Korean J. Ecol. 15(1) : 19～33, 1992

Secular Changes of Density, Litterfall, Phytomass and Primary Productivity in Mongolian Oak (*Quercus mongolica*) Forest

Kwak, Young-Se and Joon-Ho Kim

Dept. of Biology, Natural Science College, Seoul Nat'l University

신갈나무 숲의 林木密度, 落葉量, 植物量 및 1次 純生産量의 經年 變化

郭永世 · 金俊鎬

서울大學校 自然科學大學 生物學科

ABSTRACT

The density, litterfall, phytomass, and primary productivity for 7 years in *Quercus mongolica* forest located at Mt. Nambyengsan, Pyeongchang-gun, Gangwon province in central part of Korean peninsula were estimated quantitatively. At the first year in 1984, a stand had 1,450 trees/ha in tree density, which was 0.67 of skewness and 0.54 of kurtosis in frequency distribution, however, at the 7th year in 1990, the stand had 1,133 trees/ha in the density with 22%(or 316 trees/ha) in mortality, which was 1.16 of skewness and 1.89 of kurtosis in the frequency. Annual mean litterfall was 5 ton DM/ha, which was composed of 68% of leaves, 17% of branches, 3% of bud scales, 9% of arcons and cups, 0.7% of flowers and 3% of others.

The phytomass of tree layer for 7 years was gradually increased from 149.7 ton DM/ha at the first year to 188.5 ton DM/ha at the 7th year. Annual net productivity for the tree layer studied ranged from 8.76 ton DM/ha · yr^{-1} to 11.62 ton DM/ha · yr^{-1} with heavy fluctuation year by year. Average annual productivity of the stand of trunk, branches, leaves and roots for 7 years were 4.42, 0.67, 3.85 and 1.29 ton DM/ha · yr^{-1}, respectively. Turnover rate of the stand was 6.9% at the first year and 5.6% at the 7th year. Such fluctuation of the productivity was caused by the change of density, mortality and turnover rate.

INTRODUCTION

An important focus of most terrestrial ecosystems is to understand the regulation of plant population and the matter production of community. The demography of plant population was controlled by inter-plant competition for limiting resource(Koyama and Kira, 1956; Koike, 1989) and skewness in the population increases through time(Hutchings, 1986; Agren and Zackrisson, 1990). In study on intraspecific competition of even-aged coniferous monocultures(Oh, 1981) and of semi-natural pine stands in central Korea(Oh and Lee, 1989), leptokurtic distribution appears before normal distribution rather than direct change from platykurtic to normal distribution of basal area from selected stages in the development of stand.

Since the matter production of forest from the standpoint of community level was quantitatively studied in a ash forest by Boysen-Jensen(1932), numerous studies have been made in several different forests(Ovinton *et al.*, 1963; Kira and Shidei, 1967; Johnson and Risser, 1974; Whittaker and Likens, 1975; Chae and Kim, 1977; Kim and Mun, 1982; Jakucs, 1985; Kim *et al.*, 1988; Graumlich *et al.*, 1989). Kim and Yoon(1972) have estimated less net primary production of *Quercus mongolica* forest than that of *Pinus densiflora* one by allometric method. In a mongolian oak forest, annual net productivity was as small as 2.6% of the standing phytomass(Kim *et al.*, 1982). In long-term study on forest by Graumlich *et al.*(1989), annual net production was significantly correlated with both long-term variation in summer temperature and short-term variation in annual precipitation. The amount of litterfall was considerably different with the varying biological and environmental factors(Gosz *et al.*, 1972; Reiners and Lang, 1987; Lowman, 1988). The net primary productivity(NPP) of a forest and the annual growth of trunk decreased because the phytomass(B) of tree layer increased continuously as the stand developed. Accordingly, turnover rate(NPP/B) must decrease(Waring and Schlesinger, 1985). Moreover, thinning of suppressed trees by mortality could stimulate growth of the surviving trees (Romme *et al.*, 1986). In Korean peninsula(Chung and Lee, 1965) the *Quercus mongolica* forest broadly occurs above than altitude of about 100m in the northern part and about 400m in the southern part and also expands to the northeastern province of China(Wang, 1961; Hou, 1985). Seedlings of *Q. mongolica* invade the floor of plantations and of pine forests damaged by pine gall midge(Kim *et al.*, 1989; Lee, 1989).

The purpose of this study is to elucidate changes of density, litterfall, phytomass, and primary productivity in *Quercus mongolica* forest as stand developed.

STUDY AREA

This study was conducted in secondary pure forest of mongolian oak(*Quercus mongolica*) at Mt. Nambyeongsan with an altitude of 1,150 m, located in Pyeongchang-gun, Gangwon province(Fig. 1). The study area is north slope with 5~30°. The soil is originated from granite. Depth of litter was 6 cm. Physico-chemical properties at different soil horizons are shown in Table 1.

The stand studied at the first year was 30~50 year-old in age, 1,450 trees/ha in density, 57.8 m^2/ha in basal area and 12~16 m in tree height, respectively. Leafing of mongolian oak, began in early May, was two weeks earlier at low altitude than at high one

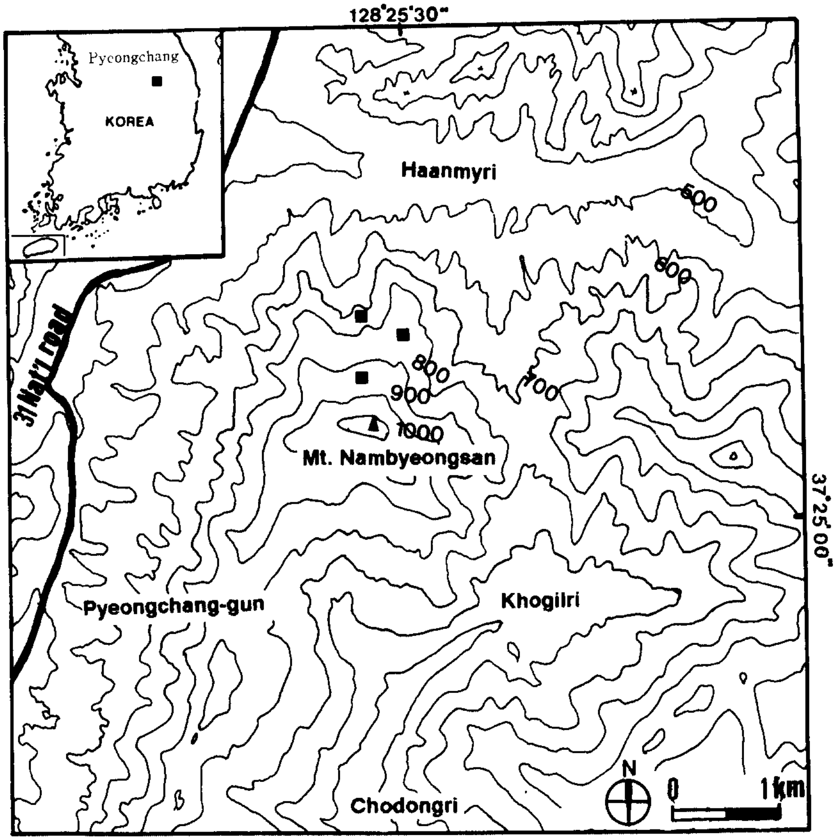

Fig. 1. A map showing study area. Black squares indicate sampling sites.

Table 1. Physico-chemical properties of soil at study area

Horizon	Depth (cm)	Soil texture Sand(%)	Silt(%)	Clay(%)	Bulk density (g/cm^3)	pH	Nitrogen (mg/g)	Phosphorus (μg/g)	Potassium (μg/g)
A	0~8	9.2	30.0	55.8	0.83	5.3	5.3	3.2	125
B	9~20	5.2	36.2	58.6	1.20	5.5	4.1	2.7	91
	21~33	4.9	37.6	57.5	1.28	5.6	3.1	2.1	47
C	34~40	5.0	30.8	64.2	1.34	5.8	2.4	1.5	39
	41~50	6.0	32.7	61.3	1.38	5.9	1.2	0.9	33

in the study area. Understory was dominated by *Acer pseudo-sieboldianum*, *Lespedeza crytobotrya* and *Actinidia arguta* as shrubs and by *Syneilesis palmata*, *Atractylodes japonica*, *Carex siderosticta* and *Pteridium aquilinum* var. *latiusculum* as herbs.

METHODS

Material Samplings

From April 1984 as the first year to December 1990 as the 7th year, three permanent quadrats with 10 m by 20 m were set at altitude of 750, 850 and 950 m in the study area (Fig. 1). The tree census including DBH and tree height(H) as well as species composition of understory were made within the quadrats. The dead trees occuring within the permanent quadrats were removed successively. In autumn, 12 standard trees selected outside the permanent quadrats were cut down.

The trees were separated into trunk, branches and leaves. The amount of the trunk was made with stem analysis. Subsamples of these materials were dried at 80°C until becoming a constant weight and reweighed. These were ground, sifted with a 0.5 mm sieve and then stored in air tight bottle until chemical analyses.

Soils were sampled at surface to 50 cm deep at 10 cm intervals in the stand at every-month intervals. The soils sampled were dried in the shade, sifted with a 2 mm sieve and stored. Soil bulk density was determined by ratio of dry weight to volume for the soil sampled with a steel sleeve of 4.5 cm in diameter and 10 cm in height.

Litterfall was collected with a litter trap of 0.25 m^2 at every month interval, especially at every week intervals for the first year, from September, 1984 to September, 1985. The litters collected were sorted out leaves, branches including twigs, arcons and cups, flowers, bud scales and others. The disappearance from the litter(LD) was calculated as: [LD] = [L] + [initial litter-mass] − [final litter-mass]. The weight loss undergone by herbaceous species during shedding was used 25% according to Gosz *et al.*(1972).

Estimates of Phytomass and Productivity

The phytomass and annual productivity for aboveground of the standard trees mentioned above were estimated by allometric method(Kira and Shidei, 1967; Kim, 1970) as well as annual ring analysis method(Schweingruber, 1987). Annual net productivity of aboveground was estimated from the difference between the phytomass at last year(Wt) and at current year(Wt+1) within the permanent quadrats.

The amount of dead wood was also estimated with the same procedure. To determine the phytomass of understory clippings were made at ground level within 0.25 m^2 quadrat for herbs and 4 m^2 quardrat for shrubs in August. These materials were divided into woody and non-woody components and weighed dry matter. The fluctuations of the root growth and shedding were regarded as one-forth of the standing root phytomass because the roots formed fresh and decayed during the growing season were ignored. The root phytomass, therefore, was estimated by multiplying the highest aboveground phytomass by 0.25(Johnson and Risser, 1974).

RESULTS AND DISCUSSION

Density Decrease by Mortality

Tree density at the first year census in 1984 within the permanent quadrat was 1,450 trees/ha. Density decrease was barely observed at the third year with 1% of mortality. The density, thereafter, gradually decreased 1,250 trees/ha at 5th year with 13% of mortality and 1,133 trees/ha at the 7th year with 22% of mortality(Fig. 2). Consequently the trees died average 45 trees/ha per year for 7 years. In the *Q. mongolica* forest studied saplings as well as seedlings were not observed because of no regeneration by recruitment of seedlings. Such decreasing trend in density would be due to death of suppressed trees by competition among trees, in other words, by the density-dependent effect(Silvertown, 1987; Koike, 1989).

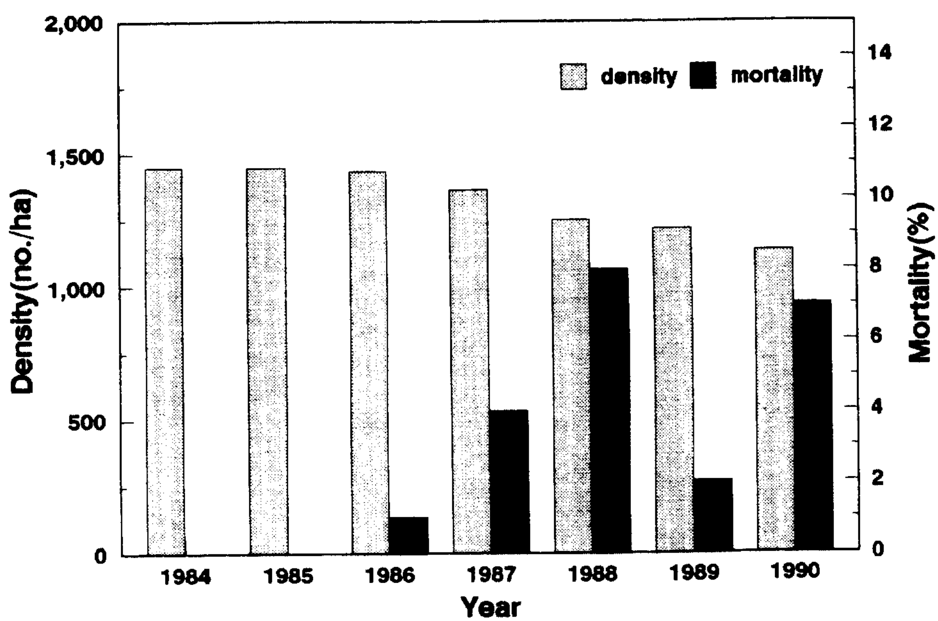

Fig. 2. Changes of density and mortality within permanent quardrat of *Quercus mongolica* forest for 7 years.

Increase of Trunk Diameter

The average value in diameter of breast height(DBH) of trees was 14.1 cm with the range from 5.0 cm to 30.9 cm at the first year census and 17.0 cm with the range from 9.7 cm to 33.4 cm at 7th year one(Fig. 3). In the calculation of normal probability distribution for the DBH skewness(g1), indicate the degree of asymmetry in the normal distribution,

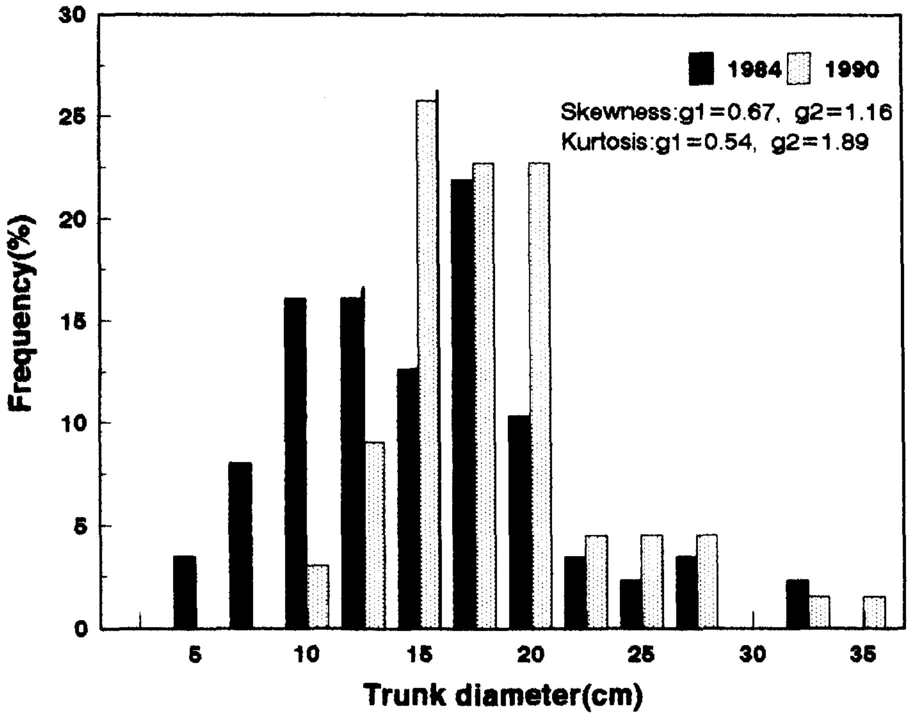

Fig. 3. Frequency distribution of trunk diameter in *Quercus mongolica* forest.

was 0.67 at the first year census, which meant the frequency distribution curve had long tail to the left side and was 1.16 at the 7th year one, which skewed toward the right (Sokal and Rohlf, 1981). Such frequency distribution skewed toward the right through time may relate to the fast growth of DBH of a small number of large plants because mortality was concentrated in the smallest DBH classes. Obeid *et al.*(1967) have observed that skewness in *Linum usitatissimum* populations with initially high density had more large value than with low one. Mohler *et al.*(1978) with *Abies balsamea* population and Ford(1975) with *Tagetes patula* population, however, showed skewness decreased with age increased and with density decreased.

In addition, Kurtosis, a measure of the degree to whether the distribution is more pointy(leptokurtic) or more flat-topped(platykurtic) than the normal distribution, was 0.54 at the first year census and 1.89 at the 7th year one, which both positive values showing leptokurtic indicated more pointy in the distribution curve at the 7th year census than that at the first year one(Sokal and Rohlf, 1981; Hutchings, 1986). The trends of leptokurtic were more conspicuous as age and density increased(Obeid *et al.*, 1967; Oh, 1981)

According to Begon(1984) the interpretation of change in skewness, when competition causes mortality, is very difficult because the different size-dependent survivorship probabilities could either exaggerate or reduce skewness over the course of a growing period. This was because mortality was concentrated in the smallest size classes(Fig. 3). Therefore, individuals of small plants in a dense density also increased in mean plant weight, but the density of individuals decreased due to mortality.

Seasonal Change of Litterfall

The amount of annual litterfall in the trap was 4,269 kg DM /kg · yr^{-1} from the overstory and 700 kg DM /ha · yr^{-1} from understory, so the whole amount of litterfall was 4,969 kg DM /ha · yr^{-1}. The litter consisted of 68% of leaves, 17% of branches, 3% of bud scales, 9% of arcons and cups, 0.7% of flowers and 3% of others(Table 2). Percentage of the leaf fall out of litter in a temperate deciduous forest was 70~80% for a young forest and 40~65% for a mature one(Rodin and Bazilevich, 1967). Consequently, the forest studied would be corresponded to a young forest. Fresh leaves decreased about 20% or 723 kg DM /ha in weight during shedding(Table 2 and Table 3), which was less than weight loss of herbs(Gosz *et al.*, 1972). The amount of flower's litter, 30 kg DM /ha or 0.7%, was similar to that of *Quercus petraca* stand(Ovington, 1963; Jakucs, 1985).

Seasonal change of the litterfall in the trap showed 3 peakes: First peak was due to fall of bud scales, flowers and old leaves in May, second was to fresh leaves and branches by a storm as well as acorns and cups during August to September and third was to leaf fall and acorns during October. Standing litter, the amount of litter lying on ground, was gradually diminished by decay from March to September but heaped thick by the litterfall in October(Fig. 4).

The amount of litterfall decreased as the elevation of the stand ascended. Particulary, the trend was conspicuous in the autumnal litterfall, that is, the litterfall was 3,465, 2,945 and 2,887 kg DM /ha · unit $time^{-1}$(100: 85: 83) in the stands at 750, 850 and 950 m above sea level, respectively(Fig. 5). Such decreasing trend was explained as decreasing heat budget in high elevation(Reiners and Lang, 1987).

Table 2. Composition of litter falling into a litter trap along altitude for a year from September 23, 1984 to Septmber 22, 1985

Plant part	Altitude(m)			Average weight (kg /ha·yr^{-1})	Percentage to total amount (%)
	750	850	950		
Leaves	2,964	2,786	2,897	2,882	67.5
Branches	535	568	1,044	716	16.7
Bud scales	124	148	115	129	3.0
Acorns and cups	211	553	450	398	9.3
Flowers	21	31	39	30	0.7
Others	125	126	90	114	2.7
Total	3,980	4,212	4,635	4,269	100.0

Table 3. Secular changes of the phytomass and the productivity of tree layer for 7 years at the *Q. mongolica* forest

	1984	1985	1986	1987	1988	1989	1990
			Phytomass(B:ton DM/ha)				
Trunk	97.93	102.26	107.80	111.59	114.91	120.07	124.45
Branches	18.13	19.45	19.75	20.12	20.63	21.48	22.16
Leaves	3.67	3.70	3.82	3.92	3.96	4.08	4.15
Roots	29.93	31.48	32.48	33.91	34.88	36.41	37.69
Total	149.66	157.41	164.21	169.53	174.38	182.04	188.45
			Productivity(Pn:ton DM/ha·yr^{-1})				
Trunk	4.33	5.54	3.97	3.32	5.16	4.38	
Branches	1.32	0.30	0.37	0.51	0.85	0.68	
Leaves	3.70	3.82	3.92	3.96	4.08	4.15	
Roots	1.55	1.36	1.07	0.97	1.53	1.28	
Total	10.90	11.02	9.15	8.76	11.62	10.49	
Pn/B(%)	6.92	6.71	5.39	5.02	6.38	5.57	

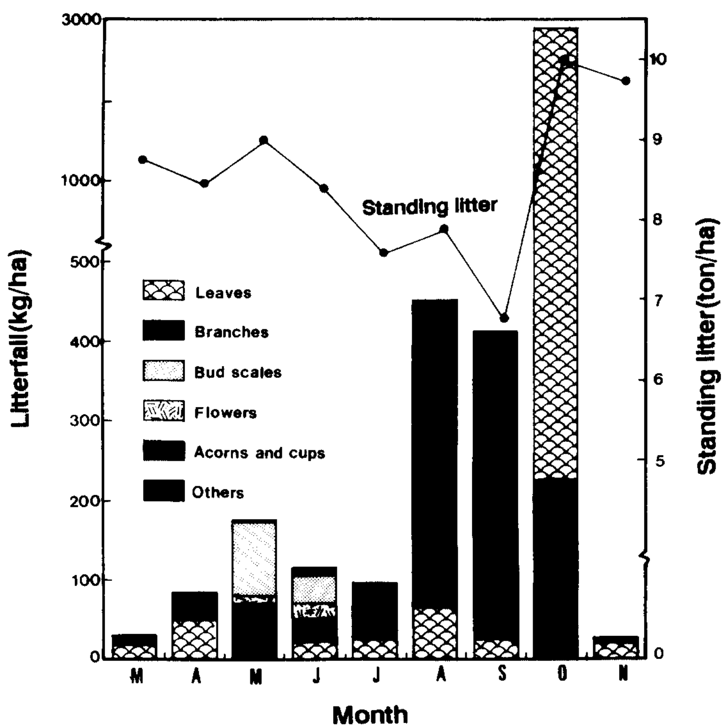

Fig. 4. Seasonal changes of litterfall and standing litter on ground in *Quercus mongolica* forest, 1985.

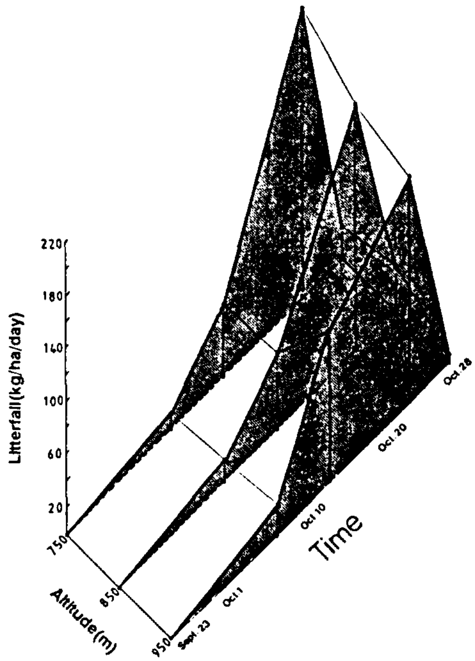

Fig. 5. Changes of litterfall of *Quercus mongolica* at different altitudes and on the different collect times of automn, 1984.

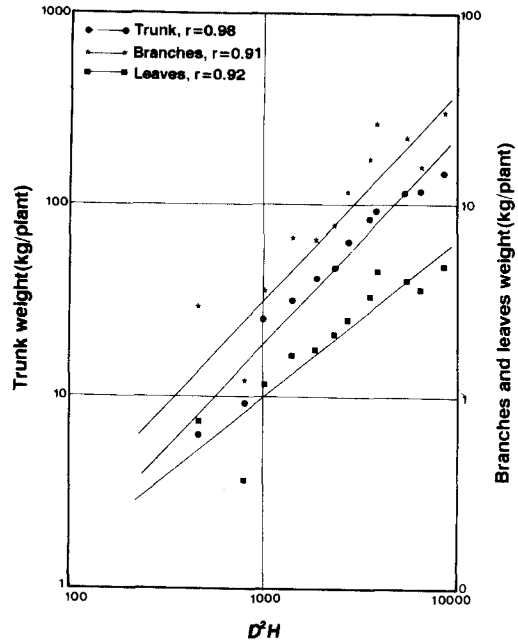

Fig. 6. Allometric relations of D^2H to trunk dry weight(Ws), branches dry weight(Wb) and leaves dry weight(Wl).

Phytomass and productivity

Allometric relation for phytomass

Allometric relation deduced from the result of the trunk analysis as well as weight of organs for the standard trees are as follows(refer Fig. 6):

$$\log Ws = 1.0962 \log(D^2H) - 2.029;\ \log Wb = 1.0167 \log(D^2H) - 2.476;$$
$$\log Wl = 0.8076 \log(D^2H) - 2.413$$

where Ws, Wb and Wl are dry weight of trunk, branches and leaves and D^2H is multiplying square of DBH(cm) by tree height(m).

Standing phytomass

The phytomass of *Q. mongolica* stand, substituting D^2H of every trees existing within the permanent quadrats for above equation, was estimated to be as much as 149.7 ton DM /ha at the first year census in 1984 and 188.5 ton DM /ha at the 7th year one in 1990, corresponding with 26% of increase for 7 years(Table 3, Fig. 7). The ratio of the woody parts to the whole phytomass of aboveground was 0.78 at the 7th year census not as well as the first year census but also but that of the leaves to the whole phytomass decreased more or less, from 0.024 at the first year to 0.022 at the 7th year. These ratios approximated to that for *Q. mongolica* forest in mid-part of Korea with 0.78 for the woody ratio and 0.02 for the leaf ratio(Kim and Yoon, 1972) and that for oak forest with 0.85 and 0.02 in Hungary (Jakucs, 1985). According to Rodin and Bazilevich(1967), in a temperate deciduous forest the woody ratio usually was 0.60~0.85 and the leaf ratio 0.015~0.030.

The amount of phytomass for tree layer in the stand changed from 150 ton DM/ha in 1984 to 188 ton DM/ha in 1990, which gradually increased as the forest aged(Fig. 7). These values were greater than that of *Q. mongolica* forest with 39~48 ton DM/ha at Chuncheon(Kim and Yoon, 1972), *Q. serrata* in Mt. Chiri with 64 ton DM/ha(Kim *et al.*, 1982) and *Q. accutissima* forest in Seoul with 59~69 ton DM/ha(Chae and Kim, 1977)(Fig. 7). This was because the density of the study site was higher than the others. Whittaker and Likens(1975) have estimated that the phytomass for the temperate deciduous forest ranged between 60 and 600 ton DM/ha. The phytomass of understory for shrubs, 407±70 kg DM/ha and herbs, 848±33kg DM/ha in 1984 was less than that of climax forest at Piagol, Mt. Chiri with 2,470 kg DM/ha(Kim *et al.*, 1982)(Fig. 8). Such less phytomass of the understory in the stand might be due to weak radiation by dense crown foliage in the stand. The whole amount of phytomass, including aboveground and underground of trees, shrubs and herbs in the stand studied was 151~159 ton DM/ha(Fig. 8). The amount of dead wood in the stand was 3.0 and 6.4 ton DM/ha in 1984 and 1990, which corresponded 2.0% and 3.4% of tree phytomass(Fig. 7).

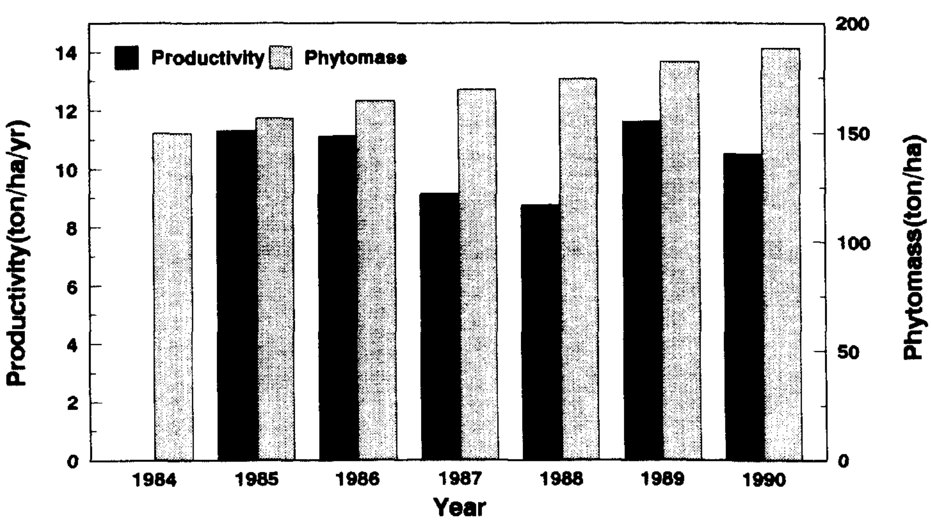

Fig. 7. Annual changes of phytomass and annual productivity of tree layer in *Quercus monlica* forest.

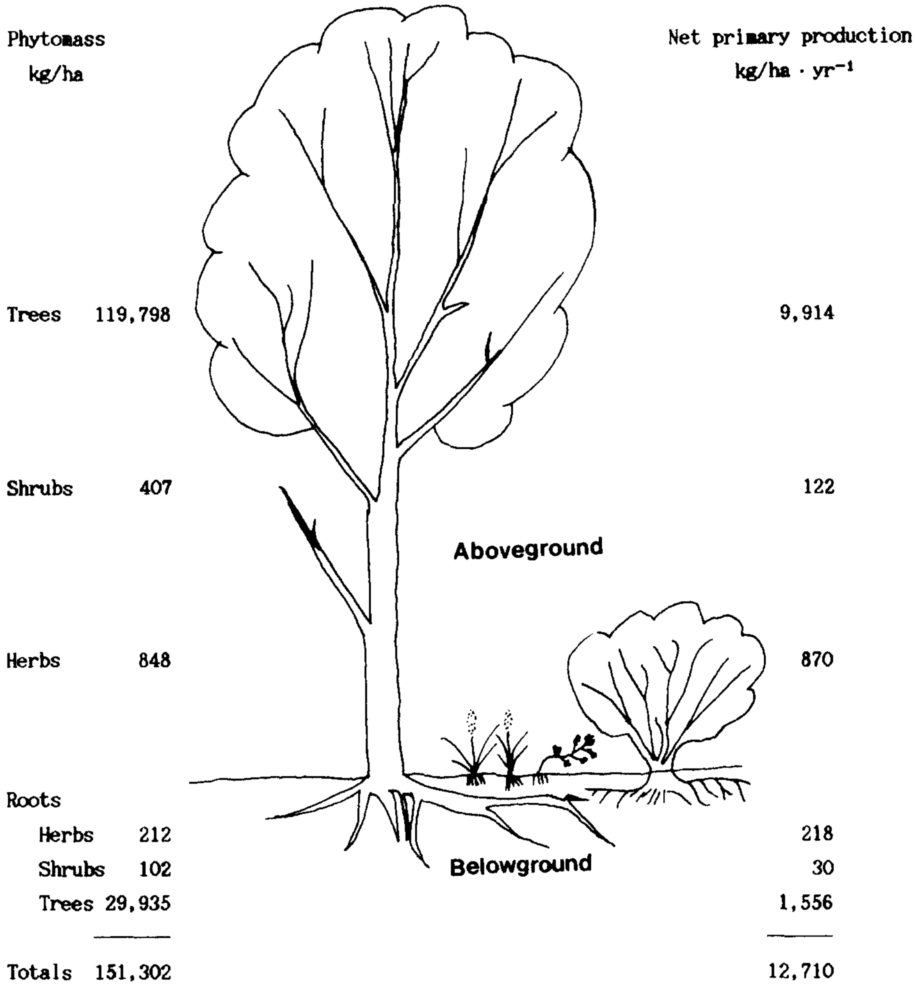

Fig. 8. Phytomass and net primary production in *Quercus mongolica* forest at the first year measurement in 1984.

Annual productivity

Annual productivity for the tree layer in the forest studied ranged from 8.76 ton DM /ha · yr^{-1} to 11.62 ton DM /ha · yr^{-1} with heavy fluctuation year by year(Table 3 and Fig. 7). Such fluctuation of the productivity would be proportionated to the change of density and mortality(refer to Fig. 2) and related to increasing phytomass(Waring and Schlesinger, 1985; Romme *et al.*, 1986).

The productivity of *Q. mongolica* approximated to that of young oak-pine forest at Brookhaven with 7.96 ton DM /ha · yr^{-1}(Whittaker and Woodwell, 1969) and typical mature deciduous forest with 7~12 ton DM /ha · yr^{-1}(Rodin and Bazilevich, 1967). The productivity of the forest, however, was less than that of *Q. accutissima* forest with 15.2 ton DM /ha · yr^{-1} (Chae and Kim, 1977) and that of post oak-blackjack oak forest with 14.9 ton DM /ha · yr^{-1}(Johnson and Risser, 1974) but was much greater than that of climax forest of *Q. serrata* with 2.4 ton DM /ha · yr^{-1} at Piagol, Mt. Chiri(Kim *et al.*, 1982). Annual productivity of temperate deciduous forest was in general known to range of 5~30 ton DM /ha · yr^{-1}(Kira and Shidei, 1967) or 6~25 ton DM /ha · yr^{-1}(Whittaker and Likens, 1975).

Average annual productivity of trunk, branches, leaves and roots for 7 years were 4.42, 0.67, 3.85 and 1.29 ton DM /ha · yr^{-1} in the forest, respectively. Allocation ratios of the new production to trunk, branches, leaves and roots were 40, 12, 34 and 14% in 1984 and 42, 7, 39 and 12% in 1990, respectively. Allocation of the new production was much more made to both stem and leaves and such trend was conspicuous as the stand aged. Allocation in Japanese deciduous forests occurred 34~64% for stem, 10~24% for branches and 25~41% for leaves(Satoo, 1970). Annual production of seeds fallen into the litter trap was 398 kg DM /ha · yr^{-1} , corresponding 3% of the annual productivity, which was greater amount than that of Hungarian oak forest with 297 kg DM /ha · yr^{-1}(Jakucs, 1985).

Production efficiency, ratio of annual productivity to leaf weight as a measure of organic matter production, of the stand was 2.91kg /kg · yr^{-1}, which approximated to that of post oak-blackjack oak forest with 2.99kg /kg · yr^{-1}(Johnson and Risser, 1974), but more or less larger that of *Fagus crenata* forest with 2.43kg /kg · yr^{-1}(Satoo, 1970).

Turnover rate, ratio of annual production(Pn) to standing phytomass(B), of the forest was 6.9% in 1984 and 5.6% in 1990. These values were larger than those of climax oak forest at Piagol(Kim *et al.*, 1982), but less than those of *Q. mongolica* forest at Chuncheon (Kim and Yoon, 1972) and oak-pine forest at Brookhaven(Whittaker and Woodwell, 1969). These results from the turnover rate as well as from the productivity suggest that the mongolian oak forest studied is a young one.

적 요

강원도 평창군 남병산의 신갈나무림에서 7년간 밀도, 낙엽량, 식물량 및 1차 순생산량을 정량적으로 측정하였다. 1984년에 밀도는 1,450본 /ha이고 그 빈도분포는 왜도 0.67과 첨도 0.54를 보였으나, 7년 후인 1990년에 사망률이 22%(316본 /ha)로 일어나 밀도는 1,133본 /ha이고 그 빈도는 왜도 1.16과 첨도 1.89를 보였다. 1984년도의 연 낙엽량은 5 ton DM /ha이었는데, 그 조성은 잎 68%, 가지 17%, 싹비늘잎 3%, 종자 9%, 꽃 0.7% 및 기타 3%로 구성되었다.

1984년도의 임상식물을 포함한 전 식물량은 151 ton DM /ha이었다. 7년간 교목층 식물량의 변화는 1984년에 149.7 ton DM /ha에서 1990년에 188.5 ton DM /ha로 점점 증가하였다. 교목층의 1차 연순생산량은 8.76 ton DM /ha에서 11.62 ton DW /ha로 심한 변동을 보였다. 그리고 7년 동안 줄기, 가지, 잎 그리고 뿌리의 평균순생산량은 각각 4.42, 0.67, 3.85 그리고 1.29 ton DM /ha이었다. 본 신갈나무림의 대사회전률은 1984년도에 6.9%, 1990년도에 5.6%이었다.

연도에 따른 교목층의 연순생산량의 변동은 임목밀도, 사망률 및 대사회전률의 변화와 관계가 있었다.

REFERENCE

Agren, J. and O. Zackrisson. 1990. Age and size structure of *Pinus sylvestris* population on mires in central and northern Sweden. J. of Ecology. 78 :1049-1062.

Begon, M. 1984. Density and individual fitness: symmetric competition. In evolutionary ecology(ed. B. Shorrocks), Blackwell, Oxford, pp. 179-194.

Boysen-Jensen, P. 1932. Die Stoffproduktion der Pflanzen. Gustove. Fischer, Jena.

Chae, M. I. and J. H. Kim. 1977. Comparisons of biomass, productivity and productive structure between Korean alder and oak stands. Korean. J. Ecol. 1: 57-65.

Chung, T. H. and W. C. Lee. 1965. A study of the Korean woody plant zone and favorable region for the growth and proper species. J. Fac. Sungkungwan Univ. 10:329-435.

Ford, E. D. 1975. Competition and stand structure in same even aged plant monocultures. J. of Ecology 63:311-333.

Gosz, J. R., G. E. Likens and F. H. Bormann. 1972. Nutrient content of litterfall on Hubbard Brook experimental forest. New Hampshire. Ecology 53(5):769-784.

Graumlich, L. J., L. B. Brubaker and C. C. Grier. 1989. Long-term trends in forest net primary productivity: cascade mountains, Washington. Ecology 70(2):405-410.

Hou, H. Y. 1985. Vegetation of China with reference of its geographical distribution. Ann. Missouri Bot. Gard. 70:509-548.

Hutchings, M. J. 1986. The structure of plant populations. In plant ecology, Crawley(ed.). pp. 97-136. Blackwell Scientific Publications, London.

Jakucs, P. 1985. Ecology of an oak forest in Hungary. Akademiai kiado, Budapest, 546pp.

Johnson, F. L. and P. G. Risser. 1974. Biomass, annual net primary production and dynamics of six mineral elements in a post oak-blackjack oak forest. Ecology 55: 1246-1258.

Kim, J. H. 1970. On the utilization of the allometric method for an estimation of the productivity of the terestrial plants. Korean J. Botany 13:47-55.

Kim, J. H. and H. T. Mun. 1982. Ecological studies on the montane grassland of Mt. Soback in Korea. II. Production and nutrient cyclings. Korean J. of Ecol. 5: 204-210.

Kim, J. H. and S. M. Yoon. 1972. Studies on the productivity and the productive structure of the forests. Ⅱ. Comparison between the productivity of *Pinus densiflora* and of stand located near Choon-Chun city. Korean J. Botany 15:1-8.

Kim, Y. T., S. W. Lee and J. H. Kim. 1988. A comparison of production and solar energy utilization among young *Pinus koraiensis* plantations of different ages. Korean J. Ecology 11:83-96.

Kim, J. H., Y. D. Rim, D. S . Cho, S. D. Koh and B. M. Min. 1982. Studies on the community structure, phytomass and primary productivity of the climax forest of the climax forest of Piagol valley in Mt. Chiri. The report of the KACN, No. 21: 53-73.

Kim, J. H., Y. S. Kang, S. W. Lee, K. H. Cho, Y. T. Kim, S. H. Ha and B. M. Min. 1989. Dynamics of plant communities under human impact in the green-belt nearby Seoul: structure of forest communities and secondary succession. Korean J. Ecol. 12(4): 209-218.

Kira, T. and T. Shidei. 1967. Primary production and turnover of organic matter in different forest ecosystems of the western pacific. Jap. J. Ecol. 17: 70-87.

Koike, F. 1989. Foliage-crown, development and interaction in *Quercus gilva* and *Q. acuta*. J. of Ecology 77:92-111.

Koyama, H. and T. Kira. 1956. Intraspecific competition among higher plants. Ⅷ. Frequency distribution of individual plant weight as affected by the interaction between plants. J. of the Institute of polytechnics, Osaka City University 7:73-94.

Lee, C. S. 1989. A study on the succession of pine forests damaged by pine gall midge. Ph D. Thesis. Seoul Nat'l Univ., Seoul. 105 pp

Lowman, M. D. 1988. Litterfall and leaf decay in three Australian rainforest formations. J. of Ecology 76:451-465.

Mohler, C. L., P. L. Marks and D. G. Sprugel. 1978. Stand structure and allometry of trees during self-thinning of pure stands. J. of Ecol. 66:599-614.

Obeid, M., D. Machin and J. L. Harper. 1967. Influence of density on plant to plant variation in Fiber Flax, *Lilium usitatissimum*. Crop Science 7:471-473.

Oh, K. C. 1981. A consideration on intraspecific competition with particular reference to basal area-class structure of even-aged coniferous monocultures. Korean J. of Botany. 24(1):47-57.

Oh, K. C. and K. S. Lee. 1989. On ordination, clustering and neighbourhood effects in the semi-natural pine stands in central Korea. Korean J. Ecol. 12(2):83-108.

Ovington, J. D. 1963. Flower and seed production. A source of error in estimating woodland production, energy flow and mineral cycling. Oikos 14: 148-153.

Ovington, J. D., D. Haitkamp and D. B. Lawrence. 1963. Plant biomass and productivity of prairie, savanna, oakwood and maize field ecosystem in central Minnesota. Ecology 44: 55-63.

Reiners, W. A. and G. E. Lang. 1987. Changes in litterfall along a gradient in altitude. J. of Ecol. 75: 629-638.

Rodin, L. E. and N. I. Bazilevich. 1967. Production and mineral cycling in terrestrial vegetation. Edinbergh, Scotland: Oliver and Boyd. Satoo, T.(1970). A synthesis of studies by the harvest method: Primary production relations in the temperate forest ecosystems, Reichle(ed.). pp. 55-72. Springer-Verlag, New York.

Romme, W. H., D. H. Knight and J. B. Yavitt. 1986. Mountain pine beetle outbreaks in the Rocky mountains: regulations of primary productivity? American Naturalist 127:484-494.

Satoo, T. 1970. A synthesis of studies by the harvest method: primary production relations in the temperate deciduous forest of Japan. In analysis of temperate forest ecosystems, Reichle(ed.). pp. 55-72. Springer-Verlag, New York.

Schweingruber, F. H. 1987. Tree rings: basis and applications of dendrochronology. CIP. Germany. 276 pp.

Silvertown, J. W. 1987. Introduction to plant population ecology. 2nd(ed.) Longman Scientific & Technical, New York, 229 pp.

Sokal, R. R. and J. E. Rohlf. 1981. Biometry. 2nd(ed.) Freeman, San Francisco, pp. 114-121.

Wang, C. W. 1961. The forests of China with a survey of grassland and desert vegetation. Harvard Univ. Cambridge, U. S. A. 313 pp.

Waring, R. H. and W. H. Schlesinger. 1985. Forest ecosystems: concepts and management. Academic Press, London, 340 pp.

Whittaker, R. H. and G. E. Likens. 1975. The biosphere and man. In primary productivity of the biospere, H. Lieth and R. H. Whittaker(ed.). pp. 305-328. Springer-Verlag, New York.

Whittaker, R. H. and G. M. Woodwell. 1969. Structure, production and diversity of oak-pine forest at Brookhaven, New York. J. of Ecol. 57:155-174.

(*Received* 2 *September*, 1991)