

Effects of Different Light Intensities and Nutrition Conditions on Photosynthesis and Ribulose - Diphosphate Carboxylase Activity of *Quercus acutissima* Carr. Seedlings¹

Su Young Woo² and Don Koo Lee²

光도와 養料 條件을 달리 했을 때 상수리나무苗木의 光合成과 Ribulose - Diphosphate Carboxylase의 活性에 미치는 影響¹

禹秀泳² · 李敦求²

ABSTRACT

This study was conducted to compare chlorophyll contents, photosynthetic abilities, and ribulose-diphosphate(RuDP) carboxylase activities of *Quercus acutissima* seedlings grown with and without cotyledons under different light intensities and different nutrient levels.

The results obtained in this study were as follows :

1. Chlorophyll contents were not significantly different among the light intensities except for 25% of full sunlight at the last harvest time.
2. RuDP carboxylase activity increased with increasing light intensity.
3. Photosynthetic abilities of seedlings grown under full and 75% of sunlight were significantly higher than that under 25% of full sunlight.
4. RuDP carboxylase activity was more related with chlorophyll *a* contents($r=0.792$) than chlorophyll *b* contents($r=0.314$).
5. RuDP carboxylase activities of the seedlings received at 1 or 2% addition rates of nutrients under 75% of full sunlight were higher than that at 0.5% addition rates.

Key words : *Quercus acutissima*, light intensity, chlorophyll content, photosynthetic ability, ribulose - diphosphate(RuDP) carboxylase activity, nutrient level.

要 約

本 研究의 目的은 子葉의 有無, 光度 및 養料條件을 變化시켜 주었을 때 상수리나무(*Quercus acutissima* Carr.) 苗木의 葉綠素含量, 光合成能力, 그리고 ribulose-diphosphate(RuDP) carboxylase의 活性을 알아 보는 것이다.

本 研究에서 얻은 結果를 要約하면 다음과 같다.

1. 마지막 수확에서 전광의 25% 條件을 제외한 모든 光度 아래서 葉綠素 含量은 거의 비슷했다.
2. 전광, 전광의 75% 條件에서 光合成能力은 전광의 25% 조건보다 더 좋게 나타났다.
3. RuDP carboxylase의 活性은 光度가 증가할 수록 커졌다.

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² 서울대학교 農業生命科學大學 山林資源學科 Department of Forest Resources, College of Agriculture & Life Science, Seoul National University, Suwon 441-744, Korea.

4. RuDP carboxylase 活性은 葉綠素 *a*의 含量이 ($r=0.792$) 葉綠素 *b*의 含量($r=0.314$) 보다 더 相關 關係가 높았다.
5. 전광의 75% 條件에서 1, 2% 養料 條件으로 사용하였을 때 RuDP carboxylase의 活性은 0.5% 養料 條件에 비해서 높았다.

INTRODUCTION

Growth of plants has been represented by interaction of environmental and genetic factors. Among the environmental factors, light intensity, nutrient levels and CO₂ concentration play an important role in growth of plants (Douglas and Walker, 1981; Tarlowski *et al.*, 1986).

Light is essential, not only as the driving force of photosynthesis, but also as a trigger and a morphogenic response. Plants have devised unique mechanisms to capture light for photosynthesis by converting solar energy to stored chemical energy as ATP, as well as to adapt to changes in their environment (Böhning and Burnside, 1956). Light intensity influences light compensation point, light saturation point, and photosynthesis ability (Hodges, 1976; Wareing *et al.*, 1986; Boardman, 1977). Photosynthesis and respiration of plants are influenced by light intensity (Rajmane and Karadge, 1986). Nygren and Kellomaki (1984) demonstrated that plants response to the light intensity through several physiological and morphological changes in function and structure. Leaf area and the thickness of leaf mesophyll tissue and maximum photosynthetic rate decreased with decreasing light intensity. And these phenomena seemed to be associated with the decrease in the amount of chlorophyll per unit of leaf area (Caesar, 1989; Gratani and Moriconi, 1989).

Depending upon the amount of nutrient absorbed, plants express different productivity. Since plants utilize the nitrogen, they show different growth pattern according to their absorption abilities (Reed *et al.*, 1988). Dimitrov *et al.* (1989) showed that ribulose-diphosphate (RuDP) carboxylase activity depended on the amounts of nitrogen uptake.

RuDP carboxylase is frequently cited as the most abundant enzymes on the earth. It is definitely the most abundant enzyme in light-grown plants. The enzyme RuDP carboxylase catalyzes the primary

step in carbon fixation in C₃ plants, as compared with phosphoenolpyruvate carboxylase which does the step in carbon fixation in C₄ plants. RuDP carboxylase is structurally composed of eight small subunits enclosed by nuclear genes and eight large subunits that encompass the active site and are encoded in the chloroplast genome (Jensen and Bahr, 1977). RuDP carboxylase is located on the surface stroma of thylakoid membrane of chloroplasts and it occupies approximately 16% of total proteins of chloroplast (Han, 1987).

The discovery that RuDP carboxylase can also function as an oxygenase has led to the understanding of the pathway of the photorespiratory cycle (Dean *et al.*, 1989; Mott and Berry, 1986). Research into their organization, structure, role and relationship between photosynthesis and RuDP carboxylase has been important elucidating basic issues of many plant physiologists (Dean *et al.*, 1989; Anderson *et al.*, 1978; Allen and Bowes, 1984).

Currently much effort is being expanded in an attempt to understand how its activity may be controlled by a key enzyme such as an initial CO₂ fixing enzyme (Black, 1973). In plants, light intensity directly influences RuDP carboxylase activity. In C₃ plants, RuDP carboxylase was increased according to increasing light intensity (Bowes *et al.*, 1972; Mahendra *et al.*, 1974). RuDP carboxylase activity depends on light and nitrogen uptake (Kobza and Seemann, 1989 a; 1989 b).

Thus RuDP carboxylase activity may be a good estimate of photosynthesis in plants (Bowes *et al.*, 1972). In Calvin cycle, RuDP carboxylates to form of phosphoglyceric acid (PGA). PGA is the first stable product from this cycle. Here, RuDP carboxylase converts from RuDP to PGA (Zima and Šesták, 1985).

Conversely a broad-leaved plant, *Q. acutissima* germinates with cotyledons remaining under ground. *Q. acutissima* utilizes nutrient in cotyledons for growth until stable state. So, removed cotyledons

influence the growth of *Q. acutissima* seedling. It is interesting to compare the growth of cotyledons removed seedlings with seedling with cotyledons in *Q. acutissima*.

Oaks are widely distributed throughout the temperate region of the Northern Hemisphere (Sargent, 1965). In Korean peninsular, they are native species, and occupy the 27% of the total stock volume in Korea. Much interest in the development and utilization of oak resources has been expressed for better management, improvements and their potential uses in Korea (Lee *et al.*, 1990). Among oak species, *Q. acutissima* grows well at low altitudinal regions in Korea. However, there were little physiological researches on *Q. acutissima*.

The purpose of this study was to compare chlorophyll contents, photosynthetic abilities and RuDP carboxylase activities of *Q. acutissima* seedling grown with and without cotyledons under different light intensities and different nutrient levels.

MATERIALS AND METHODS

1. Plant materials

The seeds of *Quercus acutissima* Carr. were collected in October, 1989 from mature trees growing at Seoul National University Forest (127° 18' E, 37° 18' N) located in Sanglim-li, Docheok-myeon, Kwangju-gun, Kyunggi-do, Korea and transported to laboratory. They were stored in a refrigerator until use.

Rotten or empty seeds were removed by flotation

in water. The collected seeds were sown on April 16, 1990 in a plastic container (61×40×20cm) filled with sterilized sand in the greenhouse (Table 1).

2. Culture conditions for *Q. acutissima* seedling growth

After germination, the seedlings were transplanted into plastic container (61×40×20cm) filled with distilled water on June 16, 1990.

Hydroponic culture was used for growing *Q. acutissima* seedlings in the greenhouse (Fig. 1). The nutrients were supplied daily on the basis of growth rates per day.

The solution used in this study is shown in Table 2. (Ingestad and Lund, 1979)

The cultivation technique based on the concept of steady state condition of nutrient was used in this study (Ingestad and Lund, 1986). Because relative addition rates were related to relative growth rates, nutrient solution was added daily during the entire growing period.

Three addition rates of nutrients were determined : 0.5% as control, 1%, and 2% per day.

Four light intensities were used : 1435μE m⁻²sec⁻¹, 1011μE m⁻²sec⁻¹, 663μE m⁻²sec⁻¹, and 284μE m⁻²sec⁻¹. Three levels of nutrients were given to the seedlings with and without cotyledons growing under the four light intensities.

3. Estimation of leaf chlorophyll contents

Intact leaf (1 g of fresh weight) was collected at every harvest time. Chlorophyll was extracted with

Table 1. Seed characteristics of *Quercus acutissima* used in this study

Species	Long diameter (mm)	Short diameter (mm)	Fresh weight (g)
<i>Q. acutissima</i>	20.25 ± 0.28*	17.54 ± 0.35*	4.25 ± 0.14*

* Standard deviation

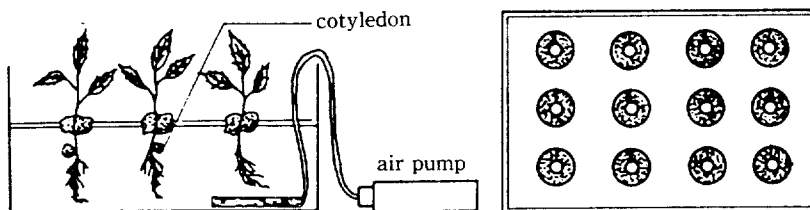


Fig. 1. Growth unit used for hydroponic culture.

Table 2. Compositions of nutrient solution used for growing *Q. acutissima*

Stock solution A (g/ℓ)		Stock solution B (g/ℓ)	
Component	Concentration	Component	Concentration
KNO ₃	63.275	Mg(NO ₃) ₂ ·6H ₂ O	44.48
NH ₄ NO ₃	137.486	HNO ₃ 1N	40.00ml
K ₂ SO ₄	24.48	Ca (H ₂ PO ₄) ₂ ·2H ₂ O	31.40
		Micro 7303	25ml

Micro nutrient solution (g/0.5 ℓ)

Component	Concentration
Fe(NO ₃) ₃ ·9H ₂ O	50.62
Mn(NO ₃) ₂ ·4H ₂ O	18.62
H ₃ BO ₃	11.46
Zn(NO ₃) ₂ ·4H ₂ O	1.37
CuCl ₂ ·2H ₂ O	0.80
Na ₂ MoO ₄ ·2H ₂ O	0.17

10 ml of 80% acetone for 7 days at 4°C and its absorbances were measured using spectrophotometer (Model Hitachi 139) at wave-lengths of 663nm and 645nm.

Chlorophyll contents (chlorophyll *a*, chlorophyll *b*, and total chlorophyll) were determined by Arnon's equation (Arnon, 1949).

4. Estimation of photosynthetic ability of the leaf

Photosynthetic ability was indirectly calculated with the amount of oxygen (μ mole) evolved from unit leaf area (cm^2) per hour under controlled environments.

Ten leaf discs (6mm in diameter) were punched from expanded leaves. The leaf discs were dipped immediately into distilled water and exposed to the tungsten lamp ($300\mu\text{E cm}^{-2}\text{sec}^{-1}$ in light intensity) at the temperature varying between 24°C and 26°C. Four milliliters of 50mM potassium-phosphate buffer (pH7.2) solution containing 0.5mM MgCl₂ and 0.1 mM CaSO₄, and 2ml of 0.625M NaHCO₃ were used as reaction solution. Photosynthetic ability per unit leaf surface area per hour (μ mole O₂·cm⁻²·hr⁻¹) was measured by oxygen electrode and meter (YSI Co. Ohio, U.S.A).

5. Estimation of ribulose diphosphate carboxylase activity

After the measurement of the leaf surface areas, 300mg of leaves were harvested at each harvest

time. The harvested leaves were frozen quickly by immersing into liquid nitrogen. Frozen leaves were ground in a mortar until the leaves were crushed. Leaf tissue was put in a vial containing 1ml buffer (0.12M Tris-Cl, pH8.0, 10mM MgCl₂, 0.25mM EDTA and 7.5mM reduced glutathione). The assay was initiated by adding an liquid of the extract to reaction vials containing 50mM Tris-Cl pH8.0, 5mM MgCl₂, 0.1 mM RuDP, 3mM reduced glutathione and 2 μ Ci NaH¹⁴CO₃ in a final volume of 2ml. The vials were capped during the assay period.

After incubating at 30°C for 3 minutes, the reaction was stopped with 6M acetic acid.

The solutions remained from the reaction were dried in air stream before determination of the radioactivity by liquid scintillation counter (Bachman L-S 100) (Mahendra *et al.* 1974; Bowes *et al.* 1972).

RESULTS AND DISCUSSION

1. Chlorophyll contents

Fig. 2 and 3 show the contents of chlorophylls *a* and *b*, respectively.

Under full sunlight, the contents of chlorophyll *a* ranged from 0.21 to 0.7mg/g. fresh weight. Generally, maximum contents of chlorophyll *a* were recorded on July 19, 1990.

The contents of chlorophyll *b* increased with increasing days (Fig. 3) under most of the light regions.

Total chlorophyll contents under the 50-75% of sunlight condition were generally greater than those under the 25% of sunlight (Fig. 4). This result was similar to that reported by Nygren and Kellomaki (1984) who observed that the amount of chlorophyll was greater in unshaded condition than in shaded condition for *Betula pendula* and *B. pubescens*. This result indicates that with increasing light intensity

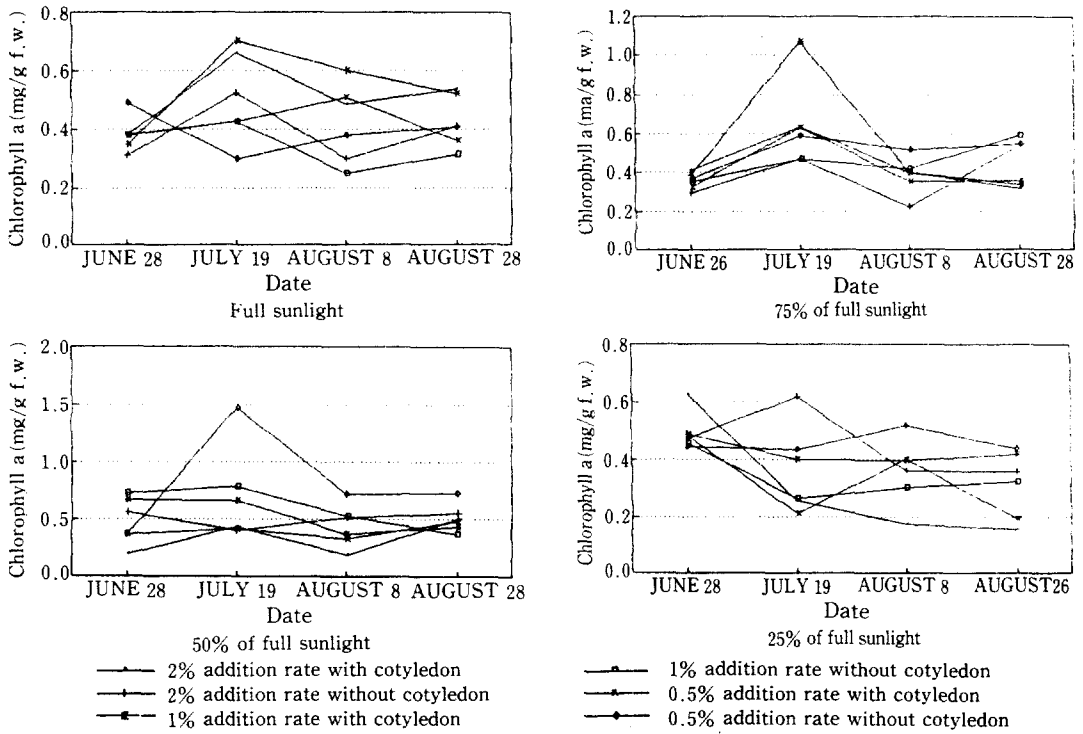


Fig. 2. Chlorophyll *a* contents(mg per 1g of leaf fresh weight) of *Quercus acutissima* seedlings, at three levels of nutrient addition rates, under four light intensities, and with or without cotyledons, grown for 11 weeks in greenhouse.

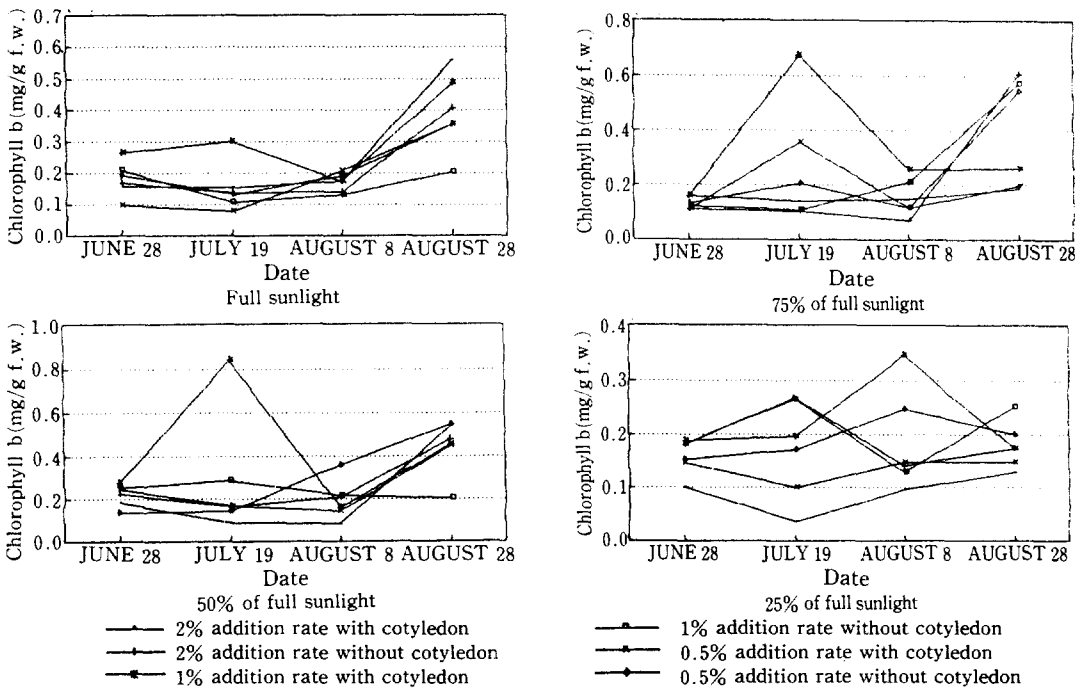


Fig. 3. Chlorophyll *b* contents(mg/g.fresh weight) of *Quercus acutissima* seedlings, at three levels of nutrient addition rates, under four light intensities, and with or without cotyledons, grown for 11 weeks in greenhouse.

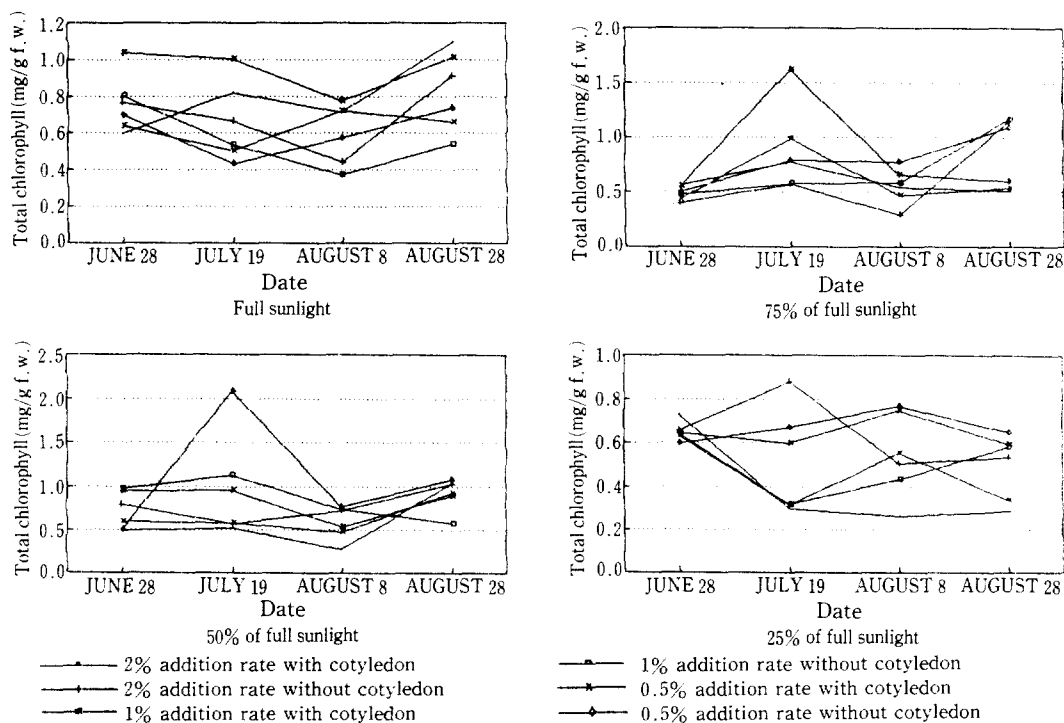


Fig. 4. Total chlorophyll contents(mg/g. fresh weight) of *Quercus acutissima* seedlings, at three levels of nutrient addition rates, under four light intensities, and with or without cotyledons, grown for 11 weeks in greenhouse.

the number of palisade layers increases and in turn, it increases the thickness of mesophyll and consequently increases the chlorophyll contents(Björkman and Holmgren, 1963). The amount of chlorophylls *a* and *b* total chlorophyll of the seedlings added at 1% rates of nutrients under 75% of full sunlight was greater than that at 0.5% rates. This result was similar to that reported by Nam(1990) who observed that the amount of chlorophyll of *Spirodela polyrrhiza* grown under sufficient nutrition was greater than that under deficient nutrient.

2. Photosynthetic ability

Photosynthetic ability generally showed the peak on August 8 1990 at all of the light intensities (Fig. 5). This was supported by the maximum photosynthesis usually occurred prior to reaching the peak of chlorophyll contents and leaf area in *Phaseolus vulgaris* (Johnson, 1981).

Light intensity affects synthesis of chlorophylls, photosynthetic rate, and hormone metabolism dur-

ing plant growth(Kramer and Kozlowski, 1979).

Photosynthetic ability of the seedlings was not significantly different at 5% level between with and without cotyledons. Photosynthetic ability under full sunlight and 75% of full sunlight was significantly higher than that under 25% of full sunlight at the final harvest time. This result was similar to those reported by Björkman and Holmgren(1963), who observed that photosynthetic rate decreased when shaded. This phenomenon seemed to be associated with the decrease in the amount of chlorophyll contents per unit of leaf area(Caesar, 1989).

Photosynthetic ability of the seedlings at 2% nutrient rates under 75% of full sunlight was higher than that at 0.5% nutrient rates. This result was similar to those reported by Nevins and Loomis(1970), who reported that nitrogen deficiency was evaluated as CO_2 assimilation in sugar beet(*Beta vulgaris* L.) leaves. They reported that nitrogen deficiency reduced the chlorophyll concentration and photochemical capacity of the older leaves but not of

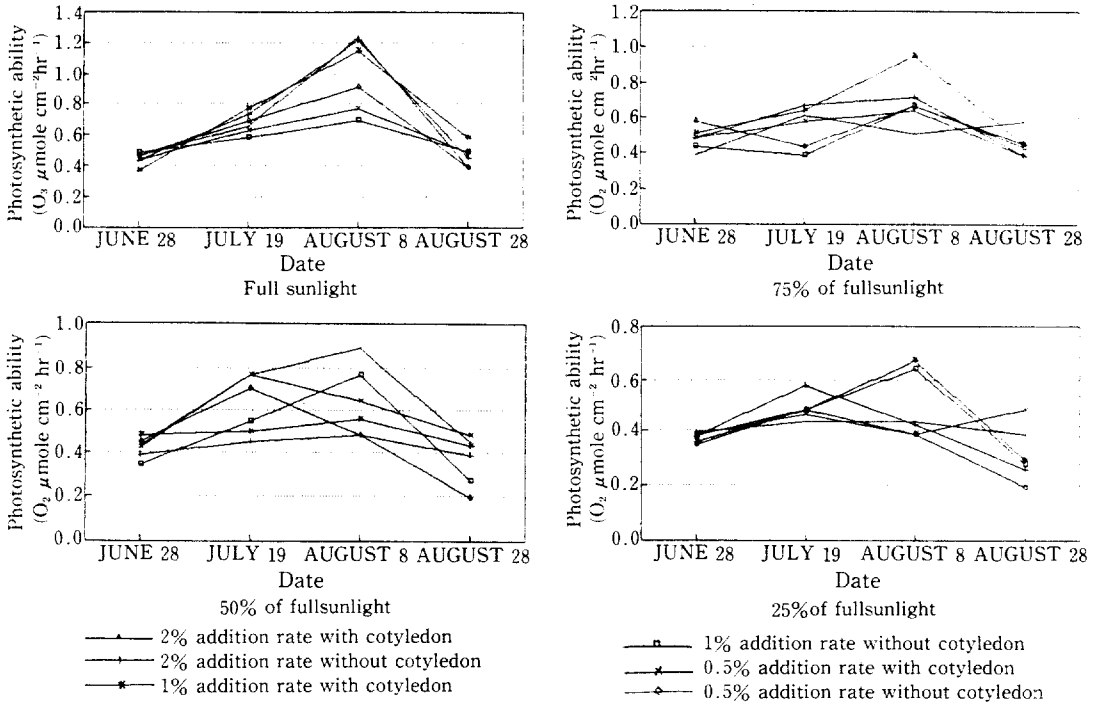


Fig. 5. Photosynthetic ability ($\mu\text{mole CO}_2 \text{ cm}^{-2}\text{hr}^{-1}$) of *Quercus acutissima* seedlings, at three levels of nutrient addition rates, under four light intensities, and with or without cotyledons, grown for 11 weeks in greenhouse.

young and recently mature leaves. And the rate of photosynthesis was also reduced as much as 40% when plants were grown for 14 days without nitrogen. This fact explained that nitrogen takes part in metabolism during plant growth. The changes in nitrogen uptake affect chloroplast synthesis and its amount and size (Birch *et al.*, 1986).

3. Ribulose-diphosphate carboxylase activity

Variations in RuDP carboxylase for each of the light intensities are shown in Figure 6. RuDP carboxylase activity is known to be related to light intensity (Kobza and Seemann, 1989 a : 1989 b). During the growing season, RuDP carboxylase activity increased for most of the addition rates of nutrients as the light intensity increased from 25% to 75% of full sunlight. This result was the same as the report of Mahendra *et al.* (1974) who found that in C₃ plant species, RuDP carboxylase activity decreased with increasing shade.

Allen and Bowes (1984) reported that RuDP carboxylase activities of several C₃ plants (*Glycine max.*,

Lycopersicon esculentum, *Nicotiana tabacum*, *Panicum bisulcatum* and *P. hylaicum*) were greater in light exposed leaves than leaves in darkness. Higher light intensity stimulated the increased synthesis of photosynthetic enzymes (Kobza and Seemann, 1989 a).

Table 3 shows the correlation coefficients among chlorophyll contents, photosynthetic ability and RuDP carboxylase activity.

RuDP carboxylase activity was more strongly correlated with contents of chlorophyll *a* ($r=0.792$) than those of chlorophyll *b* ($r=0.314$). This result indicates that RuDP carboxylase is located on surface stroma of thylakoid membrane of chloroplast and RuDP carboxylase is activated by increase of Mg²⁺ (Maruyama *et al.*, 1966).

RuDP carboxylase activity was also positively correlated with photosynthetic ability ($r=0.546$). It is because that high light intensity expanded revelation of RuDP carboxylase activity (Ford and Shibles, 1988).

It was also supported by the report of Ballantine

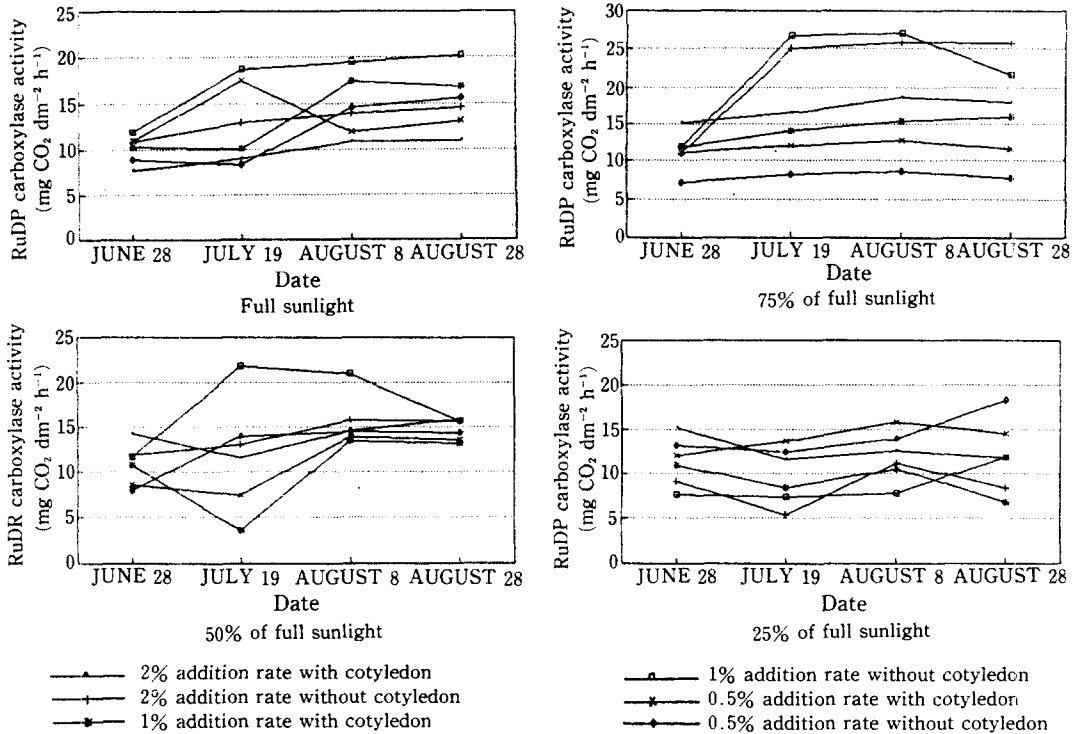


Fig. 6. Ribulose-diphosphate carboxylase activity (mg CO₂dm⁻²h⁻¹) of *Quercus acutissima* seedlings, at three levels of nutrient addition rates, under four light intensities, and with or without cotyledons, grown for 11 weeks in greenhouse.

Table 3. Correlation coefficients among chlorophyll contents, photosynthetic ability and ribulose-diphosphate carboxylase activity

	Chl. a	Chl. b	Total chl.	Pho. abil.
Chl. b	0.740*			
Total chl.	0.918*	0.946*		
Pho. abil.	-0.232	0.186	-0.002	
RuDPcase act.	0.792*	0.314	0.278	0.546*

Chl., Pho. abil. and RuDPcase act., indicate chlorophyll, photosynthetic ability and ribulose-diphosphate carboxylase activity, respectively.

* Indicate significance at 5% level.

and Forde(1970). who showed that low light intensity induced decline in photosynthetic rate per unit leaf area and consistent association with this decline resulted the diminish of RuDP carboxylase activity and chlorophyll contents.

Ford and Shibles(1988) reported that photosynthetic rate and RuDP carboxylase activity differed among six soybean species, because of differences in the amount of chloroplasts per unit leaf area. They observed that photosynthetic rate and RuDP carboxylase activity showed the maximum value when the

chloroplasts reached the maximum.

Light intensity is known to control RuDP carboxylase activity mechanism (Kobza and Seemann, 1989 b) and RuDP carboxylase influences CO₂ fixation in plant growth. Therefore, increase of photosynthetic rate under light saturation point manifested increase of RuDP carboxylase activity in chloroplast.

Especially, RuDP carboxylase activity of the seedlings added at 1 or 2% rates of nutrients under 75% of full sunlight was higher than that at 0.5% rates. This result was similar to those reported by Dimitrov

et al. (1988) who observed that the RuDP carboxylase activity of *Triticum aestivum* grown under sufficient nutrition was greater than that under deficient nutrient.

CONCLUSION

The acorns were collected from mature oak trees growing at Seoul National University Forests located in Kwangju-gun, Kyunggi-do, Korea. Complete nutrient solution was added daily to the seedlings using Ingestad and Lund (1979)'s method. Cotyledons were removed from some of the seedlings in 2 weeks after germination. This study was conducted to compare chlorophyll contents, photosynthetic abilities, and RuDP carboxylase activities of *Quercus acutissima* seedling grown with and without cotyledons under different light intensities and different nutrient levels. Chlorophyll contents were not significantly different among the light intensities except for 25% of full sunlight at the last harvest time. RuDP carboxylase activity increased with increasing light intensity. Photosynthetic abilities of seedlings grown under full and 75% of sunlight were significantly higher than those under 25% of full sunlight. RuDP carboxylase activities were more related with chlorophyll *a* contents ($r=0.792$) than chlorophyll *b* contents ($r=0.314$). RuDP carboxylase activities of the seedlings received at 1 or 2% addition rates under 75% of full sunlight were higher than that at 0.5% addition rates.

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