Primary Production Relations in a Young Plantation of *Abies sachalinensis* in Hokkaido: Materials for the Studies of Growth in Forest Stands. 11.*

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CONTENTS

Abstract

A 26-year-old plantation having 13.8 t/ha of foliage leaf produced 14.5 t/ha/year of dry matter as the aerial parts of the tree layer, of which about one half was stem. Biomass and production by the undergrowth were negligible. Distribution of produced matter into parts of tree differed by tree class: distribution into leaf was larger in dominant trees and into branch was larger in suppressed trees. Leaf mass and net production per unit ground area of forest of this species and other species of *Abies* were compared. Net production by trees was dependent on leaf mass on them but independent from the efficiency of leaf, or net assimilation rate. Net assimilation rate was larger in dominant trees than in suppressed trees. Net assimilation rate was compared with three natural forests.

1. Introduction

This paper deals with primary production relations in a 26-year-old plantation of *Abies sachalinensis* in Hokkaido. On primary production relations of forests of *A. sachalinensis*, there are studies by SHIDEI (1960) and YOSIMURA et al. (1967) on natural forests, and by HARADA et al. (1970, 1971) and YAMAMOTO and SANADA (1970) on plantations. On forests of other species of Genus *Abies*, there are many studies. In Japan, studies were made on natural forests of *A. firma* by FURUNO and KAWANABE (1967), SASA (1969), and ANDO et al. (1973), on natural forests of *A. veitchii* by TADAKI et al. (1970), and on natural forests of mixed *A. veitchii* and *A. mariesii* by KIMURA (1963),

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KIMURA et al. (1968), and OOUTI et al. (1967). YODA (1969) studied biomass of forests of *A. spectabilis* along altitudinal series in eastern Nepal. BURGER (1951), and VYSKOT (1972) studied forests of European fir. In Canada, Baskerville (1965a, b, 1966) studied young natural forests of balsam fir.

Field works of this study were made in 1960 by Mr. H. MAGARA and Mr. R. IWASAKI with cooperation of the staff of the Tokyo University Forest in Hokkaido. The author would like to express his most heartily thanks to them.

2. The forest studied

The forest studied belongs to the Compartment 87-E of Tokyo University Forest in Hokkaido. Mean of 5 year's record, 1956–1960, at the arboretum of the University Forests (43°13′N, 142°23′E, altitude 230 m) which is located about 500 m west to the plantation, mean annual temperature was 7.9°C with maximum monthly temperature of 24.5°C in July and minimum of −6.3°C in January. Annual precipitation was 1188 mm. The plantation is on a south slope of about 14°. Altitude is about 230 to 250 m from the sea level. Bedrock is diabase, and soil is brown forest soil. Planted in 1937 with nursery grown seedlings, the plantation was 26-year-old in 1960 when the field works were made. General description of the plantation is given in Table 1. Ground vegetation was so scarce that measurement was not made. Important members of ground flora were *Schizophragma hydrangeoides*, *Pachysandra terminalis*, *Celastrus articulatus*, *Vitis coignetiae*, *Aralia elata*, *A. cordata*, *Sasa paniculata and Pteridium aquilinum*.

Table 1. General description of the stand.

Age	26
D.B.H. (cm)	13.9
Height (m)	10.9
Clear Length (m)	4.4
Basal area (sq. m/ha)	32.60
Number of trees per ha	2400

3. Method

After measuring D.B.H. of all trees in the sample plot, which was 0.07 ha, seven sample trees, including three trees of mean cross-sectional area, two dominant and two suppressed trees, were cut. At the height of the ground level (0.0 m), 0.3 m, 3.3 m and then at every 2 m, samples of stem were taken for stem analysis and to determine dry matter content and bulk density. Branches were cut separately for layers, each 1 m deep, separated into new shoots with new leaves, branches with old leaves, and branches without leaves, and weighed separately. From each group, samples were collected and they were separated into branch and leaf, and weighed to assess the amount of leaf and branch. Branch and leaf were sampled for dry weight determination. Branch was sampled from every 1 m of height and its growth rate was determined by ring analysis technique. Trees did not bear any cone. Measurements of roots were not made.

4. Biomass aboveground

For conversion of the values for the sample trees into the values for unit ground area of forest, three methods were used; allometry using D.B.H. as the independent variable (aD^b), the ratio of basal area to sum of cross-sectional area of the sample trees (G/g), and trees of mean cross-sectional area ($\bar{D}$). Comparisons of these methods were already reported (SATOO 1966, 1968, and 1970). The constants of the allometric equations are given in Table 2. The estimates by these three methods are shown in Table 3. There were not much differences among them. About two third of aboveground biomass was stem and the rest was branch and leaf at nearly the same percentages. As seen from Table 4, percentage of stem in the biomass was largest in the suppressed trees and smallest in the dominant trees, whereas the percentage of branch was largest in the dominant trees and smallest in the suppressed trees; the percentage of leaf was largest in the dominant trees and there was not much difference between the suppressed and the average trees. These relationships reflect past history and present conditions of trees; the suppressed trees produce less and less crown and the dominant trees produce more and more crown, thus the dominant trees have larger crowns than in proportion to the stems and the suppressed trees have smaller crowns.

Table 2. Constants of the allometric equation: $\log W_{(kg)} = b \log D_{(cm)} - a$.

	a	b
Biomass		
Stem	1.5119	2.5920
Branch	3.5095	3.7914
Leaf	2.5495	2.8944
Production		
Stem	3.6288	3.5838
Branch	3.2263	3.0291
Leaf	4.1184	3.7350

Table 3. Biomass (t/ha).

Method	aD^b	G/g	$\bar{D}$	Mean
Stem	62.64	64.13	65.21	63.99
Branch	16.26	18.82	13.94	16.34
Leaf	14.55	15.17	11.72	13.81
Total	93.45	98.12	90.87	94.15

Table 4. Percentage distribution of aboveground biomass among parts of tree.

	Stand	Dominant tree	Average tree	Suppressed tree
Number of samples		2	3	2
D.B.H. (cm)		17.9	13.9	10.9
Height (m)		11.7	10.9	7.8
Leaf mass per tree (kg)		14.5	5.3	1.6
Stem (%)	67.0	59.4	71.9	74.9
Branch (%)	17.4	23.0	15.3	11.4
Leaf (%)	15.6	17.6	12.8	13.7

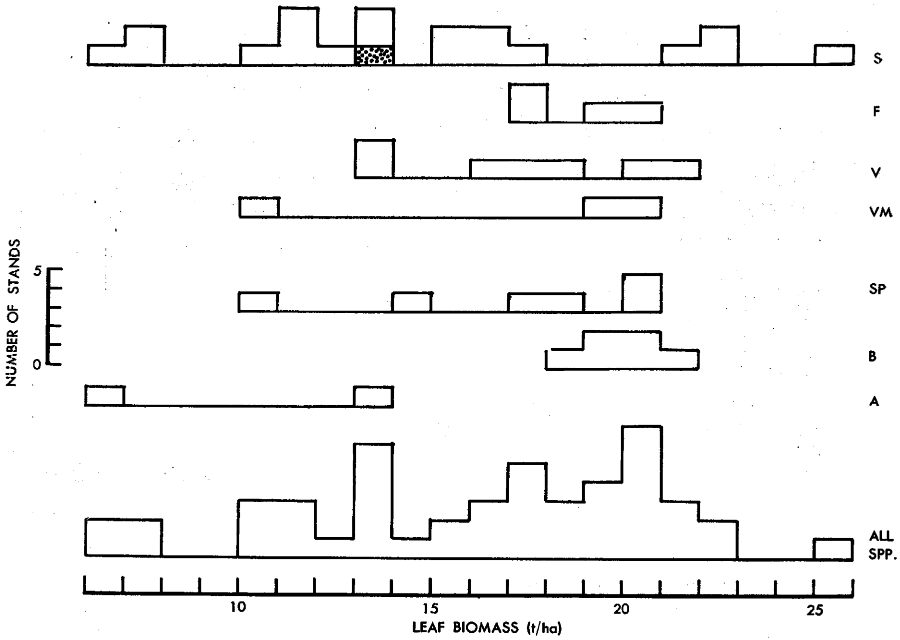

Fig. 1. Leaf mass of forests of *Abies spp.*
S: *A. sachalinensis*, F. *A. firma*, VM: *A. veitchii* + *A. mariesii*, V: *A. veitchii*, A: *A. alba*, B: *A. balsamea*, Sp: *A. spectabilis*.
Dotted: the plantation reported here.
Sources of data: S: HARADA et al. 1970, YOSIMURA et al. 1967, YAMAMOTO and SANADA 1970. 4 Universities. HARADA et al. 1972.
F: FURUNO and KAWANABE 1967, SASA 1969, ANDO et al. 1973.
VM: KIMURA 1963, KIMURA et al. 1968, OOUTI et al. 1967.
V: TADAKI et al. 1970.
A: BURGER 1951, VYSKOT 1972.
B: BASKERVILLE 1965.
Sp: YODA 1969.

Amount of leaf in this plantation was compared with forests of species of *Abies* in Fig. 1. The variation is rather wide, reflecting wide variation of growing conditions. Mean value for the 48 stands of *Abies* spp. which is available so far, was 16.1 t/ha and most of them were within a range of 10 to 23 t/ha. This value is not far from the value for *Picea abies* (SATOO 1971a). Mean value for the 20 stands of *A. sachalinensis* was 14.5 t/ha which is not much different from the mean value for all *Abies* stands available.

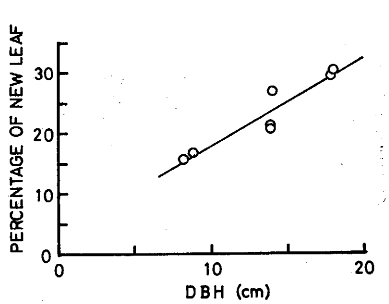

Fig. 2. Percentage of the new leaf in the total leaf per tree in relation to diameter of trees.

As shown in Fig. 2, percentage of the current year leaf (Y%) in total leaf increased proportionally to D.B.H. (D cm) and described as

$$Y=1.47\,D+3.2,\ r=0.968^{**}.$$

Percentage of new leaf increased by about 1.5% with increase of 1 cm in d. b. h.

5. Net production aboveground

Volume growth of the stem and branch was converted into dry weight with bulk density and used as production. Dry weight of new leaf was assumed as production; corrections for leaf lost bofore and produced after the sampling which is expected to be not much, and for the increase of weight in old leaf (KIMURA et al. 1968) were not made. No cone was present. Loss by bud scale and other minor losses were neglected. Conversion of the rate of net production of the sample trees into ground area basis was made by the three methods mentioned for biomass estimation. Constants for the allometric equations are given in Table 2. Net production of the plantation thus estimated is given in Table 5. Net production by this plantation was not much different from the production by other conifer stands planted within a few killometers and in the same altitudinal zone (SATOO 1970). In Fig. 3, annual net production of this plantation was compared with forests of other *Abies* species. Most of them are within a range of 8-12 t/ha/year. Production of this plantation is rather large compared with other forests of *Abies* species. As shown in Table 6, about one half of

Table 5. Aboveground net production (t/ha/year).

Method	aD^b	G/g	$\bar{D}$	Mean
Stem	7.28	7.88	6.13	7.10
Branch	3.97	4.58	3.46	4.00
Leaf	3.44	4.09	2.74	3.42
Total	14.67	16.55	12.33	14.52

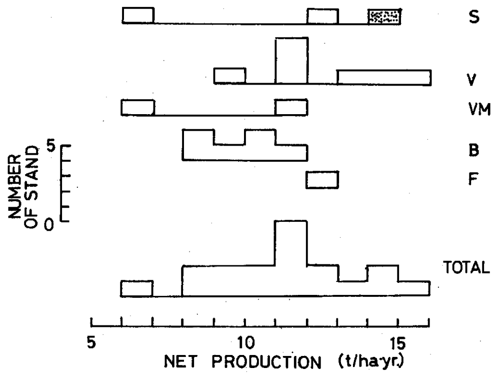

Fig. 3. Net production of forests of *Abies* spp. See the explanation of Fig. 1.
Sources of data:
S: 4 Universities.
V: TADAKI et al. 1970.
VM: KIMURA 1963, KIMURA et al. 1968.
B: BASKERVILLE 1965.
F: ANDO et al. 1972.

Table 6. Percentage distribution of net production among parts of trees.

	Stand	Dominant tree	Average tree	Suppressed tree
Number of samples		2	3	2
D.B.H. (cm)		17.9	13.9	10.9
Height (cm)		11.7	10.9	7.8
Leaf mass per tree (kg)		14.5	5.3	1.6
Stem (%)	49.5	46.9	50.6	44.6
Branch (%)	27.1	26.9	27.6	34.5
Leaf (%)	23.4	26.2	21.7	20.9

aboveground net production of this plantation was distributed into stem, and distribution into branch was a little larger than into leaf. Distribution into branch was largest in the suppressed and smallest in the dominant trees, while distribution into leaf was largest in the dominant and smallest in the suppressed trees, suggesting that differentiation of crown class is still progressing. Distribution into stem was largest in the average trees. The pattern of distribution of produced matter by tree class was somewhat different from the one in an adjacent Norway spruce plantation (SATOO 1971a).

6. Net assimilation rate

In Fig. 4 is shown the relationship between annual net production and amount of leaf of sample trees. Between net production (P kg) and leaf mass (L kg, in dry weight) was recognized a linear relationship (r=0.996**), and described as

$$p=1.123\,L\,.$$

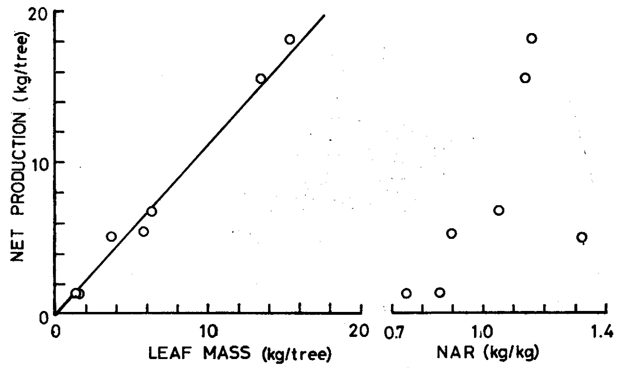

Fig. 4. Net production in relation to leaf mass and net assimilation rate (NAR).

Net production per unit leaf, or net assimilation rate, which is expressed by the slope of the regression line, of this stand was 1.123 kg/kg/year. This value is equivalent to 3.1 g/kg/day, and for growing season, which is from May to September, 7.3 g/kg/day. Net assimilation rate was also calculated by dividing the value

Table 7. Net assimilation rate (aboveground (kg/kg/year).

Forest type	Plantation	Very young natural forest	Young natural forest	Old natural forest*
Locality	Yamabe	Rubesibe	Onneyu	Yamabe
Number of samples	7	8	3	4
Mean D.B.H. for stand (cm)	13.9	4.5	13.7	—
Mean D.B.H. for samples (cm)	13.5	4.2	14.8	46.7
Mean height for samples (m)	10.05	5.31	14.55	23.63
Leaf mass per ha (t)	14.55	7.91	15.18	—
Method:				
Regression	1.123	0.863	0.852	0.569
Mean of samples	1.023	0.708	0.716	0.563
Stand: G/g	1.088	0.808	0.824	—
Stand: aD^b	1.008	—	—	—

* Dominant trees only.

of net production by leaf mass of individual trees or of forest per unit ground area. Values of net assimilation rate determined by the three methods are shown in Table 7. The difference between the methods was not too large; net assimilation rate of this plantation was 1-1.1 kg/kg/year. These values are fairly larger than the value of an adjacent plantation of *Picea abies*, 45 to 47-year-old (SATOO 1971a). There is no comparable published data of net assimilation rate of this species. Net assimilation rate was determined for two young natural forests in eastern Hokkaido (Rubesibe and Onneyu) and for dominant trees of an adjacent old natural forest (Yamabe) by the same methods and presented in Table 7, along with brief description of the stands or trees. Net assimilation rate of this plantation (Yamabe) was larger than these natural forests and trees. Net assimilation rate of *Abies balsamea* in Canada calculated from tables in BASKERVILLE (1965), mean of the values calculated from tables in TADAKI et al. (1970) on *A. veitchii* and the value calculated from the table in ANDO et al. (1973) on *A. firma* are also smaller than the value of this plantation.

Table 8. Net assimilation rate (aboveground) and efficiency of leaf to produce stemwood of different tree classes (kg/kg/year).

	Dominant trees	Average trees	Suppressed trees
Number of samples	2	3	2
Height (m)	11.2	10.9	7.9
D.B.H. (cm)	17.9	13.9	8.5
Leaf mass (kg/tree)	14.5	5.3	1.6
Net assimilation rate	1.144	1.089	0.803
Efficiency for stemwood production	0.533	0.556	0.354

Net assimilation rate of the suppressed trees was smaller than the dominant and the average trees (Table 8). Net production of trees was rather independent from net assimilation rate ($r=0.576$, insignificant), but among trees with smaller net production, production seemed to depend on net assimilation rate (Fig. 4), suggesting that these trees are rather suppressed and photosynthetic rate is lower because of shading. This result is somewhat different from the relationships found on *Pinus densiflora* (SATOO 1968), *Larix leptolepis* (SATOO 1971b), and *Betula maximowicziana* (SATOO 1970), in which net production was clearly independent from net assimilation rate. These three species belong to shade intolerant trees whereas *A. sachalinensis* belongs to shade tolerant species. Further studies are necessary to make any conclusion in this respect.

7. Relationship between stem wood production and leaf mass

As shown in Fig. 5, stem wood production (Ps kg) was proportional to leaf mass (L kg, dry weight) as described as

$$Ps = 0.530\,L,\ r = 0.990^{**}.$$

Stem wood production per 1 kg of leaf was 0.530 kg. The values calculated by other methods mentioned for net assimilation rate are also shown in Table 9. The values similarly determined for two young natural regenerations in eastern Hokkaido and dominant trees of an adjacent old natural forest are shown in Table 9. The value for this plantation was not much different from values for the young natural forests and larger than old trees. BURGER (1951) reported that the amount of leaf necessary for production of 1 cubic meter of wood in an even-aged stand of

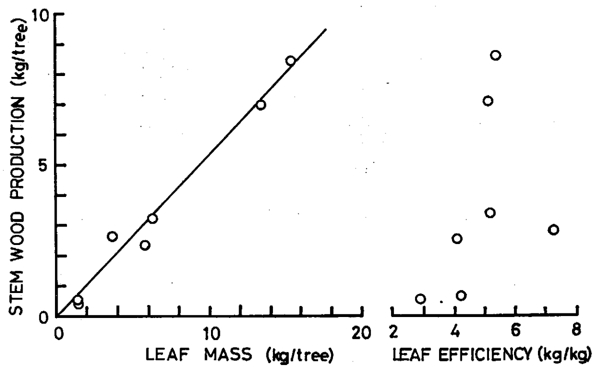

Fig. 5. Stem wood production in relation to leaf mass and the "efficiency of leaf to produce stem wood".

Table 9. Efficiency of leaf to produce stemwood (kg/kg/year).

Type of forest	Plantation	Very young natural forest	Young natural forest	Old natural forest*
Locality	Yamabe	Rubesibe	Onneyu	Yamabe
Number of samples	7	8	3	4
Mean D.B.H. for stand (cm)	13.9	4.5	13.7	—
Mean D.B.H. for samples (cm)	13.5	4.2	14.8	46.7
Mean height for samples (m)	10.05	5.31	14.55	23.63
Method:				
Regression	0.530	0.544	0.538	0.341
Mean of samples	0.492	0.432	0.367	0.339
Stand: G/g	0.519	0.537	0.515	—
Stand: aD^b	0.499	—	—	—

* Dominant trees only.

European fir was 1500 kg in fresh weight. In this plantation, 1300 kg of leaf in fresh weight was necessary for producing 1 cubic meter of wood. As seen from Fig. 5, stem wood production was rather independent from the "efficiency of leaf to produce stem wood". This efficiency is far lower in suppressed trees than in the dominant and average trees, reflecting lower net assimilation rate (Table 8) and lower distribution ratio into the stem (Table 6) of them. The "efficiency of leaf to produce stem wood" is a product of net assimilation rate and distribution ratio into stem The relationship of distribution ratio to leaf mass on trees is rather complicated (SATOO 1966)..

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* in Japanese with English summary.

** in Japanese only.

Titles in parentheses are tentative translation from the originals by the present author.

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北海道のわかいトドマツの植栽林の物質生産
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1 ha あたり 13.8 t の葉をもった 26 年生の植栽林は，地上部だけで，1 年 1 ha あたり 14.5 t の乾物を生産し，その半分が幹だった。シタバエの現存量と生産量は無視できるほどのものだった。生産物の樹体の部分えの分配のアリサマは，林のなかでの木の優劣関係によってことなり，葉えの分配率は優勢木でおおきく，枝えの分配率は劣勢木でおおきかった。幹えの分配率は中ほどの木でややおおきかった。林分の葉の量と生産量をほかのモミ属の林とくらべた。ひとつひとつの木の純生産量はその木のもつている葉の量できまり，葉の能率 (NAR) とは関係がなかった。葉の能率は劣勢木よりも優勢木がたかかつた。葉の能率をほかのトドマツ林とくらべた。

Appendix 1. Sample tree data.

Tree (age)	D.B.H. (cm)	Height (m)	Stem volume (cu. m)	Biomass (kg)			Net production (kg)		
				Stem	Branch	Leaf	Stem	Branch	Leaf
1	18.0	11.6	0.1356	53.1	21.4	15.5	8.47	4.74	4.71
2	17.8	10.8	0.1155	45.2	16.1	13.5	7.04	4.21	4.03
3	14.0	11.2	0.0808	31.6	6.7	6.3	3.25	1.59	1.71
4	13.8	10.8	0.0761	29.8	5.2	3.7	2.66	1.44	0.84
5	13.8	10.4	0.0738	28.9	5.9	5.8	2.36	1.63	1.22
6	8.1	6.7	0.0165	6.0	1.0	1.5	0.60	0.36	0.24
7	8.7	9.0	0.0258	10.1	1.4	1.6	0.45	0.45	0.25
A (98)	50.0	23.8	2.059	809.2	263.2	71.5	28.1	10.5	14.3
B (114)	39.6	21.6	1.485	581.1	172.6	70.0	26.0	11.2	11.7
C (111)	52.0	24.6	2.547	1000.2	342.4	66.0	21.1	7.2	8.9
D (119)	45.6	24.6	1.974	673.4	249.3	64.5	17.5	6.6	8.4

Appendix 2. Stand table.

D. B. H.	n/ha	D. B. H.	n/ha
6	71	14	629
8	114	16	329
10	529	18	171
12	471	20	86