Korean J. Ecol. 19(2) : 125~139, 1996

An Experimental Study on the Comparison of the Establishment and Growth of Seedlings among Three Oak Species

Baek, Myeong-Su and Do-Soon Cho

Department of Biology, The Catholic University of Korea, Puchon 422-743, Korea

참나무속 3종의 유식물 정착과 생장의 비교에 대한 실험적 연구

백 명 수 · 조 도 순

가톨릭대학교 자연과학대학 생물학과

ABSTRACT

The relationships between environmental factors and the establishment and growth of oak seedlings were studied in the greenhouse. The early seedling performances of three oak species (*Quercus mongolica*, *Quercus serrata*, *Quercus variabilis*) were compared. Mean seed weight was the biggest in *Q. variabilis*, and the smallest in *Q. serrata*, and the germination rate was higher in *Q. variabilis* than in *Q. mongolica* and *Q. serrata*. The germination rate was significantly affected by seed weight class in *Q. serrata*, but not in *Q. mongolica*. Emergence of oak seedlings was similar in all three oak species, and especially the first leaf emergence increased about twenty days after germination. An experiment was designed using three environmental factors (light, soil moisture, fertilizer) to compare the response of the three oak species. Light and soil moisture significantly affected the seedling height growth of *Q. variabilis*, but the effect was marginal in *Q. mongolica* and *Q. serrata*. However, growth of seedling biomass was significant in all three oak species. In contrast, fertilizer did not affect seedling growth of any of the oak species. *Q. variabilis* is expected to grow well in large gaps because it is very sensitive and responds well to high light and high moisture conditions. *Q. mongolica* and *Q. serrata* are relatively tolerant to shade but may need gaps for the seedlings to grow into saplings.

Key words: Fertilizer, Light, Oak, *Quercus mongolica*, *Quercus serrata*, *Quercus variabilis*, Seedling establishment, Seedling growth, Soil moisture

INTRODUCTION

In the life history of trees, the most drastic change in a cohort population occurs in seed and seedling stages. The processes occurring in these stages may explain many aspects of the adult population. For most plants, mortality rate is higher in seed and seedling stages, and the processes causing early mortality can be critical determinants of adult abundance and distribution (Clark and Clark 1985). Actually, future forest composition and structure are directly dependent on new seedling establishment (Peet and Christensen 1980, McPherson 1993). However, observation of established populations of plants yields little information about the factors that were important during the establishment phase, since the combination of environmental conditions that led to seedling survival are unlikely to still exist or to be important to the success of mature plants. Therefore, only through direct study within populations of both seedlings that live and those that die can the causes of mortality and their demographic consequences be understood (Hett 1971, Sacchi and Price 1992).

It is particularly important to understand the factors limiting seedling growth because of the significance of the regeneration phase (Burslem *et al.* 1995). "Regeneration strategy" is a useful concept to characterize the demographic traits of the species in seed and seedling stages. The study of demographic variations of seed and seedling stages that are caused by physiological or biological factors are indispensible in understanding the regeneration niche of the species (Shibata and Nakashizuka 1995). It is necessary to understand the most important environmental facors affecting the early stages in this regeneration process.

In forests, seedling establishment and growth are limited by complex environmental conditions. Variability in several regeneration processes, including seed production, seed dispersal, seedling emergence, seedling survivorship, and seedling growth, is related to the temporally or spatially varying effects of a wide variety of environmental and biotic factors (Streng *et al.* 1989). For woody seedling survivorship, light regime, weather, disturbance, predation, competition, and allelopathy have been shown to cause variation in mortality rate for individual species, and microsite conditions of light, moisture and temperature can often control the germination and subsequent establishment of a plant species (Burton and Bazzaz 1991), so the response of seedlings to these factors plays a major role in population dynamics and plant community structure (Flowler 1988, McCarthy and Bailey 1990, Parrish and Bazzaz 1982, Streng *et al.* 1989).

Deciduous oak species are widely distributed in Korea. Major distribution regions of oak species are the southern and central parts of Korea. *Q. mongolica* is mainly distributed in the upland and other species are distributed in the lowland of mountains (Han and Kim 1989). The distribution of oak species is determined by such environmental factors as soil moisture, temperature, light, slope aspect and altitude. Along the soil moisture gradient, oak species are distributed in the following order: *Q. aliena*, *Q. serrata*, *Q. mongolica*, and *Q. variabilis* from mesic to xeric site (Kim 1990). Production of oak species is also closely associated with several forest environmental factors (Kim and Jeong 1985, Lee and Chung 1986).

The purposes of this study are 1) to analyze the effect of environmental factors on the establishment and growth of seedlings, and 2) to compare the seedling performance of the three oak species affected by these environmental factors.

MATERIALS AND METHODS

Seed germination and seedling emergence

For this experiment, seeds of the three oak species were collected from August to November, 1994 in the Mt. Sorak Biosphere Reserve. To determine the frequency of seed weight class of the three oak species, five hundred seeds per species were weighted. Then the seeds were stratified at 4℃ until the experiments were begun. Seeds of each species were sown on $48.3\times33.3\times9.0$ cm^3 flats (fifty seeds per flat). Each flat was filled with river sand, and placed in the greenhouse with daily temperature fluctuations from 10℃ to 36℃ and with natural light conditions. Each flat was watered once every three days for a month.

The seeds were classified into five weight-classes for each species, and the radicle length of germinated seeds was measured on each sample. The criteria for germinated seeds was determined by the presence of newly emerged radicle. To see if there was any difference in viability among the seed weight-classes, germination rate was determined for each weight class of *Quercus mongolica* and *Q. serrata*.

Germinated seeds were transplated onto thirty-six $50\times33\times20$ cm^3 wooden boxes filled with river sand. The number of seedlings grown to determine the rate of emergence was 33, 33 and 30 individuals in *Q. mongolica*, *Q. serrata*, and *Q. variabilis*, respectively. Seedling emergence was monitored weekly for two months. Emergence was determined by two stages; epicotyl emergence and the first leaf emergence.

Seedling growth along environmental regime

After the emergence rate of the seedlings exceeded 50% on each flat, the seedlings of each species were treated with three environmental factors: light, soil moisture and fertilizer. A total of thirty six blocks were used for the experiment. The light factor was designed into three treatments: no shade (high light: L_h) (100% incident ray within the greenhouse), 50% shade (medium light: L_m) and 95% shade (low light: L_l). The shade was produced by stretching shade cloth over a wooden frame. To identify relative light conditions, light levels in the each treatment were measured at midday on cloudless days with a lux meter.

High fertilizer (F_h) was composed of 0.95 g/box urea (nitrogen content 46%), 2.19 g/box phosphate fertilizer (potassium phosphate content 20%) and 0.73 g/box potassium chloride (potassium content 60%) to give N:P:K fertilizer ratio of 1:1:1, while the amount of fertilizer applied to each box at low fertilizer (F_l) was one tenth of that at high fertilizer. Fertilizer was applied only once at the start of the whole experimental period. Soil moisture treatment was also divided into two levels: watered once every three days (high moisture: W_h) and once every nine days (low moisture: W_l) for the experimental period. Hoagland's solution without N, P and K was applied in the watering process.

The seedlings were harvested five months after the initiation of the treatments of environmental factors. The height of seedlings was measured after the harvest. Harvested seedlings were separated into leaves, stems and roots. The plants were dried in an oven at 80℃ for 48 hours before weighing.

Data analysis

Statistical tests were carried out using the SAS statistical package (SAS Institute Inc. 1985). Correlation analysis was performed using Spearman's rank correlation test. The General Linear Models procedure was used for all unbalanced analyses of variance. MANOVA was used for all studies in which multiple response variables were measured from individual experimental units. MANOVA was employed for analysis of light, soil moisture, fertilizer, and the factorial combination of treatments. Significance of differences in multiple comparison was examined using Tukey's studentized range test.

RESULTS

Seed germination and seedling emergence

In the seed weight distributions of three oak species, both *Q. mongolica* and *Q. variabilis* were similar in terms of mean seed weight and frequency distribution. However, the mean seed weight of *Q. serrata* was lower than that of the other two species (Fig. 1).

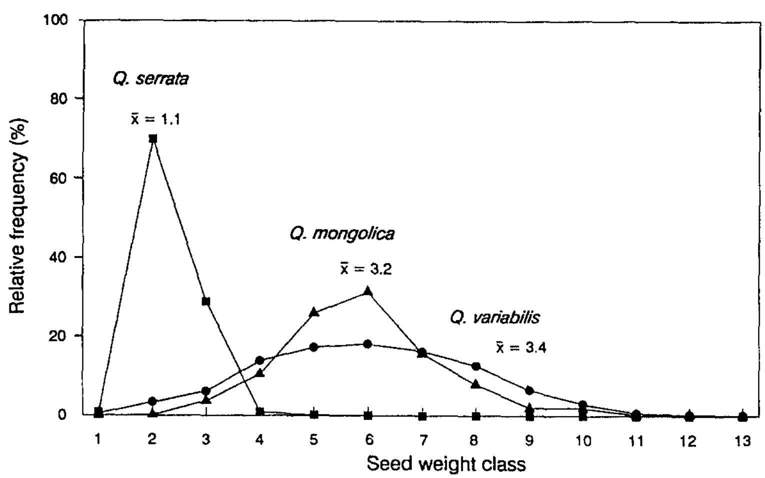

Fig. 1. Seed weight distributions of three oak species collected from August to November, 1994. Each value on the lines is mean seed weight. Seed weight classes represented by 1-13 are as follows (unit: g/acorn); 1: $0 \le x < 0.6$, 2: $0.6 \le x < 1.2$, 3: $1.2 \le x < 1.8$, 4: $1.8 \le x < 2.4$, 5: $2.4 \le x < 3.0$, 6: $3.0 \le x < 3.6$, 7: $3.6 \le x < 4.2$, 8: $4.2 \le x < 4.8$, 9: $4.8 \le x < 5.4$ 10: $5.4 \le x < 6.0$, 11: $6.0 \le x < 6.6$, 12: $6.6 \le x < 7.2$, 13: $7.2 \le x < 7.8$.

Table 1. Potential germination rate and radicle length (mean±SE) in the greenhouse experiment. Numbers in parentheses are the number of seeds

Species	Germination rate (%)	Radicle length (cm)
Q. mongolica	70 (n=173)	3.4±0.15 (n=137)
Q. serrata	32 (n=219)	3.2±0.18 (n=123)
Q. variabilis	94 (n=146)	10.5±0.27 (n= 70)

Potential germination rates, which were determined in the greenhouse after one month of the germination experiment, differed among the three oak species. The germination rate and radicle length were the highest in *Q. variabilis*, and the lowest in *Q. serrata* (Table 1). No significant correlations were found between relative germination rates and seed weight-classes in *Q. mongolica* (r_s=0.25, P>0.05, Spearman's rank correlation). However, the relative germination rates of *Q. serrata* seeds were significantly negatively correlated with seed weight-classes (r=−0.90, P<0.05). However, the mean length of radicles from germinated seeds in *Q. mongolica* and *Q. serrata* was positively correlated with seed weight-classes, although it was not statistically significant in the former (Table 2).

Fig. 2 shows the rate of seedling emergence of the three oak species for two months. The tendency of epicotyl emergence was similar to that of the first leaf emergence. The frequency of epicotyl emergence of the three oak species gradually increased. However, the frequency of the first leaf emergence increased rapidly after twenty days from the beginning of the experiment. Generally, the frequency of seedling emergence of *Q. variabilis* was higher than that of the other species.

Table 2. Germination rate and radicle length (mean±SE) of *Q. mongolica* and *Q. serrata* by seed weight class. Number of investigated seeds is 50 in each class

Seed weight (gDM)	*Q. mongolica*		*Q. serrata*	
	Germination rate (%)	Radicle length (cm)	Germination rate (%)	Radicle length (cm)
0.0~0.6	–	–	52	22.1±0.24
0.6~1.2	–	–	38	28.4±0.31
1.2~2.4	58	21.4±0.29	42	24.3±0.28
2.4~3.6	58	26.6±0.31	36	37.4±0.48
3.6~4.8	68	21.0±0.28	32	53.0±0.50
4.8~6.0	58	31.2±0.31	–	–
6.0~7.8	69[a]	28.7±0.60	–	–
Coefficient[b]	0.25[ns]	0.70[ns]	−0.90*	0.90*

[a] : Total seed number is thirteen.

[b] : Spearman's rank correlation test

[ns] : not statistically significant

* : statistically significant (P<0.05)

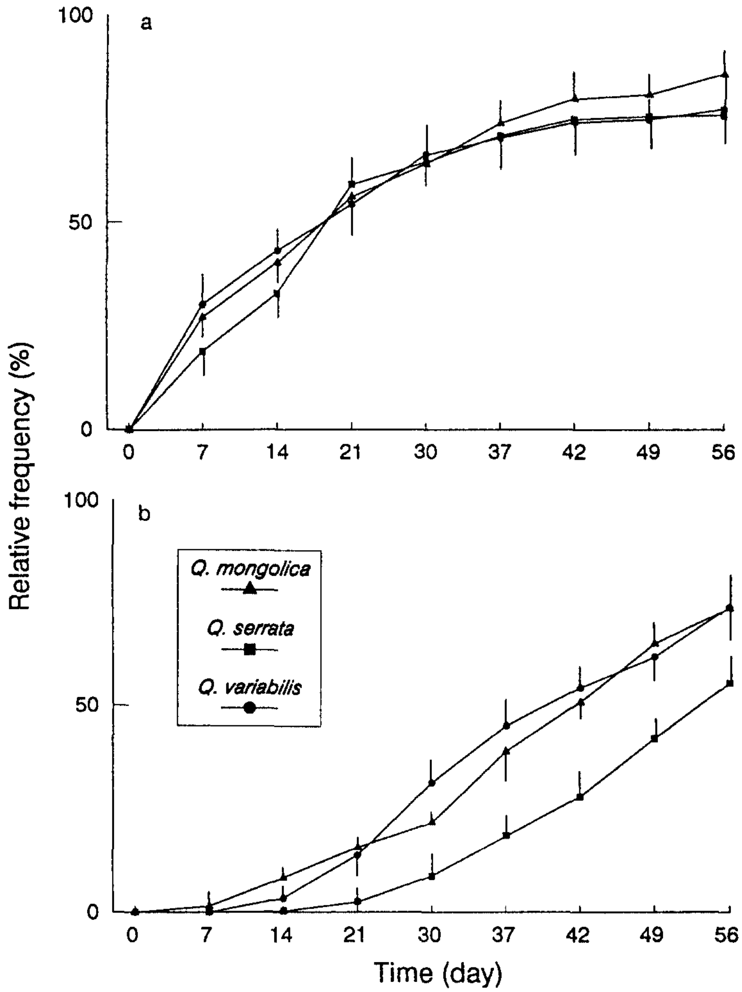

Fig. 2. Cumulative relative emergence of oak seedlings emerged from seeds. a: epicotyl emergence, b: leaf emergence. Vertical bar indicates twofold standard errors (±2SE).

Seedling growth

Seedling growth of each species showed different responses to the combination of treatments of environmental factors. Growth in height is often a useful indicator of fitness because it is usually correlated with increases in biomass and because it measures seedling response to competition for light. The height of *Q. mongolica* after five months of growth was significantly affected by the interaction of soil moisture and fertilizer ($P<0.05$, MANOVA) (Table 3). Height was not altered significantly by the treatments (Fig. 3a). The height growth of *Q. serrata* showed significant differences according to soil moisture levels ($P<0.05$, Tukey's studentized range test) and to the interaction of soil moisture and fertilizer ($P<0.01$): height growth of the species was the greatest in $L_hW_hF_h$ treatment,

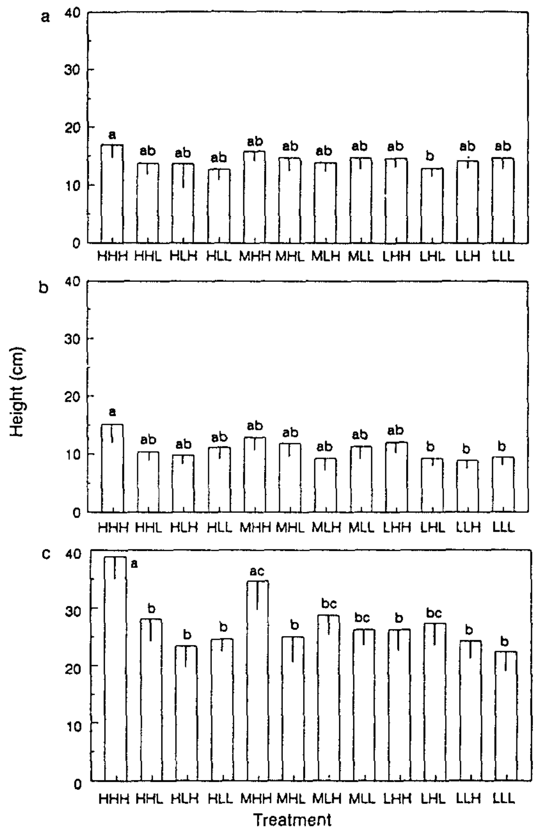

Fig. 3. Height of oak seedlings at treatments in the greenhouse experiment. a: *Q. mongolica*, b: *Q. serrata*, c: *Q. variabilis*. Standard errors are shown, one-sided only (−2SE). Bars with the same letter are not significantly different among treatments (Tukey's studentized range test, $P<0.05$). The three characters at the bottom of each bar indicate conditions for light, soil moisture and fertilizer, respectively. H: High, M: Medium, L: Low

Table 3. Results of MANOVA in seedling height growth of the three oak species by the treatments of environmental factors. Degrees of freedom for the sources of variance for L, W, F, L×W, L×F, W×F and L×W×F are 2, 1, 1, 2, 2, 1, and 2, respectively. Probabilities less than 0.05 are statistically significant

Source of	*Q. mongolica*		*Q. serrata*		*Q. variabilis*	
variance	F	P	F	P	F	P
L (light)	0.57	0.5669	2.48	0.0863	5.02	0.0074
W (moisture)	1.85	0.1753	8.25	0.0045	21.80	0.0001
F (fertilizer)	2.75	0.0988	1.26	0.2635	11.86	0.0007
L × W	2.10	0.1254	0.15	0.8610	4.19	0.0615
L × F	0.85	0.4306	0.97	0.3789	2.47	0.0869
W × F	5.28	0.0225	9.34	0.0025	6.24	0.0133
L × W × F	0.08	0.9207	0.46	0.6294	4.22	0.0160

and the least in the $L_lW_hF_l$, $L_lW_lF_h$ and $L_lW_lF_l$ treatments ($P<0.05$, Tukey's studentized range test). In contrast, the height growth of *Q. variabilis* was significantly affected by light, soil moisture, fertilizer, interaction of soil moisture and fertilizer (W×F), and interaction of light, soil moisture and fertilizer (L×W×F). The height of *Q. variabilis* was the greatest in $L_hW_hF_h$ and $L_mW_hF_h$ treatments ($P<0.05$, Tukey's studentized range test) (Fig. 3c). Height growth of the three oak species was significantly affected by the interaction of soil moisture and fertilizer (Table 3).

The biomass of the three oak species at the end of the experiment was significantly affected by the environmental regime, especially light and soil moisture regime ($P<0.01$, MANOVA). The biomass of the three species significantly ($P<0.05$) increased in response to high light (L_h) treatment compared to low light (L_l) treatment. Response to the factor combination with fertilizer (F, L×F, W×F, L×W×F) differed among the three species, e.g. biomass of *Q. mongolica* was not significantly affected by such combination of

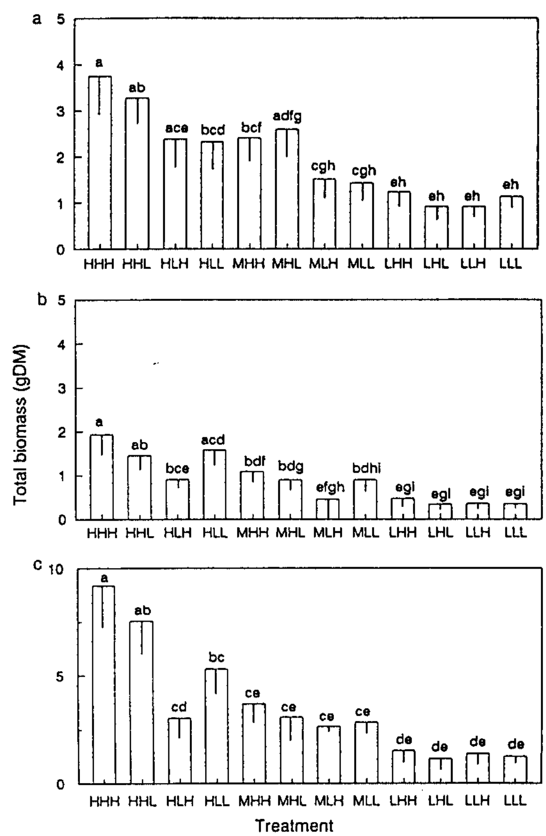

Fig. 4. Total biomass of oak seedlings at treatments in the greenhouse experiment. a: *Q. mongolica*, b: *Q. serrata*, c: *Q. variabilis*. Standard errors are shown, one-sided only (−2SE). Bars with the same letter are not significantly different among treatments (Tukey's studentized range test, $P>0.05$). See Fig. 3 for the characters at the bottom of each bar.

Table 4. F values dervied from the results of MANOVA in biomass for *Q. mongolica* seedlings. Degrees of freedom for the sources of variance for L, W, F, L×W, L×F, W×F and L×W× F are 2, 1, 1, 2, 2, 1, and 2, respectively

Source of	Total mass			Root:shoot ratio		
variance	*Q. mongolica*	*Q. serrata*	*Q. variabilis*	*Q. mongolica*	*Q. serrata*	*Q. variabilis*
L(light)	45.95***	41.60***	76.27***	74.52***	23.17***	40.68***
W(water)	19.67***	7.57**	25.60***	3.68	0.15	0.11
F(fertilizer)	0.09	0.27	0.00	2.42	18.54***	8.06**
L×W	4.80**	1.56	14.94***	1.08	1.52	0.18
L×F	0.18	0.46	0.25	2.05	4.23*	1.09
W×F	0.55	10.34**	5.43*	7.89**	1.10	0.36
L×W×F	0.66	1.93	3.44*	0.58	0.32	0.34

*** : P<0.001, ** : P<0.01, *: P<0.05

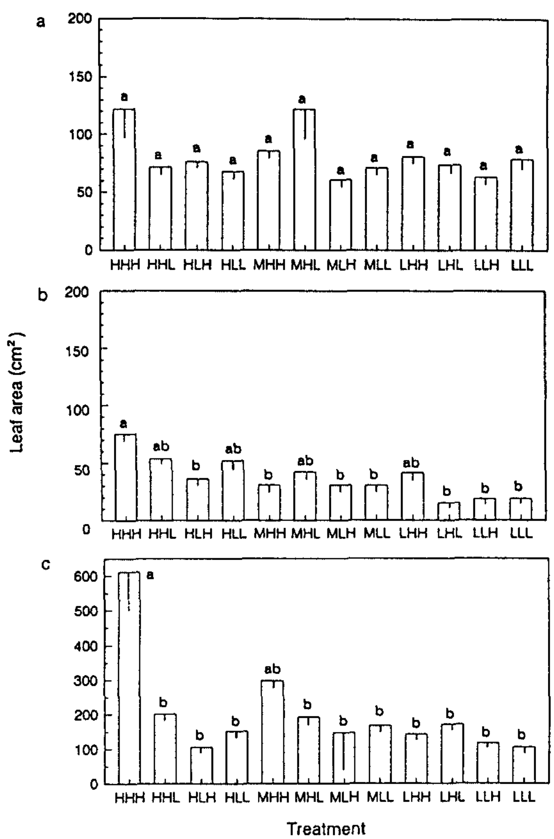

Fig. 5. Leaf area of oak seedlings at treatments in the greenhouse experiment. a: *Q. mongolica*, b: *Q. serrata*, c: *Q. variabilis*. Standard errors are shown, one-sided only (−2SE). Bars with the same letter are not significantly different among treatments (Tukey's studentized range test, P< 0.05). See Fig. 3 for the characters at the bottom of each bar.

Table 5. Effects of different environmental conditions on biomass of seedlings of three oak species (mean±SE). Same letters within each environmental factor are not significantly different (Tukey's studentized range test, P>0.05)

Species	Source of variance	Dry weight (gDM)				Root : shoot ratio
		Roots	Stems	Leaves	Total	
Q. mongolica	L_h[1]	8.2±0.15[a]	1.8±0.05[a]	1.8±0.03[a]	11.8±0.21[a]	9.4±0.09[a]
	L_m	5.2±0.09[b]	1.4±0.02[b]	1.4±0.01[b]	8.0±0.13[b]	7.5±0.08[b]
	L_l	2.1±0.03[c]	1.0±0.01[c]	1.2±0.01[b]	4.2±0.15[c]	4.1±0.04[c]
	W_h[2]	9.4±0.11[a]	2.5±0.03[a]	2.4±0.02[a]	14.2±0.15[a]	11.0±0.07[a]
	W_l	6.1±0.07[b]	1.7±0.01[b]	1.9±0.02[b]	9.7±0.10[b]	9.9±0.09[b]
	F_h[3]	7.8±0.10[a]	2.2±0.03[a]	2.3±0.02[a]	12.2±0.15[a]	9.8±0.07[a]
	F_l	7.8±0.09[a]	1.9±0.01[a]	2.1±0.02[a]	11.7±0.12[a]	11.1±0.09[a]
Q. serrata	L_h	3.9±0.08[a]	0.9±0.03[a]	1.0±0.03[a]	5.9±0.13[a]	8.2±0.09[a]
	L_m	2.1±0.04[b]	0.6±0.02[b]	0.7±0.02[b]	3.4±0.07[b]	6.5±0.07[b]
	L_l	0.8±0.01[c]	0.3±0.01[c]	0.3±0.01[c]	1.5±0.02[c]	5.2±0.07[c]
	W_h	3.9±0.05[a]	1.2±0.02[a]	1.2±0.02[a]	6.2±0.08[a]	9.7±0.06[a]
	W_l	3.0±0.04[b]	0.8±0.01[b]	0.9±0.01[b]	4.6±0.06[b]	10.3±0.07[a]
	F_h	3.1±0.60[a]	1.1±0.22[a]	1.1±0.21[a]	5.2±0.99[a]	8.4±0.71[a]
	F_l	3.7±0.51[b]	0.8±0.10[b]	1.0±0.14[a]	5.5±0.71[a]	11.8±0.75[b]
Q. variabilis	L_h	15.8±0.29[a]	4.0±0.10[a]	5.3±0.12[a]	25.1±0.48[a]	7.1±0.12[a]
	L_m	6.6±0.13[b]	2.5±0.05[b]	3.3±0.06[b]	12.3±0.22[b]	4.7±0.07[b]
	L_l	2.3±0.04[c]	1.3±0.02[c]	1.7±0.03[c]	5.3±0.08[c]	3.2±0.04[c]
	W_h	15.1±0.23[a]	4.9±0.07[a]	6.3±0.08[a]	26.2±0.37[a]	7.3±0.09[a]
	W_l	9.6±0.16[b]	2.9±0.03[b]	4.0±0.04[b]	16.5±0.21[b]	7.7±0.07[a]
	F_h	11.5±0.21[a]	4.4±0.07[a]	5.6±0.08[a]	21.5±0.35[a]	6.4±0.49[a]
	F_l	11.3±0.22[a]	3.4±0.04[b]	4.7±0.06[b]	21.1±0.31[a]	8.6±0.41[b]

[1] : Light - high, medium, low
[2] : Moisture - high, low
[3] : Fertilizer - high, low

factors. Root:shoot ratio of the three oak species was also signigicantly affected by light treatment (Table 4, Fig. 4).

The seedling biomass of the three oak species showed significant differences in light and soil moisture gradient treatments ($P<0.05$, Tukey's studendized range test). However, *Q. mongolica* seedlings were not significantly affected by fertilizer gradient treatments. The root:shoot ratio of *Q. serrata* and *Q. variabilis* was significantly affected by fertilizer treatment levels, but not by soil moisture levels (Table 5).

Leaf area differed significantly ($P<0.05$) among treatments or combinations of tr-

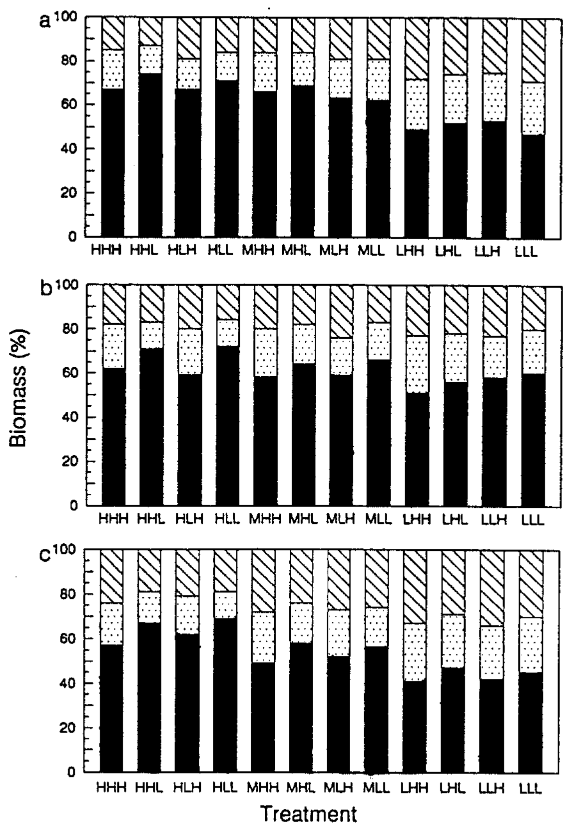

Fig. 6. Relative biomass of leaves, stems, and roots of seedlings of oak species in each treatment in the greenhouse experiment. a: *Q. mongolica*, b: *Q. serrata*, c: *Q. variabilis*. See Fig. 3 for the characters at the bottom of each bar.

eatments for *Q. serrata* and *Q. variabilis* seedlings, being the largest in $L_hW_hF_h$ and the smallest in $L_lW_hF_l$ (*Q. serrata*) or $L_hW_hF_l$ (*Q. variabilis*). The leaf area of *Q. mongolica* did not differ among treatments (Fig. 5).

Allocation of biomass to roots, stems and leaves was similar for the three species, with the highest shoot (stem+leaves) allocation at low light treatment and the lowest at high light treatment. Within the same light conditions, the relative ratio of roots was higher at low fertilizer treatment than at high fertilizer treatment, regardless of soil moisture treatments. In particular, the relative ratio of leaves increased with decreasing light levels in the three oak species (Fig. 6).

DISCUSSION

Harper (1977) and Grubb (1977) proposed that the most critical change in determining the fate of individual trees in their life history occurs in the stages of seedling establishment and seedling growth. The germination and emergence of these seedlings are the first barrier of establishment. The processes occurring in these stages may explain many aspects of adult trees (Clark and Clark 1985, Peet and Christensen 1980, McPherson 1993).

The mean seed size of *Q. mongolica* and *Q. variabilis* were similar to each other, although that of the latter was a little larger than the former, but that of *Q. serrata* was much smaller than the other two species. In addition, the germination rate of the three oak species also increased with mean seed size. This indicates that species with relatively larger seeds such as *Q. variabilis* have an advantage in early seedling establishment and growth.

It is supposed that the germination rate differs with seed weight within an oak species. In *Q. serrata*, the germination rate was significantly negatively correlated with seed weight, which was probably due to the effect of acorn beetles, which prefer larger seeds (personal observation), but the germination rate was not correlated with seed weight in *Q. mongolica*. However, the mean radicle length increased with seed size, which indicates that larger seeds can be advantageous too in their survival within a species (Leishman and Westoby 1994).

The emergence of oak seedlings, especially the emergence of the first leaves, increased about 20 days after germination. This happens because the growth of roots temporarily stops during the epicotyl emergence, and then the roots start to grow with the onset of epicotyl growth (Forestry Research Institute 1988).

The fate of seedlings are determined by environmental regime, and the growth response of plants are considered as a result of the interaction between plants and their environment (Brand 1991). In particular, the height growth of seedlings is very important in the regeneration process when the disturbance regime is dominated by large scale disturbances (Runkle 1985). In the greenhouse experiment, all the seedlings of the three species showed better growth under high light, high soil moisture and high fertilizer conditions. However, the growth characteristics of seedlings responding to environmental changes differed a little among the three oak species. The height growth of *Q. variabilis* showed more variable response to light and soil moisture than the other two species: the height growth was more conspicuous at high light and high moisture levels than the other species. It seems that *Q. variabilis* is an opportunistic species which is able to use short-lasting abundant resources very efficiently. In contrast, the difference in height growth between different combinations of environmental factors was generally not statistically significant in *Q. mongolica* and *Q. serrata*. A similar trend was observed in the growth of leaf area.

In contrast, the growth of total dry weight was significantly influenced by light and soil moisture in all three species. In addition, the root:shoot ratio also differed in all three species according to light treatment. This means that light and soil moisture actually affected the growth of seedlings of *Q. mongolica* and *Q. serrata* as well as *Q. variabilis*, although the effect was not evident externally in *Q. mongolica* and *Q. serrata.*

Adults and seedlings can differ in their response to environmental factors, and oaks show some shade-intolerance in the early seedling stage (Cho 1992). Early seedlings of oak species can survive at any place because of their large food reserves in acorns (Racine 1971). However, seedlings of the three oak species showed more or less different reactions to light, moisture and fertilizer treatment. When gaps are formed, light and moisture conditions can be improved and this may stimulate the growth of seedlings of trees (Lee 1995a,b). The results of this study suggests that *Q. variabilis* can grow best in large gaps because it is the most sensitive and responds well to high light and high moisture conditions among the three oak species, and that *Q. mongolica* and *Q. serrata*, which are more or less shade tolerant, may need gaps or a similar environment to grow into saplings because more light and moisture promote their biomass growth.

적 요

환경요인에 대한 참나무 유식물의 정착과 생장반응을 조사하기 위하여, 3종의 참나무 즉, 신갈나무 (*Quercus mongolica*), 졸참나무 (*Q. serrata*) 및 굴참나무 (*Q. variabilis*)의 유식물을 대상으로 온실조건에서 재배하여 초기정착과정을 실험적으로 연구하였다. 평균 종자 무게는 굴참나무가 가장 컸고 졸참나무가 가장 작았으며 발아율은 굴참나무가 가장 높았고 신갈나무와 졸참나무는 낮았다. 졸참나무는 종자 크기에 따른 발아율의 유의한 차이를 보였으나 신갈나무에서는 유의한 상관관계가 나타나지 않았다. 참나무 3종의 유식물 출현은 모두 유사한 경향을 보였으며, 특히 3종의 참나무 유식물의 첫번째 잎의 출현은 발아 후 약 20일 이후부터 빠르게 증가하였다. 빛, 토양수분 및 비료의 3가지 환경요인의 조합으로 설계된 온실실험에서 참나무 3종의 유식물의 생장반응을 조사하였다. 빛과 토양수분은 굴참나무 유식물의 신장생장에 유의하게 영향을 주었으나, 신갈나무와 졸참나무의 유식물에서는 그 영향이 미약하였다. 그러나 빛과 토양수분은 굴참나무 뿐만 아니라 신갈나무와 졸참나무의 생물량의 생장에 유의한 효과를 나타내었다. 비료는 3종의 참나무 유식물의 생장에 유의한 영향을 주지 못하였다. 굴참나무는 빛과 토양수분에 잘 반응하여 큰 숲틈에서 잘 자랄 것으로 생각되며 신갈나무와 졸참나무도 어느 정도의 내음성을 보이나 유목으로의 생장을 위해서는 숲틈의 형성이 필요할 것으로 사료된다.

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(*Received December 20, 1995*)