Korean J. Ecol. 18(2) : 265~273, 1995

Responses in Net Photosynthetic Rate of *Quercus mongolica* Leaves to Ozone

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오존에 대한 신갈나무 잎의 순광합성능의 반응

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ABSTRACT

Net photosynthetic rate (Pn) of *Quercus mongolica* leaves was determined under the controlled O_3 concentrations of 0, 20, 30, 40, 50 or 60 ppb at every 10 min for 7 hr. Under the fumigation of the different O_3 concentrations the relative net photosynthetic rate (RNPR) of the leaves decreased rapidly until 1 hr and thereafter decreased slowly. At below 20 ppb O_3 the decrease of the RNPR was scarce but at above 20 ppb O_3 the RNPR was inversely proportional to O_3 concentration on a logarithmic curve. The RNPR at 60 ppb O_3, for example, was reduced 30% less than that without O_3. Under the different O_3 concentrations fumigated for the short period of time the Pn dependent upon PPFD was depicted as saturation equation and Pn dependent upon temperature as quadratic equation. Results of this study suggest that short-term low O_3 of less than 60 ppb concentration may lead to reductions of Pn in *Q. mongolica* leaves.

Key words: Air pollution, Net photosynthetic rate, O_3 effects, *Quercus mongolica*

INTRODUCTION

Increase of ambient O_3 is particularly significant because of the phytotoxic concentrations over broad geographic regions (Swank and Vose 1990/1991). In both Europe and North America, O_3 pollution has brought about extensive damage to vegetation (Reich and Lassoie 1985).

Leaves exposed to large doses of O_3 display the typical symptoms of mottling with decreasing photosynthesis and increasing dark respiration, which may lead to reduction of tree growth (Olszik and Tibbits 1981, Pell 1987, Lehnherr *et al.* 1987, Lange *et al.* 1987, Lee *et al.* 1990, Lee 1993).

In Seoul, Korea, the ambient O_3 has been monitored in high concentrations since 1990.

For example, during the summer of 1993, the maximum 1-hour mean concentration was recorded as high as over 300 ppb due to increased number of automobiles (Korean Ministry of Environment 1993).

Recent research found out the evidence of the ambient O_3 as the primary-causal agent affecting foliar symptoms related to chronic damage of plant leaves (Kim 1995, Reich and Amundson 1984, Reich *et al.* 1984).

The purpose of this study is to develope the simulation model based on the practical measurements of net photosynthetic rate of *Q. mongolica* leaves under different levels of O_3 concentrations, photosynthetic photon flux density (PPFD) and air temperature for a short term.

MATERIAL AND METHODS

One-year old seedlings of *Quercus mongolica* were used in this study. Each seed was sown in a polystyrene pot filled with about 150 mL of soil (clay: humus = 5: 1 by vol.) and germinated in greenhouse. Seedlings with stem about 5 cm long were transplanted into plastic pots (18 cm d., 13 cm h.) filled with 3 kg of soil (clay: humus = 4: 1 by vol.), and irrigated with tap water 3 times a week and with half-strength Hoagland's solution once a month.

Fumigations were conducted in O_3 fumigation chamber in National Environmental Research Institute in Seoul. Plants were exposed to 0, 20, 30, 40, 50 or 60 ppb O_3 under the condition of 25 ~ 27℃, 60 ~ 70% of relative humidity and 2.5 mmol $m^{-2}sec^{-1}$ of PPFD. O_3 was generated by a ozonator (UV-Ozonizer, KIMOTO, Japan), monitored by chemiluminescent O_3 analyzer (Model-813, KIMOTO, Japan) and maintained within ± 2 ppb of the desired concentration. Net photosynthetic rate of the mature leaves was recorded at 10 min intervals for 7 hr by data logger (LI-COR 1000, NE) connected to an infrared gas analyzer (Model LCA-2, ADC, U.K.).

RESULTS AND DISCUSSION

Response in net photosynthetic rate to O_3 fumigation

The relative net photosynthetic rate (RNPR), the ratio of net photosynthetic rate under O_3 fumigation to net photosynthetic rate without O_3 fumigation (P_o), was expressed by two relationships: one was the relationship between the RNPN and the O_3 fumigation period of time ($P_{o3(t)}$) and the other was the relationship between the RNPN and the O_3 concentration fumigated ($P_{o3(C)}$).

Within the period of the first 1 hr the RNPR of leaves under over 20 ppb O_3 was rapidly reduced and thereafter decreased slowly as fumigation period of time elapsed (Fig. 1). In Fig. 1 the data of over 120 min were omitted because they were kept constant within about ± 2%. The relationship between the RNPR and the O_3 fumigation period of time

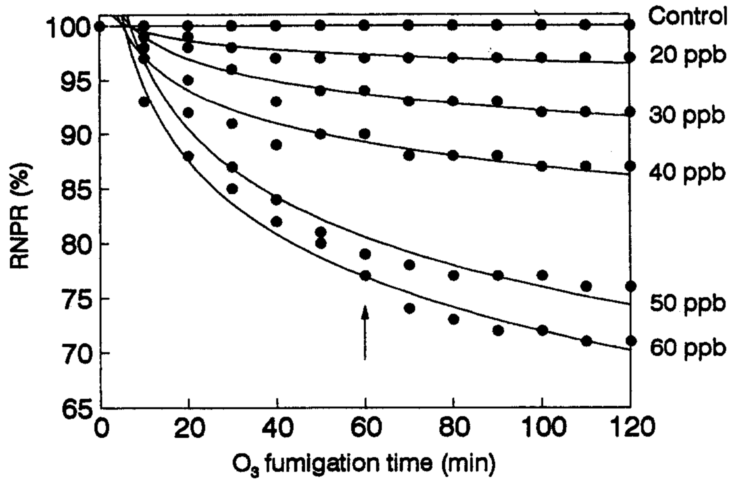

Fig. 1. Relative net photosynthetic rate of *Q. mongolica* leaves dependent upon the periods of fumigation time under each O_3 concentration fumigated.

($P_{O3(t)}$, %) was fitted by Eq. (1):

$$P_{O3(t)} = \frac{P_{O3(ft)}}{P_O} = at^{-b_t} \quad \cdots\cdots (1)$$

where $P_{O3(ft)}$, t and b_t are the RNPR with fumigation period of time under different O_3 concentrations, O_3 fumigation time, and inhibition coefficient of P_n related to the fumigation time, respectively.

The RNPR was lowest under 60 ppb O_3 fumigation, the value of which was 30% less than that without O_3 (Fig. 1).

The RNPR with O_3 fumigation was exponentially reduced as O_3 concentration increased (Fig. 2). Therefore, the relationship between the RNPR and O_3 concentration fumigated ($P_{O3(C)}$) was fitted by Eq. (2):

$$P_{O3(C)} = \frac{P_{O3(fc)}}{P_O} = aC^{-b_c} \quad \cdots\cdots (2)$$

where $P_{O3(fc)}$, C and b_c are the RNPR with increase of O_3 concentration fumigated in respective O_3 fumigation time, O_3 concentration fumigated (ppb), and inhibition coefficient of P_n related to O_3 concentration fumigated, respectively.

Below 20 ppb O_3 fumigation the RNPR was kept almost constant but above 20 ppb O_3 fumigation the RNPR decreased logarithmically (Fig. 2).

The value of b_t in Eq. (1) increased abruptly as O_3 concentration increased (Table 1) and the value of b_c in Eq. (2) increased gradually as the fumigation time elapsed (Table 2).

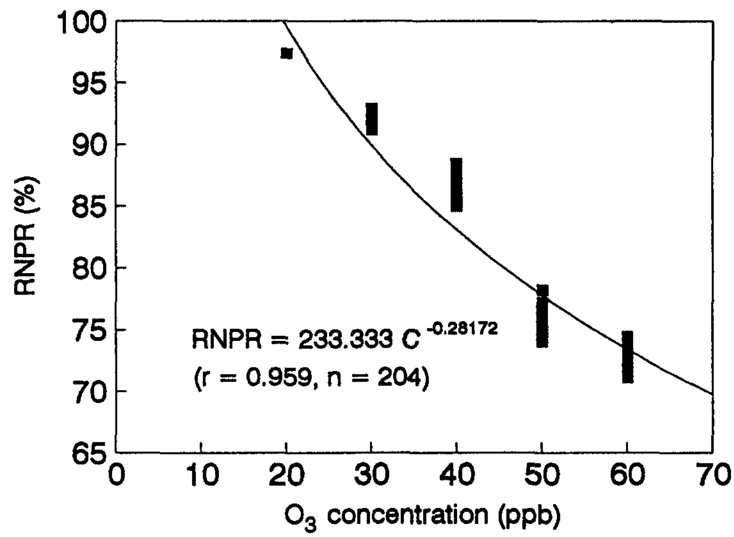

Fig. 2. Relative net photosynthetic rate of *Q. mongolica* leaves dependent upon O_3 concentration for all data of over 60 min.

Table 1. Inhibition coefficient (b_t) of P_n of *Q. mongolica* leaves with fumigation time under each O_3 concentration fumigated. b_t represents the inhibition coefficient of P_n derived from the relationship between O_3 fumigation time and $P_{O3(t)}$ ($P_{O3(t)} = at^{-b_t}$). r is correlation coefficient. t ranges from 0 to 120 min.

O_3 concentration (ppb)	b_t	r
0	0.00000	–
20	0.01195	0.903***
30	0.02972	0.955***
40	0.04375	0.963***
50	0.09334	0.987***
60	0.09722	0.991***

*** $P \leq 0.001$

The foregoing results showed that the relationship between P_n of the leaves and O_3 concentration fumigated was well fitted by logarithmic function. Heck *et al.* (1966) already found out that the relationship between leaf injury and dose of O_3 concentration fumigated for a short period of time, i.e. the product of concentration and time, was nonlinear. This relationship was developed as a model using logarithmic scales (Larson and Heck 1976, Nouchi and Aoki 1979). Dose-effect relation between O_3 concentration and yield of crops fumigated with O_3 during the growing season was estimated using nonlinear Webull model (Somerville *et al.* 1990). However, growth of plant organ fumigated with O_3 for a long-term was reduced linearly (Reich and Lossoie 1985, Reich and Amundson 1984).

Table 2. Inhibition coefficient of P_n of *Q. mongolica* leaves (b_c) with different O_3 concentration fumigated for each fumigation period of time. b_c represents the inhibition coefficient of photosynthesis derived from relationship between $P_{O3(C)}$ and O_3 concentration ($P_{O3(C)} = aC^{-b_c}$). r is correlation coefficient.

Fumigation time (min)	b_c	r	Fumigation time (min)	b_c	r
0	0.0000	–	100	0.2668	0.955***
10	0.0428	0.655$^{n.s.}$	110	0.2779	0.945***
20	0.1000	0.927***	120	0.2790	0.950***
30	0.1317	0.972***	130	0.2736	0.947***
40	0.1551	0.983***	140	0.2670	0.946***
50	0.1867	0.954***	150	0.2686	0.952***
60	0.2145	0.940***	160	0.2725	0.968***
70	0.2414	0.948***	170	0.2713	0.961***
80	0.2606	0.940***	180	0.2595	0.959***
90	0.2636	0.969***			

$^{n.s.}$ not significant *** $P \leq 0.001$

P_n dependent upon PPFD or air temperature under different O_3 concentrations

The P_n of *Q. mongolica* leaves ($P_{O3(Q)}$) with increasing photosynthetic photon flux density (PPFD) (mmol $m^{-2}s^{-1}$) as shown in Fig. 3 was fitted by the equation of Tenhunen *et al.* (1976) (Eq. (3)) :

$$P_{n(Q)} = \frac{\alpha \, \mathrm{PPFD} \, P_{ml}}{P_{ml}{}^2 + (\alpha \, \mathrm{PPFD})^2} \quad \cdots\cdots (3)$$

where P_{ml} (=20.272) (mg CO_2 $dm^{-2}hr^{-1}$) is P_n under saturated PPFD and α (=35.655) is initial slope of Pn response to PPFD (mg /mmol).

The relationship of P_n ($P_{n(T)}$, mg CO_2 $dm^{-2}hr^{-1}$) of *Q. mongolica* leaves to air temperature (T) under saturated PPFD as shown in Fig. 4 was fitted by the equation of quadratic function (Suh 1992):

$$P_{n(T)} = -24.9296 + 3.0705\,T - 0.0522\,T^2 \quad \cdots\cdots (4)$$

The b_c increased rapidly until 60 min and thereafter was kept almost constant (Table 2). Thus, we fitted the relationship between $P_{O3(C)}$ and O_3 concentration fumigated to the following equation using all the data of over 60 min instead of Eq. (2) (Fig. 2):

$$P_{O3(C)} = \frac{P_{O3(fc)}}{P_O} = 233.33\,C^{-0.28172} \quad \cdots\cdots (5)$$

Therefore, under the optimum temprature or the saturated PPFD, P_n dependent upon PPFD (P (Q, C)) or P_n dependent upon temperature (P (T, C)) under different O_3 concentrations can be estimated by the following equations:

$$P\ (Q, C) = P_{n(Q)}\ P_{O3(C)} \qquad (6)$$

$$P\ (T, C) = P_{n(T)}\ P_{O3(C)} \qquad (7)$$

The P_n of *Q. mongolica* leaves to PPFD under different O_3 concentrations was depicted by Eq. (6) (Fig. 3). The maximum P_n of the leaves at saturated PPFD was 19.9, 17.8, 16.5, 15.4, and 14.7 mg CO_2 $dm^{-2}hr^{-1}$ (100: 90: 83: 78: 74) under 0, 30, 40, 50 and 60 ppb O_3 fumigation, respectively. The maximum P_n of *Q. mongolica* leaves without O_3 fumigation was less than those of *Q. lobata* (26.6 mg CO_2 $dm^{-2}hr^{-1}$) (Hollinger 1992), and poplar species (22~38 mg CO_2 $dm^{-2}hr^{-1}$) under the saturated irradiance at 25℃ (Roden and Pearcy 1993).

The P_n of *Q. mongolica* leaves to air temperature was depicted under different O_3 concentration by Eq. (7) (Fig. 4). The optimum temperature for P_n of *Q. mongolica* leaves was 30℃ and was lower than those of *Q. rubra* (23℃) (Jurik *et al.* 1988), *Q. pubescens* (24℃) and evergreen *Q. glauca* (26℃) (Larcher 1969).

The P_n of *Q. mongolica* leaves at the optimum temperature was 20.2, 18.1, 16.7, 15.7 and 14.9 mg CO_2 $dm^{-2}hr^{-1}$ under 0, 30, 40, 50 and 60 ppb O_3 fumigation, respectively. Carbon dioxide uptake of vegetative bean shoots with 80~350 ppb O_3 fumigation was progressively reduced (Moldau *et al.* 1991). One ppm O_3 for the short-term fumigation (2~8hr) brought about the visible leaf injury, which was recovered 1 month later (Jensen and

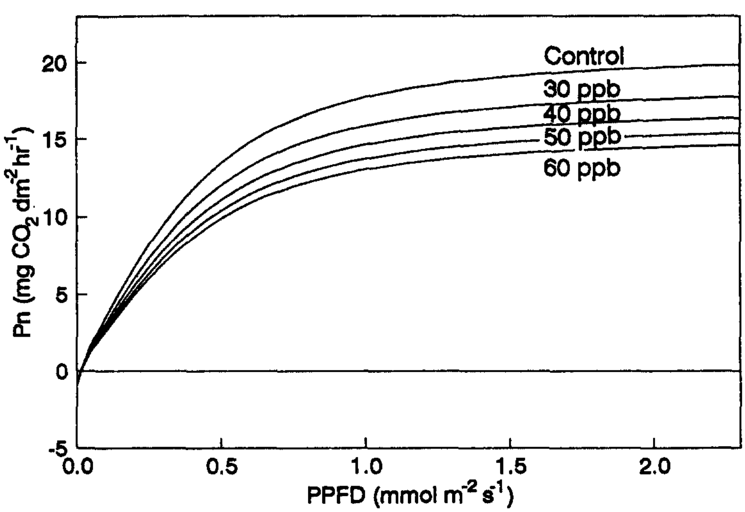

Fig. 3. P_n of *Q. mongolica* leaves dependent upon PPFD under different O_3 concentrations.

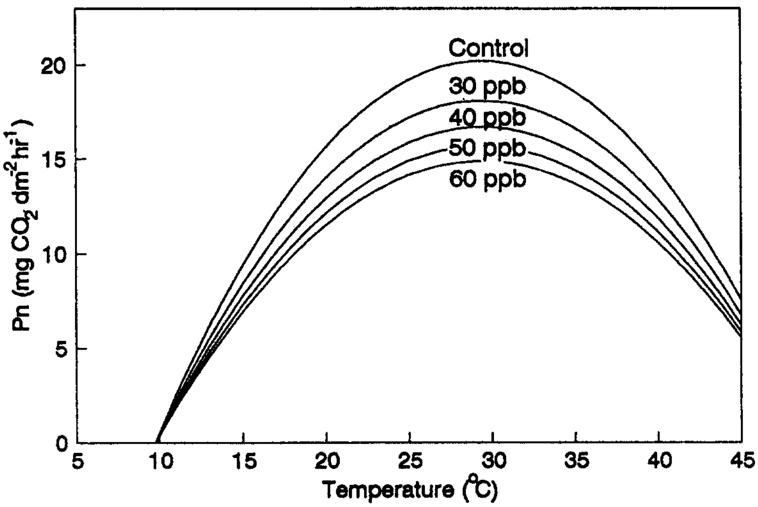

Fig. 4. P_n of *Q. mongolica* leaves dependent upon temperature under different O_3 concentrations.

Dochinger 1974). In the case of *Q. mongolica* leaves, while 60 ppb O_3 fumigation for the short-term (7hr) did not bring about the visible leaf injury, only P_n was reduced and recovered by next day.

적 요

신갈나무 잎에 0, 20, 30, 40, 50 및 60 ppb O_3 농도로 각각 7 시간씩 2회 노출하면서 매 10분마다 순광합성률을 측정하였다. O_3 노출농도와 노출시간에 따른 순광합성률의 감소율이 대수함수식으로 적합되었다. 여러 O_3 농도의 폭로 실험에서 시간이 경과함에 따라 잎의 상대순광합성률 (RNPR)은 O_3 처리 초기에 감소하다가 1 시간 이후부터 일정한 수준을 유지하였다. 한편 60 ppb O_3 농도에서 가장 낮은 RNPR 값은 O_3 비폭로 잎의 RNPR의 30% 수준이었다. RNPR은 20 ppb O_3 이하에서는 감소하지 않았지만 이상에서는 급속히 감소되었다. 본 연구 결과는 단기간·저농도의 O_3 폭로로 신갈나무 잎의 순광합성률이 감소됨을 보였다.

ACKNOWLEDGEMENTS

We express our thanks to Mr. J.K. Hwangbo in Dept. of Biology, SNU and Prof. C.S. Lee in Dept. of Biology, Seoul Women's Univ. for their help in O_3 fumigation experiment. Thanks are also due to two anonymous reviewers for their constructive comments on this manuscript.

LITERATURE CITED

Furukawa, A. 1991. Inhibition of photosynthesis of *Populus euramericana* and *Helianthus annuus* by SO_2, NO_2 and O_3. Ecol. Res. 6: 79-86.

Heck, W.W. 1968. Factors influencing expression of oxidant damage to plants. Ann. Rev. Phytopathol. 6: 165-188.

Heck, W.W., J.A. Dunning and I.J. Hindawi. 1966. Ozone: non-linear relation of dose and injury in plants. Science 151: 577-578.

Hollinger, D.Y. 1992. Leaf and simulated whole-canopy photosynthesis in two co-occurring tree species. Ecology 73: 1-14.

Jensen, K.F. and J.M. Skelly. 1982. Response of several eastern forest tree species to chronic doses of ozone and nitrogen dioxide. Plant Disease 66: 1149-1152.

Jurik, T.W., J.A. Weber and D.M. Gates. 1988. Effects of temperature and light on photosynthesis of dominant species of a northern hardwood stands. Bot. Gaz. 149: 203-208.

Kim, J.W. 1995. Ecophysiological responses of *Quercus mongolica* stands to air pollutants and a model for its productivity affected by ambient ozone. Ph.D. Thesis. Seoul National Univ., Seoul, 136p.

Korean Ministry of Environment. 1993. Environmental White Paper. Korean Ministry of Environment. 395p.

Lange, O.L., H. Zellner, J. Gebel, P. Schramel, B. Köstner and F.-C. Czygan. 1987. Photosynthetic capacity,chloroplast pigments, and mineral content of the previous year's spruce needles with and without the new flush: analysis of the stands-decline phenomenon of needle bleaching. Oecologia 73: 351-357.

Larcher, W. 1969. The effect of environmental and physiological variables on the carbon dioxide gas exchange of trees. Photosynthetica 3: 167-198.

Larson, R.I. and W.W. Heck. 1976. An air quality data analysis system for interrelating effects, standards and needed source reductions. Part 3. Vegetation injury. J. Air Pollut. Control Assoc. 26: 325-333.

Lee, W.S. 1993. Gas exchange rates and ascorbate and glutathione concentrations of *Pinus strobus* needles exposed to ambient ozone. Korean J. Ecol. 16:397-408.

Lee, W.S., B.I. Chevone and J.R. Seiler. 1990. Growth response and drought susceptibility of red spruce seedlings exposed to simulated acidic rain and ozone. For. Sci. 36: 265-275.

Lehnherr, B., A. Grandjean, F. Mächler and J. Furher. 1987. The effect of ozone in ambient air on ribulose biphosphate carboxylase/oxygenase activity decreases photosynthesis and grain yield of wheat. J. Plant Physiol. 130: 189-200.

Moldau, H., J. Sõber, A. Karolin and A. Kallis. 1991. CO_2 uptake and respiration losses in vegetative bean plants due to ozone absorption. Photosynthetica 25: 341-349.

Nouchi, I. and K. Aoki. 1979. Morning glory as a photochemical oxidant indicator. Environ. Pollut. 18: 289-303.

Olszyk, D.M. and T.W. Tibbitts. 1981. Stomatal response and leaf injury of *Pisum sativum* L. with SO_2 and O_3 exposures 1. Influence of pollutant level and leaf maturity. Plant Physiol. 67: 539-544.

Pell, E.J. 1987. Ozone toxicity - is there more than one mechanism of action ? *In* T.C. Hutchinson and K.M. Meema. (eds.), Effects of Atmospheric Pollutants on Forests, Wetlands and Agricultural Ecosystems. Nato ASI Series Vol. G16., Springer-Verlag, Berlin, Heidelberg. pp. 229-240.

Reich, P.B. and J.P. Lassoie. 1985. Influence of low concentrations of ozone on growth, biomass partitioning and leaf senescence in young hybrid poplar plants. Environ. Pollut. Ser. A. 39: 39-51.

Reich, P.B. and R.G. Amundson. 1984. Low level O_3 and/or SO_2 exposure causes a linear decline in soybean yield. Environ. Pollut. Ser. A. 34: 345-355.

Reich, P.B., J.P. Lassoie and R.G. Amundson. 1984. Reduction in growth of hybrid poplar following field exposure to low levels of O_3 and (or) SO_2. Can. J. Bot. 62: 2835-2841.

Roden, J.S. and R.W. Pearcy. 1993. Photosynthetic gas exchange response of poplars to steady-state and dynamic light environments. Oecologia 93: 208-214.

Somerville, M.C., K.A. Dassel and J.O. Rawlings. 1990. Adequacy of interval estimates of yield responses to ozone estimated from NCLAN data. Crop Sci. 30: 836-844.

Suh, K.H. 1992. Carbon dioxide budget in oriental arborvitae (*Thuja orientalis*) population. Ph.D. Thesis. Seoul National Univ., Seoul, 106pp.

Swank, W.T. and J.M. Vose. 1990/1991. Watershed-scale responses to ozone events in a *Pinus strobus* L. plantation. Water, Air, and Soil Pollution 54: 119-133.

Tenhunen, J.D., O.L. Lange, P.C. Harley, W. Beyschlag and A. Meyer. 1985. Limitations due to water stress on leaf net photosynthesis of *Quercus coccifera* in the Portuguese evergreen scrub. Oecologia 67: 23-30.

(Received 6 May, 1995)