig.1

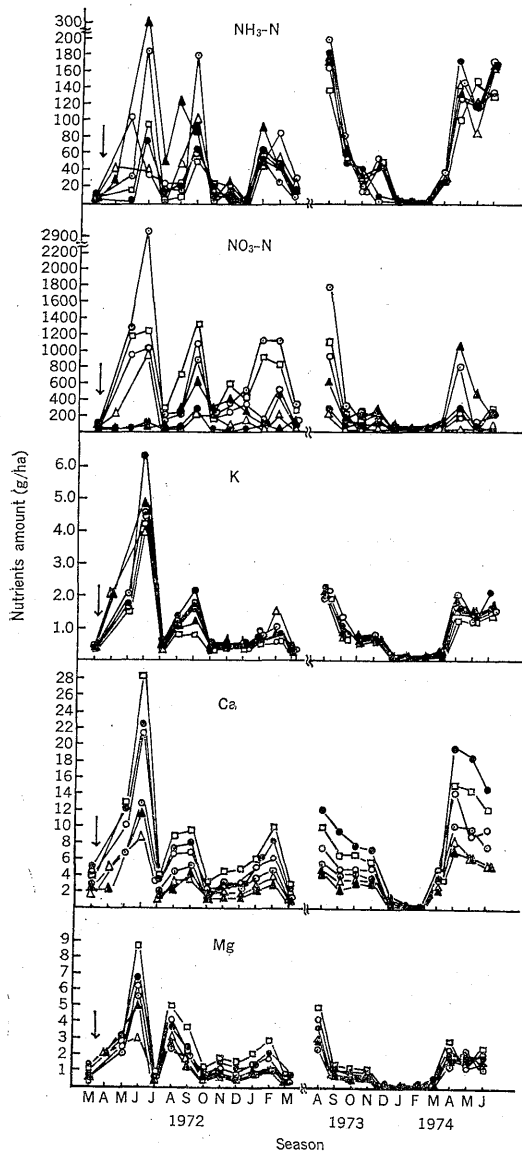


Fig. 10. The changes of nutrients amounts per ha per month discharged to the sampling places

Arrow: fertilization date, Δ : No. 1, $\blacktriangle$: No. 2, $\circ$: No. 3, $\odot$: No. 4, $\square$: No. 5, $\bullet$: No. 6, No. 1 to No. 6: see Fig. 1

fertilization (Fig. 8), the subsequent difference could not solely be attributed to fertilization. In any case, the $\text{NO}_3\text{-N}$ amount went up to a certain extent after fertilization, and the period of increase seemed to last longer than that of $\text{NH}_3\text{-N}$. A comparison of No. 3, No. 4 and No. 5, located on the same stream, showed that the amount of $\text{NO}_3\text{-N}$ at No. 3 which

Table 4. Kilogram per ha of $\text{NH}_3\text{-N}$, $\text{NO}_3\text{-N}$, K, Ca and Mg discharged from the fertilized and unfertilized watershed in one year (Apr. 1972 to Mar. 1973)

Plot	$\text{NH}_3\text{-N}$	$\text{NO}_3\text{-N}$	K	Ca	Mg
1	0.4	2.3	13.7	34.5	12.9
2	0.8	2.5	13.5	33.2	14.8
3	0.4	5.3	13.1	70.3	17.5
4	0.6	9.5	13.5	46.6	16.4
5	0.4	8.5	10.5	94.6	28.7
6	0.3	1.3	15.1	78.2	23.5

is on the lower reaches, was considerably lower than that at the other points. Such variation due to location was not observed for potassium. The calcium concentration, however, differed from one plot to another, and the total flow-out amount was greater than any of the other nutrients. A similar variation was also seen in magnesium although the difference was not as great as calcium.

The flow out amount of nutrients per ha from April, 1972 to March, 1973 is shown in Table 4. The $\text{NH}_3\text{-N}$ flow out amount was 0.3 to 0.8 kg/ha. The amount in the fertilized plots was 0.1 to 0.5 kg/ha greater than in the unfertilized plots. The $\text{NO}_3\text{-N}$ range was 1.3 to 9.5 kg/ha. At No. 1 and No. 2, which were fertilized twice in two years, the amount was 1.0 to 1.2 kg/ha greater than at the unfertilized plot. A greater flow-out observed at No. 3, No. 4 and No. 5 of the same stream, where the fertilization was done only once. The flow-out amount per unit area at No. 3, which was on the lower stream, was considerably less than that of No. 4 and No. 5, both located on the upper stream. The flow-out amount of potassium was 10.5 to 15.1 kg/ha and it seemed that the flow-out amount was greater in the unfertilized plots than in the fertilized. The amount of calcium was 33.2 to 94.6 kg/ha and magnesium was 12.9 to 28.7 kg/ha. As seen in Fig. 10, the differences between the collection points were greater than differences caused by fertilization.

IV. Discussion

As there are numerous reports on the relative merits of helicopter fertilization (26~29), they are omitted from this report. In order to fertilize a large area, one generally needs to secure enough labor. At least ten laborers are needed per ha for manual fertilization. So, fertilization of 60 ha would mean an employment of 600 laborers. Considerable manhours can be saved if one makes use of helicopters. As the result of this research clearly indicates, 6,800 yen per ha is saved by helicopter application. Moreover, if one makes use of helicopters, the expenses per ha decrease with

the increase of application area. TSUTSUMI (33) noted that in order to fertilize effectively, one should have at least 80 to 90 ha.

It was observed in the needles of 20, 21-year-old *Hinoki* trees and 14-year-old *Sugi* trees of the fertilized plots that the phosphorus content increased at a greater rate than nitrogen or potassium content. The previous experiment, which was done on the same plot and in which a 6-year-old *Hinoki* stand was fertilized by calcium cyanamide-P-K (7), and a 37-year-old *Hinoki* stand and a 42-year old *Sugi* stand were fertilized by either urea-P-K, or by calcium-P-K fertilizer (8, 21), showed that the phosphorus concentration in the needles did not increase by such a considerable amount. The reason for the increase in the phosphorus concentration in this experiment is not clear. Further analysis is needed in order to clarify the cause of the increase of phosphorus content in the needles after fertilization. The needles of 20 and 21-year-old *Hinoki* stands, which increased in nitrogen, phosphorus, and potassium content, in contrast marked a decrease in calcium and magnesium content. It is generally accepted that after the fertilization of 3 elements, nitrogen, phosphorus, and potassium, the content of calcium in the needles decreases; but there is no widely accepted opinion with regard to the changes in the magnesium content (11, 18, 19). In the previous reports (9), 37-year-old *Hinoki* stand, which reacted positively to the urea compound fertilizer, showed increases in the amounts of nitrogen, phosphorus, potassium, and calcium, but there was no increase of magnesium. Also, in the younger *Sugi* stands, fertilized every year, the nitrogen, phosphorus, and potassium content increased; but the calcium and magnesium content was lower than the unfertilized. The analysis of nutrient contents in the needles, with respect to periodic change, indicates that the difference in the calcium and magnesium content between the fertilized and the unfertilized stand is greatest during the dormant season (2). Further consideration of the fertilizers containing magnesium may be necessary.

The cost of fertilizers which were used in the helicopter application in 1971 was 21,154 yen per ha and the cost of application was 21,449 yen. The total was 42,603 yen. Taking into account the 6% interest, the total cost would be 50,740 yen three years later. A similar calculation gives 47,869 yen per ha for 1972. Adding the two years' cost gives the total of 98,609 yen per ha. Figure 6 shows that the volume growth per ha increased about 13 m³ in years. This implies that fertilization may be considered economically profitable.

Moreover, 13 m³ per ha is the value of the third year, when there is still steady growth. So, if the cutting is delayed for a few years, the volume growth is estimated to give even higher values.

The change in the water quality of the stream after helicopter fertilization was given by researchers like AUBERSTIN *et al.* (3) who, in his analysis of water in the stream, reported of an increase in NH₃-N immediately after helicopter application of 600 kg/ha of urea over 30 ha, and an increase in NO₃-N a little later. HORNBECK *et al.* (15) also found that the nutrients concentration increased in the streams and that the increase was due to fertilizers which fell directly into the stream. In this particular experiment, NH₃-N and NO₃-N concentrations increased by 0.01 to 0.03 ppm, and 0.1 to 0.3 ppm at certain plots after fertilization. An increase in the flow-out amount per ha of nutrients was also seen at some sampled spots, but the amount of NH₃-N gradually decreased until it went back to the normal concentration in 5 to 6 months. On the other hand, the NO₃-N concentration seemed to have remained at a high level for a relatively long period. Since there was no increase of nutrients in the stream where the fertilization was done twice in 2 years, and the area of unfertilized plots is 2 to 8 times greater than the fertilized, one can not easily conclude that the differences in the nutrient is solely due to fertilization. One can at least say that at some places, there is an increase in the nitrogen content to a certain extent. By tracing the fertilized plots where the nitrogen concentration was increased by fertilization, one can see that the concentration decreases when the stream approaches its lower reaches. HASHIMOTO *et al.* (12) gave a similar report. By citing many papers, VIETS (34) discussed the eutrophic pollution of nitrogen and phosphorus caused by fertilization in the lakes and streams. According to TAYLOR (32), the biological activity of algae is controlled by the amount of phosphorus in the water, and that it works as a limiting factor in concentrations below 0.01 ppm and serves as a growth-promoting factor in concentrations above 0.05 ppm. In this experiment, the phosphorus concentration was below 0.01 ppm, and thus, there probably is no problem pertaining to phosphorus. Unlike agricultural methods, fertilization and irrigation are not as intensively taken up in forests, so there is little possibility of phosphorus movement through penetrated ground water. The only possible movement is the seat erosion by rain water. Considering the fact that the movement of nitrogen is large after clear cutting (4, 22), and that the nitrogen flow out is great when the seat erosion by rain water is great

in waste or fallow land (24), one can surmise that Japanese forest plantations, which have a rich undergrowth, help to prevent nitrogen movement by seat erosion. Moreover, the concentration of $\text{NH}_3\text{-N}$ and $\text{NO}_3\text{-N}$ is only 0.05 ppm and 0.5 ppm, respectively. Thus, the effect of fertilization is relatively small.

If fertilization were done on a small scale, then the increased nutrients would probably be completely diluted before they reach downstream. Forest fertilization over a large area of a region would be an inappropriate method, but it is still quite different from the agricultural method of fertilization which is done over a total area, each year, in an extremely large quantity.

HANYA (10) reported of the changes in the water quality caused by different geological states, especially in cations such as calcium and magnesium, but this experiment pointed out the differences in calcium and magnesium even under the same geological state. The calcium concentration, in particular, fluctuates from place to place.

Currently, the nutrient concentrations of ground water and surface water of the forest land are being surveyed (16, 17), but more research needs to be done on the water pollution caused by fertilization. Also, further research is necessary on the movement of nutrients in the ground water, and the differences in the amount of nutrients leached out due to soil type or inclinations. Finally, consideration should be given to the extent of nutrients leaching out into the stream, the economical area for fertilization, the relative area ratio in a catchment forestry system, and the means of minimizing the pollution of downstream by limiting the leaching out of nutrients.

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Literature cited

- (1) AIBA, Y.: Ashing methods of plant tissues for mineral nutrition. Bull. Exp. For. Tokyo Univ. of Agric. & Tech. 7: 45~46, 1968 (in Japanese with English summary)
- (2) AIBA, Y. & HAIBARA, K.: Study on the reddish symptom of *Sugi* needles (I) Seasonal changes of nutrients of the fertilized needles in *Sugi* stands. Transact. 86th Annual Mtg. Jap. For. Soc., 187~188, 1975 (in Japanese)
- (3) AUBERTIN, G.M., SMITH, D.W. & PATRIC, T.H.: Quantity and quality of streamflow after urea fertilization on a forested watershed: first year results. Forest Fer. Symp. Proc., 88~100, USDA, For. Ser. Gene. Tech. Rep. NE-3, 1973
- (4) BORMANN, F.H., LIKENS, G.E. & PIERCE, R.S.: Nutrient loss accelerated by clear-cutting of a forest ecosystem. Science 159: 882~883, 1968
- (5) BREZONIK, P.L.: Nitrogen: source and transformation in natural water. Nutrients in natural water (ALLEN, H.E. & KRAMER, J.R., ed.). 447 pp, Wiley-Interscience, New York, 1972
- (6) HAGNER, S. (trans. KAWANA): The present situation of forest fertilization in the world (review). Ringyo Gijutsu 368: 20~26, 1972
- (7) HAIBARA, K., KAWANA, A. & AIBA, T.: Effects of fertilization of Lime nitrogen-P-K compound fertilizer and Lime nitrogen to the young *Hinoki* (*Chamaecyparis obtusa*) plantation. Bull. Exp. Tokyo Univ. of Agr. & Tech. 8: 1~8, 1969 (in Japanese with English summary)
- (8) HAIBARA, K., KAWANA, A., AIBA, Y. & NABESHIMA, H.: Studies on fertilization in established stands (VIII) The effects of fertilization on nutrients, stem volume and log yield percentage in *Sugi* (*Cryptomeria japonica*) stands. (unpublished)
- (9) HAIBARA, K., KAWANA, A. & AIBA, Y.: Studies on fertilization in established stands (IX) The effects of fertilization on the stem volume, nutrients in needles and yields of logs in *Hinoki* (*Chamaecyparis obtusa*) stands. Bull. Exp. For. Tokyo Univ. of Agr. & Tech. 11: 39~56, 1974 (in Japanese with English summary)
- (10) HANYA, T.: *(Study on correlation between chemical properties of natural water and geologic environment (III) The characteristics of chemical composition of Japanese stream). Nihon Kagaku-shi 74: 522~525, 1953
- (11) HARADA, T., HARA, T. & ASAHI, M.: *(The effects of fertilizer's constituents on soil and absorbed components of trees (I) Change of the soil and constituents of tree in *Sugi* stands). Transact. 82nd Mtg. Jap. For. Soc., 111~113, 1971 (in Japanese)
- (12) HASHIMOTO, Y., FUJITA, K. & IWAZAKI, M.: *(On the nitrogen, potassium, calcium and magnesium concentrations discharged from fertilized and unfertilized stands (preliminary note)). Transact. 84th Mtg. Jap. For. Soc., 141~143, 1973 (in Japanese)
- (13) HILMON, J.B. & DOUGLAS, J.E.: Potential impact of forest fertilization on range, wildlife and watershed management. 10th Ann. For. Fer. Clearing House Rep., 197~201, 1967
- (14) Hokkaido Branch of Japan Analytical Chemistry Society: *(Analysis of water). 398 pp, Kagaku Dōjin, Tokyo, 1971 (in Japanese)
- (15) HORNBECK, J.W. & PIERCE, R.S.: Potential impact of forest fertilization on streamflow. Forest Fer. Symp. Proc.: 79~87, USDA, For. Ser. Gene. Tech. Rep. NE-3, 1973
- (16) HOTTA, T., ARIMITSU, K. & YOSHIMOTO, M.: *(Examples of analysis of carbon and nitrogen of soil water in forest land). Transact. 84th Mtg. Jap. For. Soc., 121~123, 1973 (in Japanese)
- (17) IWATSUBO, G. & TSUTSUMI, To.: On the amount of plant nutrients supplied to the ground by rain-

- water in adjacent open plot and forest (III) On the amount of plant nutrients contained in rain-off water. Bull. Exp. For. Kyoto Univ. 39 : 140~155, 1967 (in Japanese with English summary)
- (18) KAWADA, H. & KINUGASA, T. : A study on fertilization on young *Cryptomeria japonica* forest in Hangatani National Forest (studies on forest fertilization in Kansai area part 2). Bull. Gov. For. Exp. Sta. 216 : 75~97, 1968 (in Japanese with English summary)
- (19) KAWADA, H. & KINUGASA, T. : Studies on fertilization of young *Cryptomeria japonica* forest in Mt. Kōya National Forest (the studies on forest fertilization in Kansai area part 4). Bull. Gov. Exp. Sta. 248 : 1~13, 1972 (in Japanese with English summary)
- (20) KAWANA, A. : On the fertilization in established forest. 47 pp, Ryunkogyo Kyokai, Tokyo, 1970 (in Japanese)
- (21) KAWANA, A., AIBA, Y. & HAIBARA, K. : Studies on fertilization in established stands (V) Comparison with urea-P-K and calcium cyanamide-P-K compound fertilizer in *Hinoki* (*Chamaecyparis obtusa*) stand. Bull. Tokyo Univ. Agr. & Tech. 9 : 1~10, 1971
- (22) LIKENS, G.E., BORMANN, F.H., JONSON, N.M. & FISHER, D.W. : Effects of forest cutting and herbicide treatment of nutrient budgets in the Hubbard brook watershed-ecosystem. Ecol. Monogr. 40 : 23~47, 1970
- (23) MIYAKE, A. & KITANO, T. : *(The method of chemical analysis of water quality). 200 pp, Chijin shokan, Tokyo, 1967 (in Japanese)
- (24) MOE, P.G., MANNERING, J.V. & JONSON, C.B. : Loss of fertilizer nitrogen in surface runoff water. Soil Sci. 104 : 384~394, 1967
- (25) NOGAMI, K. : Study on the effects of fertilizer applied to the forest land. Bull. Exp. For. Kyushu Univ. 48 : 1~111, 1974 (in Japanese with English summary)
- (26) Norin Suisan Kōku Kyokai : *(Forest aerial fertilization symposium proceedings part III). 30 pp, Tokyo, 1972 (in Japanese)
- (27) ——— : *(Forest aerial fertilization symposium proceedings part IV). 39 pp, Tokyo, 1972 (in Japanese)
- (28) ——— : *(Forest aerial fertilization symposium proceedings part V). 39 pp, Tokyo, 1972 (in Japanese)
- (29) SASAKI, S. : *(Young forest fertilization by helicopter). For. and Fertilization (Shinrin to Hibai) 62(3) : 7~11, 1970 (in Japanese)
- (30) SEGAWA, Y. : *(Mature forest fertilization by helicopter). Ringyo Gijutsu 336 : 21~23, 1970 (in Japanese)
- (31) Silviculture section, Nagoya Regional Forest Office : *(Forest fertilization by helicopter). For. and Fertilization (Shinrin to Hibai) 54(7) : 5~9, 1968 (in Japanese)
- (32) TAYLOR, A. : Phosphorus and water pollution. J. Soil Wat. Conserv. 22 : 228~231, 1967
- (33) TSUTSUMI, Ta. : *(Forest fertilization and aerial fertilization). For. and Fertilization (Shinrin to Hibai) 65(10) : 4~7, 1970 (in Japanese)
- (34) VIETS, F.G. Jr. : Fertilizers. J. Soil Wat. Conserv. 26 : 51~53, 1971
- (35) WERNER, R.G. : Water quality-limnological concern about forest fertilization. For. Fer. Symp. Proc. 72~78, USDA, For. Ser. Gene. Tech. Rep. NE-3, 1973
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