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Community Structure, Phytomass, and Primary Productivity in *Thuja orientalis* Stands on Limestone Area

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The community structure, phytomass, and primary productivity in *Thuja orientalis* stands on a limestone area located in Maepo-up, Chungbuk province in Korea were estimated quantitatively. Seven species including a small proportion of *Quercus dentata* were identified in the tree layer, 26 species including *Ulmus macrocarpa* in the shrub layer, and 79 species including *Carex lanceolata* in the herb layer of the *Thuja* stands. The vertical distribution of the fine root phytomass exhibited a power functional decrease relative to the soil depth. The seasonal changes in the fine root phytomass at a soil depth of 5 cm were closely related to the precipitation in the study area. The productivity of the stand of stems, branches, leaves, and roots were 10.72, 0.82, 0.45 and 6.46 ton DM · ha^{-1} · yr^{-1}, respectively. The *Thuja* stand had a high foliage(25 %) and low rate of production per unit of foliage. The annual turnover rate of the fine roots in the *Thuja* stand was 6.71 yr^{-1}. The net primary production of the overstory including the understory was estimated at 19.48 ton DM · ha^{-1} · yr^{-1} including an underground section of 6.46 ton DM · ha^{-1} · yr^{-1}(33 %). The allocation ratio of net production to root was lower in the limestone *Thuja* communities than at the nearby non-limestone ones, whereas the production efficiency to leaf weight was higher in the limestone communities. These results would seem to indicate that the limited production capacity is due to the calcium toxicity and low availability of iron and phosphorus in a limestone soil with a high pH, calcium, and bicarbonate content combined with a strategy for survival in a hostile habitat.

Key words : Limestone, Phytomass, Fine roots, Productivity, *Thuja*

1. Introduction

A *Thuja orientalis* forest is the most pronounced plant community in the limestone area of Korea (Kwak, 1993). A previous survey on the distribution, age, and size structures of *T. orientalis,* revealed that most trees were stunted, deformed, and bell-shaped at the cliff-edges and cliff-faces of the forests. *Thuja* is more tolerant of cliff-edge conditions, therefore, it is excluded from the deciduous zone because other species are excluded from cliff-edges because they are intolerant of such hostile conditions(Bartlett and Larson, 1990). The lower and more rapidly fluctuating soil moisture levels combined with low photosynthetically active radiation in a cliff edge habitat are more severe conditions for plants than a deciduous forest in summer(Bartlett *et al.*, 1990). *Thuja* is restricted to a cliff edge habitat. Although some reports exist of *T. occidentalis* forming old-growth stands on cliffs, most previous literature describes *Thuja* as a relating short-lived lowland species growing in a swampy area or on flat limestone rock(Larson *et al.*,1989 ; Larson and Kelly, 1991). Many of the habitat characteristics and morphological features of *T. occidentalis* growing on limestone cliffs are superficially similar to *Pinus longgaeva* from the south western United States(Larson *et al.*, 1989). In the Korean peninsula, a *T. orientalis* stand usually occurs in a mosaic pattern in a limestone area. The vegetation in this type of area has been previously described on both large(Kwak ;

1993) and small scales(Kim *et al.* 1991, 1992). However, the community structure, phytomass, and primary productivity of a *T. orientalis* forest in a limestone area is still unknown.

2. Study area and Methods

Thuja orientalis stands featuring large shrubs or small trees that are dense, compact, conical, or columnar are located in Maepo, Tanyang-gun, Chungbuk province. The study area was determined as a north-facing(SW250-EE90) slope with an angle of 10~40°. Nine stands in the study area were chosen for the analysis of the community structure(refer to Kwak, 1993). Two sites(Nos. 8 and 38) located at Sangshiri, were selected for the determination of the phytomass and productivity of the *Thuja* stands. The soil originated from dolomitic limestone and had a typically thin depth, often below 15 cm and rarely above 15 cm. The soil was rich in calcium(4.9~5.4 mg/g) and magnesium(0.4~0.5 mg/g), yet low in potassium(0.1~0.5 mg/g) compared with the nearby non-limestone soil. The soil texture of the *Thuja* stands was sandy loam(sand 62~72 %, silt 20~25%, clay 8~13 %) and the soil pH was neutral or weak alkalic ranging from 7.6 to 7.9(refer to kwak, 1993). The age of the stands was 40-50 years old, the tree density 5100 trees/ha, the basal area 18.9 m^2/ha, and the tree density 2.8±0.3 m. All the analytical methods used to determine the structure and productivity of the *Thuja* stands have been previously described in detail by Kwak(1993). The phytomass and annual productivity for the aboveground of the standard trees were estimated using the allometric method(Kira, 1975) combined with the annual ring analysis method(Schweingruber, 1987). To determine the phytomass of the understory, clippings were made in August at ground level within a 0.25 m^2 quadrat for herbs and a 4m^2 quadrat for shrubs. These materials were then divided into woody and nonwoody components and the dry matter weighed.

3. Results and Discussion

3.1. Community structure

Seven species were identified, however, the forest was almost entirely composed of *Thuja* (94 %), with only a small proportion of *Quercus dentata* and occasional individual *Juniperus rigida, Pinus densiflora,* and *Fraxinus rhynchophylla* in the tree layer of the *Thuja* stands in the limestone area(Table 1). The number of species in the shrub layer was 26. *Ulmus macrocarpa, Lespedeza cyrtobotrya,* and *Rhus chinenesis* exhibited higher importance values than the other species(Table 2). The herb layer consisted of 79 species and was dominated by *Carex lanceolata* with a 79 % coverage. The species composition of the *Thuja* stands was very poor in comparison with the nearby non-limestone vegetation. Such lower values may have been due to weak radiation caused by the dense bell-shaped crown foliage and the high density of the tree layer in the *Thuja* stands. The stem diameter(D_{30}) 30cm above ground ranged from 1.5 cm to 14.1 cm(mean 5.7 cm) (Fig. 1). The normal probability distribution calculated for the D_{30}H skewness(g1) was 0.58, which means that the frequency distribution curve had a long tail to the right(Sokal and Rohlf, 1981). Such a frequency distribution skewed to the right may relate to the low growth of the DBH in a small number of large plants. Furthermore, the Kurtosis was -0.22 and the negative values showing the platykurtic trend were more flat-topped in the distribution curve(Sokal and Rohlf, 1981). This platykurtic trend indicates that the *Thuja* population had a clumped distribution and signifying the onset of competition and the development of a two tier canopy. The *Thuja* species requires a rich base of abundant soil in the field, yet it also grows well in acidic soils. It is likely that *Thuja* may be unable to compete with other species in soils with a low pH under field conditions as suggested by Nelson and Coker(1974) for *Erica vagans.*

3.2. Phytomass and productivity

3.2.1. Belowground phytomass

Vertical distribution of fine roots : The fine root phytomass of the *Thuja* stands decreased with the soil depth(Fig. 2). In the *Thuja* stands, the total phytomass above a soil depth of 15 cm was 333±65 g DM/m^2 for live roots, 70±20 g DM/m^2 for the necromass of the overstory, and 47±13 g DM/m^2 for the phytomass with the necromass of the understory. In particular, the fine root phytomass above a soil depth of 5cm was 259±47 g DM/m^2(78 %) for live roots, 51±18 g DM/m^2(73 %)

for the necromass of the overstory, and 24±8 g DM/m^2(51 %) for the phytomass with the necromass of the understory. The ratio of phytomass to necromass in the fine roots was 27 %. Many environmental factors related to the soil can also influence root production which can become less favorable according to the soil depth. Accordingly, a shallow depth in limestone soil would most likely limit root growth and depth. In contrast, a large proportion of fine roots near the soil surface could also be the result of favorable nutrient, moisture, and root respiration conditions in the upper part of the soil. However, fine roots are vulnerable to stress including drought, high temperature, calcium, and bicarbonate(Caldwell, 1987 ; Makay and Malcom, 1988 ; Kwak and Kim, 1994). It is assumed that *Thuja orientalis,* as a calcicoles, is tolerant in hostile conditions.

Seasonal changes of fine root phytomass : Sea-sonal changes in the live fine-roots at a depth

Table 1. Importance values for the tree and shrub layers and the relative cover of the herb layer in the *Thuja orientalis* community in the Maepo limestone area

Species	Relative density	Relative basal area	Canopy area(%)	Relative cover	Importance value
Tree layer(7 species)					
Thuja orientalis	90.5	96.5	–	–	93.5
Quercus dentata	4.3	2.0	–	–	3.2
Juniperus rigida	2.6	0.8	–	–	1.7
Ulmus macrocarpa	1.1	0.3	–	–	0.7
Pinus densiflora	0.9	0.1	–	–	0.5
Quercus variabilis	0.4	0.2	–	–	0.3
Fraxinus rhynchophylla	0.2	0.1	–	–	0.1
Shrub layer(26 species)					
Ulmus macrocarpa	16.6	–	16.4	–	16.5
Quercus dentata	12.3	–	14.8	–	13.6
Rhus chinensis	10.5	–	10.5	–	10.5
Thuja orientalis	9.8	–	10.4	–	10.1
Lespedeza cyrtobotrya	5.4	–	11.8	–	8.6
Rhamnus davurica	8.3	–	6.4	–	7.4
Spiraea chinensis	10.5	–	3.7	–	7.1
Securinega suffruticosa	6.1	–	6.1	–	6.1
others					
Herb layer(79 species)					
Carex lanceolata	–	–	–	45.3	–
Spodiopogon cotulifer	–	–	–	4.0	–
Patrinia rupestris	–	–	–	4.0	–
Arundinella hirta	–	–	–	3.7	–
Isachne globosa	–	–	–	3.0	–
Clematis mandshurica	–	–	–	2.2	–
Themeda triandra var. japonca	–	–	–	1.8	–
Isodon inflexus	–	–	–	1.6	–
Lithospermum arvense	–	–	–	1.4	–
Viola variegata	–	–	–	1.4	–
Miscanthus sinensis	–	–	–	1.3	–
Lespedeza cuneata	–	–	–	1.3	–
Swertia japonica	–	–	–	1.0	–
Polygala japonica	–	–	–	1.0	–
Others					

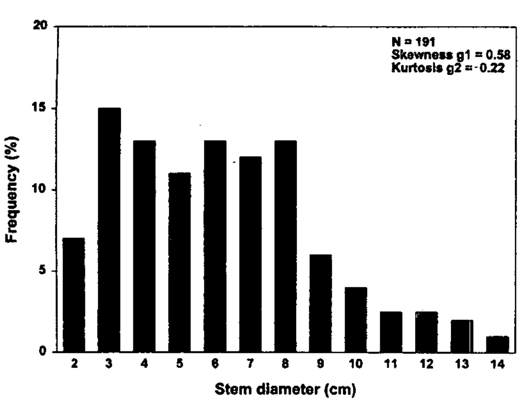

Fig. 1. Frequency distribution of stem diameter for *Thuja* community in Tanyang limestone area.

of 5 cm exhibited bimodal peaks : the first peak was in June(273 ± 149g DM/m^2) and the second in September(305 ± 105g DM/m^2). The necromass increased in the summer and winter and decreased in the spring and fall, the fine-roots of the understory increased gradually from January to July with a maximum value of 45 ± 17g DM/m^2 and then gradually decreased(Fig. 3). The pattern of the fine root phytomass in *Thuja* stands was closely related with precipitation which varied seasonally with the smallest values being recorded in March 1991(Fig. 3). It is assumed that dry conditions in the upper soil portions had a profound impact on the fine root growth since fine roots can uptake water and nutrients over a wide range of water conditions. The fine root growth in the top profile of the mineral soil(5cm depth) increased with the water supply in the *Thuja* stands. The net productivity of the live fine roots in the top soil(5cm depth) in April, May, June, September, and December was 72, 83, 32, 182, and 61g DM m^{-2} · $month^{-1}$, respectively (Fig. 3). Based on a summation of the positive differences in the seasonal changes and subsequent peak phytomass estimates, the annual net productivity of the live fine roots was 430 g DM m^{-2}. $year^{-1}$ above a soil depth of 5cm and 550g DM m^{-2} · $year^{-1}$ above a 15cm depth. This value at a depth of 15 cm was half that of the leaf production and 4.3-fold that of the woody production aboveground(Table 2). Water stress seems to be the leading factor regulating fine root death(Pereira and Pallardy, 1989). It is widely accepted that water stress can increase the carbon allocation in root systems. A large fraction(sometimes more than 50 %) of the total carbon fixed by a tree can be used in the production and replacement of fine roots (Axelson and Axelsson, 1986 ; Caldwell, 1987). The ratio of annual net primary productivity to phytomass of fine roots in the *Thuja* stands was 3.4 which is higher than that for *Abies amabilis* (0.5 ~ 0.7), *Pinus resinosa*(0.8), *Pseudotsuga menziesii*(0.6) and *P. strobus* forests(0.7) (Vogt *et al.* 1987 ; MaClaugherty *et al.*, 1982 ; Nadelhoffer *et al.*, 1985). This result indicates that a high amount of fine root production occurs in a *Thuja* forest. The annual turnover rate for fine root production in a *Thuja* forest was 6.71 yr^{-1}, with the highest value being recorded in May at 3.50 $month^{-1}$, above a soil depth of 5 cm and 8.59 yr^{-1} above a 15 cm depth(Fig. 4). It is also probable that fine root longevity may be related to the soil nutrient status.

3.2.2. Aboveground Phytomass

Allometric relation for phytomass : The allometric relation deduced from the result of the stem analysis as well as the weight of the organs for the standard trees were as follows (refer to Kwak, 1993) :

$$\log Ws = 0.8068 \log(D^2_{30}H) - 1.378 \ ; \ \log Wb = 0.8723 \log(D^2_{30} \cdot H) - 1.283 \ ;$$

$$\log Wl = 0.6826 \log(D^2_{30}H) - 1.050$$

where *Ws*, *Wb* and *Wl* are the dry weights of the stems, branches and leaves, respectively, and $D^2_{30}H$

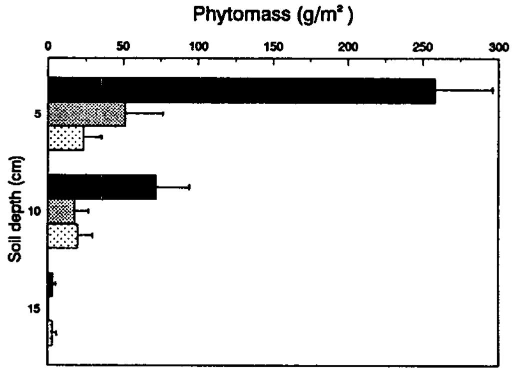

Fig. 2. Vertical distribution of Fine-roots for *Thuja* community, on July, 1996. Phytomass(black histogram) and necromass(gray histogram) of overstory and phytomass with necromass(dotted histogram) of understory.

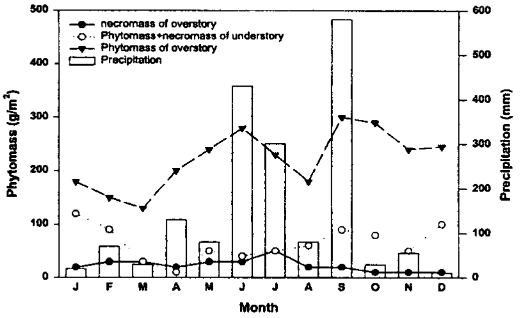

Fig. 3. Seasonal changes of fine-roots for *Thuja* community.

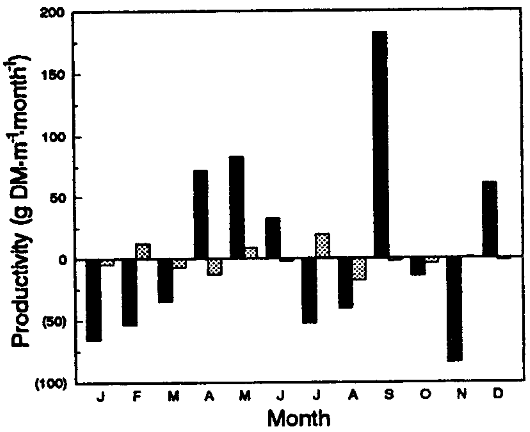

Fig. 4. Seasonal changes of fine-foots productivity(g DM · m^{-2} · $month^{-1}$) for overstory(black histogram) and understory(dotted historgram) on top soil of 5 cm layer for *Thuja* community.

is the square of D_{30} multiplied by the tree height. In productive structure of *Thuja, t*he photosynthetic part and the distribution of the foliage between the whorl and the interwhorl branches varied at different positions ranging from ground to a height of 310 cm with the highest phytomass measured at a height between 180-230 cm(Fig. 6). Accordingly, it is suggested that the most efficient foliage canopies of *T. orientalis are* where the photosynthetic activity is evenly distributed relative to the depth. As the nonphotosynthetic part, the whorled branches(52 %) from the ground to the top level exhibited the highest phytomass at a height between 80 ~ 130 cm, which was two-fold that of the stems(23 %) (Fig. 6).

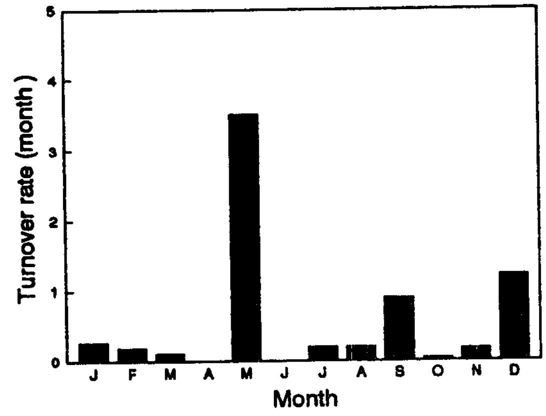

Fig. 5. Seasonal changes of turnover rates of fine-roots on soil of 5 cm layer for *Thuja* community.

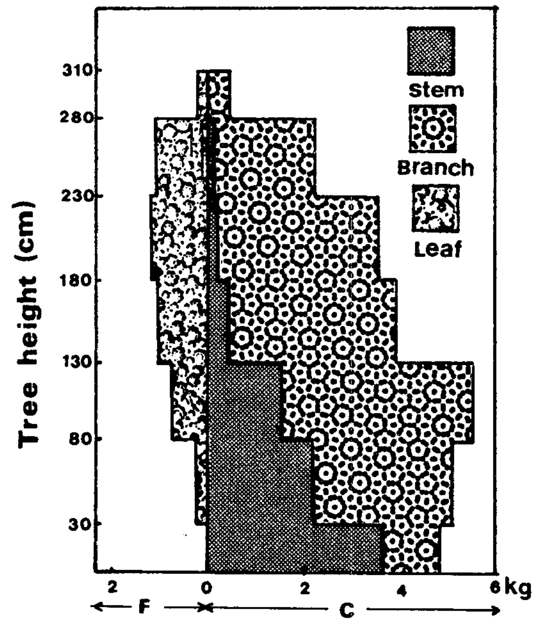

Fig. 6. The productive structure in a 40 years old of *Thuja*. F ; photosynthetic, C ; nonphotosynthetic part.

Standing Phytomass: The phytomass of the *Thuja* stand, substituting $D^2_{30}H$ for every tree existing within the permanent quadrats for the above equation, was estimated to be as much as 33.1 ton DM/ha in 1996 and 34.5 ton DM/ha in 1997. In the *Thuja* stand, the phytomass of the aboveground tree layer was 10.3 ~ 10.7 ton DM/ha for the leaves, 14.3 ~ 15.2 ton DM/ha for the branches, 8.5 ~ 9.0 ton DM/ha for the stems, and 16.4 ~ 17.5 ton DM/ha for the root(Table 2). The ratio of the woody parts to the whole aboveground phytomass was 0.31. The phytomasses of the aboveground and belowground understories were 0.2 ~ 0.5 ton DM/ha and 0.6-0.8 ton DM/ha, respectively(Table 2). The total phytomass of *T. orientalis* was 50.5 ~ 53.1 ton DM/ha(Table 2). The phytomass of the *Thuja* stand in smaller than those of a *Picea sitchensis* forest at 108 ton DM/ha in Scotland(Ford, 1982), the *P. rigida* plantation in the Choongnam Forest Experiment Station at 82 ~ 88 ton DM/ha(Kim, 1971), and temperate evergreen forests ranging between 60 and 600 ton DM/ha(Whittaker and Likens, 1975). The phytomass of the *Thuja* stand approximates that of the *Pinus densiflora* in Chuncheon at 26 ~ 39 ton DM/ha(Kim and Yoon 1972) and that of the *Pinus koraiensis* plantation at 32.3 ~ 48.4 ton DM/ha(Kim *et al.*, 1988). Even though the density of the study site is higher than those of other studies, it is suggested that the reason for the lower phytomass value for *Thuja* is due to its bell-shaped stunted growth architecture. The phytomass of the understory is 230 ~ 510 kg DM/ha lower than that of the climax forest at Piagol, Mt. Chiri at 2,470 kg DM/ha, a *Q. variabilis* forest at 1,185 kg DM/ha, a *Q. dentata* forest at 1680 kg DM/ha and a *P. densifolora* forest at 1725 kg DM/ha(Kim *et al.* 1990 ; Kwak, 1993). This lower phytomass of the understory in the stand may be due to weak radiation caused by a dense crown foliage and the high density of the tree layer in the stand. The total phytomass, including the aboveground and underground of the trees, shrubs, and herbs in the stand studied was 50.5 ~ 53.1ton DM/ha(Table 2). The phytomass of the coarse roots including the fine root phytomass in the *Thuja* stand was 14.8 ~ 15.8 ton DM/ha(Table 2). This value is lower than that of a *Picea sitchensis* forest at 20.1 ton DM/ha in Scotland(Ford, 1982).

Annual productivity : The annual productivity for the tree layer in the *Thuja* stand studied was 12.0ton DM · ha^{-1} · yr^{-1}. The productivity of the *Thuja* stand approximates that of the *Pinus densiflora* in Chuncheon at 12.7 ton DM · ha^{-1} · yr^{-1}(Kim and Yoon, 1972) and that of a *P. desiflora* forest at 11.9 ton DM · ha^{-1} · yr^{-1}, and yet is higher than that of the *P. rigida* plantation at the Choongnam Forest Experiment Station at 6.5 ton DM · ha^{-1} · yr^{-1}(Kim, 1971), a *Q, dentata* forest at 3.7 ton DM · ha^{-1} · yr^{-1}, and a *Q. variabilis* forest at 8.5ton DM · ha^{-1} · yr^{-1}. The productivity of the forest, however, is less than that of a *Picea sitchensis* forest at 35.2 ton DM · ha^{-1} · yr^{-1}(Ford, 1982) and the mean value of 14.5ton DM · ha^{-1} · yr^{-1} for all age estimates of temperate coniferous forest production, as given by Kira(1975). The productivity of the stems, branches, leaves, and roots in the *Thuja* stand were 0.45, 0.82, 10.72, and 6.46 ton DM · ha^{-1} · yr^{-1}, respectively(Table 2). The allocation ratios of the new production to the stems, branches, leaves, and roots were 2, 5, 58, and 35%, respectively. The productivity of the understory

Table 2. Phytomass(ton/ha) and productivity(ton · ha^{-1} · yr^{-1}) of *Thuja orientalis* stands

Belowground	Overstory			Understory		
	Phytomass		Productivity	Phytomass		Productivity
	1996	1997		1996	1997	
Coarse roots	14.76	15.75	0.99	0.06	0.06	–
Fine roots	1.64	1.75	5.42	0.74	0.56	0.83
Subtotal	16.40	17.50	6.46	0.80	0.62	0.80
Aboveground	Overstory			Understory		
	Phytomass		Productivity	Phytomass		Productivity
	1996	1997		1996	1997	
Leaves	10.26	10.72	10.72	–	0.25	0.25
Branches	14.34	15.16	0.82	0.23	0.26	0.03
Stems	8.50	8.95	0.45			
Subtotal	33.10	34.47	11.99	0.23	0.51	0.28
Total	49.50	51.97	18.40	1.03	1.13	1.08

was 1.1 ton DM · ha^{-1} · yr^{-1} and the ratio of the productivity of the understory to the overstory was 0.06(Table 2). The allocation of the new production was mainly attributed to the leaves. This is due to the efficiency of the foliage canopy with a high rate of production per unit of foliage in a hostile habitat. The belowground total productivity was 35 % in the *Thuja* stand. This value is larger than that of a *Picea glauca* forest at 23 %(Nadelhoffer *et al.*, 1985), a *P. sitchensis* forest at 24 %(Ford, 1982), and a *Pinus densiflora* forest at 8 %(Satoo and Madgwick, 1982), with the exception of a *P. sylvestris* forest in a dry site at 55 %(Agren *et al.*, 1980). The production efficiency of the stand, that is the ratio of annual productivity to leaf weight as a measure of organic matter production, was 1.72 yr^{-1}, which approximates that of a *P. densiflora* forest at 2.00 yr^{-1}(Kwak, 1993), yet is slightly lower than that of a *Picea glauca* forest at 3.39yr^{-1} (Nadelhoffer *et al.*, 1985), a *P. strobus* forest at 3.81 yr^{-1}, and a *P. densiflora* forest at 3.72 yr^{-1}(Satoo and Madgwick, 1982). These results indicate that the photosynthetic capacity of a *Thuja* stand is limited by the calcium toxicity and low availability of iron and phosphorus in a limestone soil.

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