Interactions of nitrogen supplying level and elevated CO2 on Growth and Photosynthesis of *Picea koraiensis* Nakai seedlings

Wang Y.-J.[1] **Mao Z.-J.**[1] **Park K.-W.**[2]

1. **Key Laboratory of Forest Plant Ecology Ministry of Education China, Northeast Forestry University, Harbin, China, 150040**
2. **National Arboretum, Korea Forest Service, Pochen-Gun, Korea, 487-820**

Abstract

To evaluate the biological and physiological response of *Picea koraiensis* Nakai to elevated CO_2 and nitrogen.3-year old seedlings were planted in an ambient and 700 ppm CO_2 at low (2mM NH_4NO_3) or high nitrogen (16mM NH_4NO_3) supplying treatments for 3 months. Photosynthetic parameters were measured monthly. Seedlings were harvested at monthly intervals and growth parameters of root system, stem and needle fractions were evaluated. The result showed that height of the seedlings grown at both of elevated $CO_2 \times$high nitrogen and elevated $CO_2 \times$low nitrogen supplying treatments increased significantly more than that of at ambient CO_2 treatments. Seedlings grown at elevated CO_2 $\times$high nitrogen produced more root biomass than at elevated $CO_2 \times$low nitrogen and ambient $CO_2 \times$ high nitrogen treatments. This result suggested that the root growth response of *Picea koraiensis* seedlings was greater in elevated $CO_2 \times$high nitrogen regime, which is very important for carbon sequestration in soil. A_{max} of the seedlings grown at elevated $CO_2 \times$ high nitrogen increased during the three months significantly, and A_{max} of the seedlings grown at the other three treatments decreased significantly, suggesting that the interaction between elevated CO_2 and high nitrogen supplying stimulates the A_{max} of *Picea koraiensis*. A_{max} of the seedlings grown at elevated $CO_2 \times$ low nitrogen showed higher than other three treatments in the first month of the experiment, but decreased in succedent two months, suggesting that elevated CO_2 promotes the photosynthesis of the seedlings. However long term growth in elevated $CO_2 \times$ low nitrogen supplying condition resulted in an acclimatory decreased in leaf photosynthesis.

Key words: Elevated CO_2, Photosynthesis, Nitrogen, Biomass, *Picea koraiensis*

Introduction

With increasing atmospheric CO_2 concentrations and associated climate change, the potential for direct effects of elevated CO_2 on forest trees is large (Woodward 2002). Numerous studies on leaves, stems, and branches have shown that elevated CO_2 increases carbon assimilation and plant biomass of both of aboveground and belowground (Johnsen et al. 1996, Tingey et al 1996). In *Pinus echinata* Mill. *Quercus alba* L. *Pinus taeda* L. and *Pinus ponderosa* Dougl. ex Laws, elevated CO_2 increased root growth more than shoot growth, suggesting a greater allocation of carbohydrates to roots (King et al. 1996).

The majority of research on the effects of elevated CO_2 on plants has focused on crops grown under optimal conditions; however, in natural ecosystems, plants are often limited by suboptimal resource availability (e.g., soil N and water). Under conditions of resource limitation, plant growth responses to elevated CO_2 are variable (Griffin et al. 1993, Johnson et al. 1995, Hymus et al. 2001). Prior (1997) reported that elevated CO_2 increased biomass production only in the high-N treatment, and the relative growth enhancement was greater for the root system than for the shoot system for *Pinus palustris* Mill. However, Zak et al. (1993) proposed that, even under nutrient limiting conditions, CO_2 enrichment could increase belowground carbon allocation by increasing root exudation into the soil which, in turn, would result in increased organic matter mineralization and N availability.

Different plant species respond differently to elevated CO_2. So increasing CO_2 concentrations could alter competitive relationships and thereby change ecosystem structure and function (Bazzaz 1990, Mooney et al. 1991). Species-specific differences in response elevated CO_2, emphasize the importance of investigating whole-plant responses to multiple stresses of native species.

Spruce is one of the main components of boreal forest and plays an important role in boreal forest ecosystem. The objectives of the current study were to determine if elevated CO_2 and N fertilization effect on the growth of stem, leave and root growth of *Picea koraiensis* Nakai seedlings grown in plant growth chamber, the photosynthesis and carbon assimilation characteristics of the seedlings growing in different CO_2 concentration and nitrogen supplying regimes.

Materials and Methods

Plant materials

Three-year old *Picea koraiensis* Nakai seedlings grown in Breeding Experiment Station of Binxi Forest Farm (45°N, 127°E) were used for the experiment. Every seedling were transplanted to a vinyl pot (diameter 13cm, depth 15cm) containing sand and chernozem soil (2:1), and placed in greenhouse for 2 weeks, and then put them into (Plant Growth Chamber E8, Canada) in the beginning of June 2003 before the seedling begin to sprout.

Treatments

Seedlings were assigned to growth chamber with elevated CO_2 concentration 700ppm and with ambient CO2 (350ppm±20ppm) . Temperatures regime in growth chamber were programmed with self-regulating based on the mean temperature of natural condition in Xiaoxingan Mountain China (45-46°N, 127-128°E) where the spruce distributes. Seedlings were fertilized with Hoagland,s solution, 2mM and 16mM NH_4NO_3 for the low (LN) and high (HN) nitrogen treatments respectively every ten days. Namely four treatments were set in all: elevated CO_2 conjunction with high nitrogen (ECHN), elevated CO_2 conjunction with low nitrogen (ECLN), ambient CO_2 conjunction with high nitrogen (ACHN), and ambient CO_2 conjunction with low nitrogen (ACLN)Plants were watered to saturation with de-ionized water every morning and evening to prevent desiccation and salt accumulation. The whole experiment was taken 3 months.

Measurements

Biological measurement

Base stem diameter, plant height and dry weight of needles, stem and root system were measured at every 20th June, July and August respectively to recognize the relative growth. Mean value of every treatment was got from 3 repeat measurements of seedlings, which were selected at random.

Photosynthesis measurement

Measurements on gas exchange parameters were taken one time every month. Maximal carbon assimilation rate (A_{max}), photo compensation point (Ic), photo saturation point (Is) etc. were determined with Li-Cor portable photosynthetic system (Model Li-6400, USA) equipped with a leaf chamber.

Result and discussion

Growth in height and in diameter

Averaged height of the seedlings grown at both of elevated CO_2×high nitrogen and low nitrogen supplying treatments increased significantly more than that of at ambient CO_2 treatments by the end of experiment (Fig1a). Effects of elevated CO_2 with two nitrogen treatments on the growth of stem diameter were not significant comparing with control CO_2 condition×low nitrogen supplying. High nitrogen treatment at control CO_2 condition showed positive significant effect on diameter growth of seedlings (Fig1b).

Dry biomass ratio of root system, stem and needles fractions

The effect of different treatment on relative ratio of root system, stem and needles biomass during three months experiment are shown in Figure 2. Seedlings grown at elevated CO_2×high nitrogen produced more root biomass (Fig.2a) than at elevated CO_2×low nitrogen and ambient CO_2×high nitrogen treatments(F.g.2b,2c), which have a similar dry biomass ratio of root system, stem and needles fractions, in three months measurement, suggesting significant CO_2 × high nitrogen interactions for promoting carbon assimilation in root system. The biomass measurement for different root fractions showed that the biomass of the secondary root fraction was significant bigger than that of the fine root fraction, suggesting that the CO_2 root growth response of *Picea koraiensis* seedlins was greater in high nitrogen regime, which is very important for carbon sequestration in soil.

However, the root system fraction of the seedlings grown at ambient CO_2 × low nitrogen (fig.2d) also showed bigger than that of at elevated CO_2 × low nitrogen and ambient CO_2 × high nitrogen treatments, indicating that the dry matter accumulation of the seedlings more in underground part than aboveground part to insure their survival when they grown in nutrition stress condition.

Photosynthetic characteristics

A_{max} of the seedlings grown at elevated CO_2 × high nitrogen increased during the three months significantly, and A_{max} of the seedlings grown at the other three treatments decreased significantly (Tab.1). This result suggests that the interaction between elevated CO_2 and high nitrogen supplying stimulates the A_{max} of *Picea koraiensis*. A_{max} of the seedlings grown at elevated CO_2 × low nitrogen showed higher than other three treatments in the first month of the experiment, but decreased in succedent two months, suggesting that elevated CO_2 promotes the photosynthesis of the seedlings. However long term growth in elevated CO_2 × low nitrogen supplying condition resulted in an acclimatory decreased in leaf photosynthesis due to nitrogen insufficiency. Our results were similar to those reported for other tree species. Sage et al. (1989) demonstrated that the photosynthetic rate of five plant species grown in elevated CO_2 was regulated by leaf-level nitrogen. Tissue et al. (1993) concluded that the decline in the photosynthetic rate of loblolly pine seedlings grown for 2 years in a CO_2-enriched atmosphere was caused by decreases in nitrogen and Rubisco content rather than by inactivation of Rubisco.

The net photosynthetic rate (P_n) of the seedlings responded more positively to elevated CO_2 × low nitrogen treatment in both June and July than other three treatment (F.g.1a, 1b). The P_n value of the seedlings grown at ambient CO_2 × low nitrogen treatment showed higher compared to that of at elevated CO_2 × high nitrogen and at ambient CO_2 × low nitrogen in June. But The P_n value of the seedlings grown at elevated CO_2 with high nitrogen showed the biggest among all of the four treatments in August (Fig.1c). This result suggests that proper C/N rate is demanded for the growth of *Picea koraiensis* seedlings. Excessive nitrogen supplying makes against the seedling growth. With the growing of the seedlings, more soil nutrition was be absorbed by seedlings. The nitrogen concentration decreased in the soil relatively, so the P_n of the seedlings growing at elevated CO_2 with high nitrogen showed the highest after three months.

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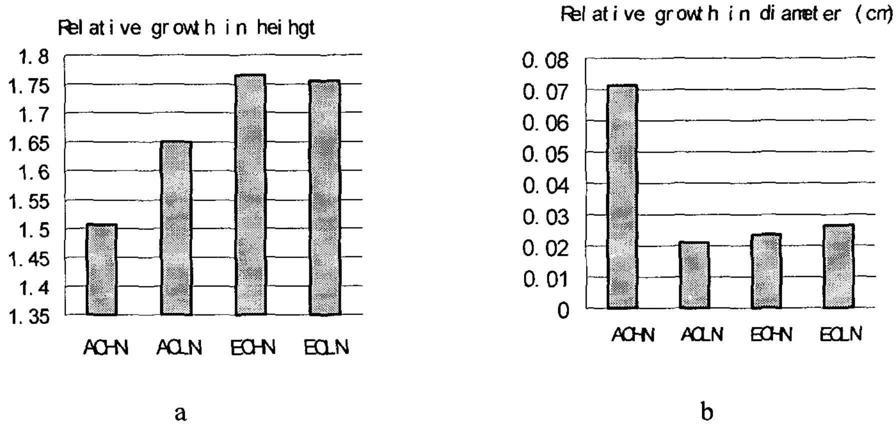

Fig. 1. Relative growth ratio in height (a) and diameter (b) of *Picea koraiensis* seedlings grown in different CO2 and nitrogen supplying treatment after 3 months experiment. Treatment ACHN: Ambient CO2×high nitrogen. ACLN: Ambient CO2×low nitrogen. ECHN: Elevated CO2×high nitrogen. ECLN: Elevated CO2×low nitrogen.

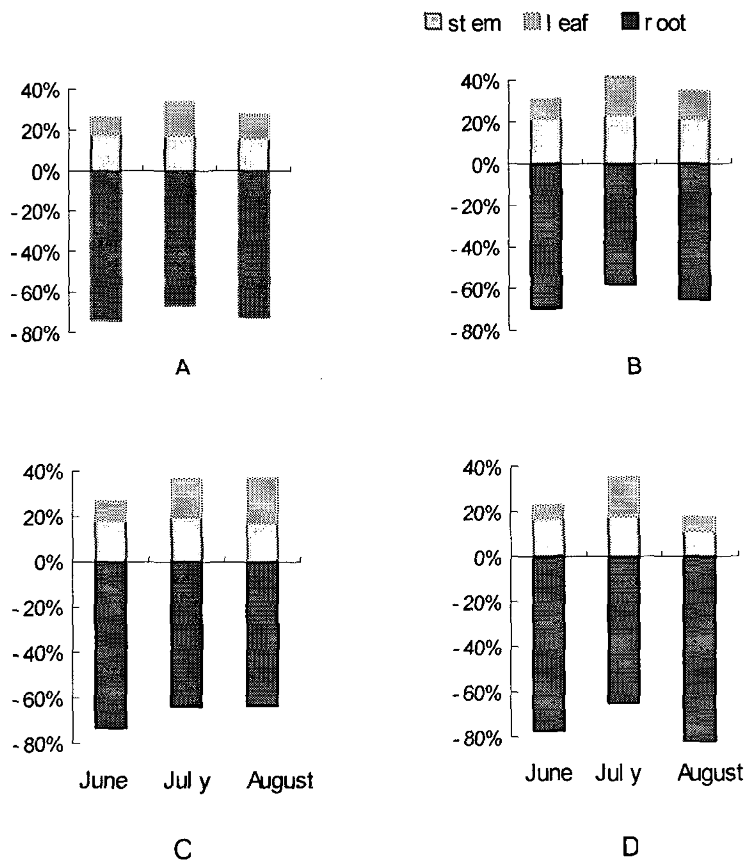

Fig.2.Dry biomass ratio in root system, stem and needles of the seedlings at different CO2 and nitrogen treatments, A. ECHN. B. ECLN. C. ACHN. D. ACLN.

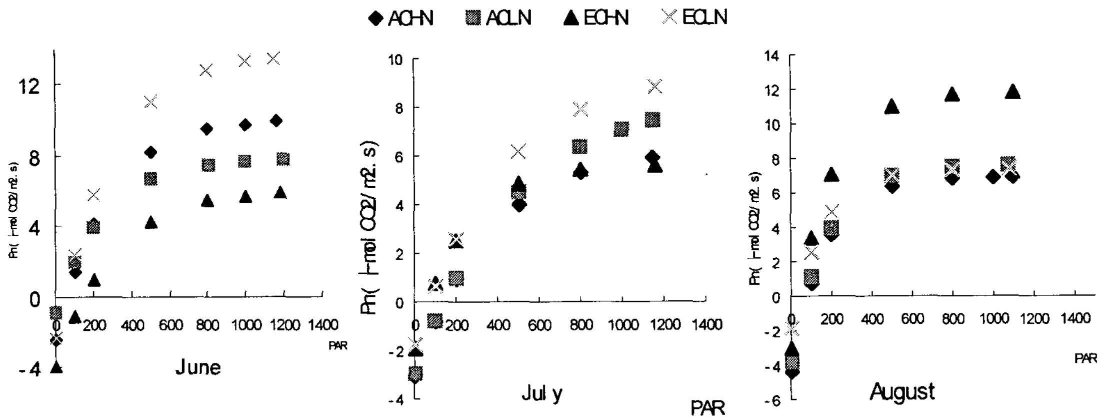

Fig.3 Photoresponse curves of *Picea koraiensis* under elevated CO2 during the growth season

Table 1. Photosynthetic parameters of the spruce seedlings grown at different treatments (CO2 and nitrogen supplying

Treatment		Date	A_{max} (μmol $CO_2/m^2.s$)	Is (μmol photons/m^2.s)	Ic (μmol photons/m^2.s	AQYmax (mmol CO_2/mol photons)	R (μmol CO_2/m^2.s)
ECO_2	HN	Jun.	6.01±1.31	805.9±26.6	148.0±34.4	0.027±0.0096	4.61±1.57
		Jul.	9.47±1.52	643.4±99.7	77.5±21.7	0.042±0.0275	2.9±0.463
		Aug.	11.85±2.75	474.6±73.9	39.0±13.8	0.072±0.0103	3.20±1.78
	LN	Jun.	13.77±1.49	703.1±52.8	47.8±4.6	0.051±0.0081	2.53±0.31
		Jul.	9.48±1.44	1188.9±112.	84.2±42.7	0.024±0.0143	2.01±0.05
		Aug.	7.38±1.99	383.6±21.7	33.3±5.5	0.051±0.0044	1.8±0.425
ACO_2	HN	Jun.	10.06±1.41	667.3±40.53	65.0±10.03	0.040±0.0045	2.64±0.33
		Jul.	8.33±1.06	865.6±100.3	120.2±46.1	0.027±0.0045	3.77±0.71
		Aug.	6.91±0.76	462.4±73.84	82.3±11.71	0.044±0.0064	4.58±1.61
	LN	Jun.	9.44±3.01	771.9±110.6	67.7±10.15	0.031±0.0037	3.10±0.35
		Jul.	8.44±1.71	1205.5±115.4	127.5±28.5	0.0183±0.002	2.80±0.90
		Aug.	7.62±1.01	478.1±96.2	73.1±10.14	0.046±0.0093	3.99±0.65

ECO_2: elevated CO_2; ACO_2: ambient CO_2; Amax: maximal carbon assimilation; Is: light saturation point; Ic: light compensation point.