ARBORETUM KÓRNICKIE
ROCZNIK XXXI – 1986

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Some effects of exposure to sulphur dioxide on the metabolism of Scots pine in the winter. I. Effects on photosynthesis and respiration*

Abstract

Lorenc-Plucińska G. 1986. Some effects of exposure to sulphur dioxide on the metabolism of Scots pine in the winter. I. Effects on photosynthesis and respiration. Arbor. Kórnickie 31: 229 - 236.

The rates of carbon dioxide exchange were studied during winter depression and emergence from it in shoots of three Scots pine clones, a SO_2-tolerant one, a SO_2-relatively tolerant one and a SO_2-susceptible one, following exposure to 1.0 ppm SO_2 for 1, 2, or 3 days 6h a day. The CO_2 exchange rates were measured using an infra-red CO_2 analyser. The rates of photosynthesis (P_N) and photorespiration (R_L) were inhibited by SO_2 much more in the susceptible clone than in the tolerant one over a 55 h period following transfer from natural winter (January) conditions into the laboratory. On the other hand dark respiration rate (R_D) was either stimulated or inhibited by SO_2 depending on the duration of warm conditions and fumigation with SO_2.

Additional key words: carbon dioxide exchange, fumigation, winter depression

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INTRODUCTION

It is generally believed that coniferous trees are most sensitive to SO_2 in late spring and in early summer. However there are also reports indicating that the joint action of low winter temperatures and air-borne pollutants may cause more serious damage (Börtitz 1968, Huttunen 1973, Keller 1978). According to Huttunen (1979) in December and January one observes the highest concentrations of sulphur in the atmosphere. It is at that time that first injuries to leaves are inflicted and they become visible as late as March-April when the weather warms up. Börtitz (1968) has shown that SO_2 absorbed by pine and spruce needles during the winter causes many "physiological injuries" such as reduction of CO_2 assimilation later during warmer conditions and a consequent lowering of biomass production.

* This study was performed under the MR II/16 program coordinated by the Institute of Dendrology of the Polish Academy of Sciences.

Abbreviations: P_N rate of net photosynthesis, D_R rate of dark respiration, R_L rate of photorespiration

In the present paper the effect is compared of various durations of fumigation during the winter with 1.0 ppm of SO_2 on the P_N, R_L and R_D in needles of pine clones differing in sensitivity to this gas. The changes in $^{14}CO_2$ assimilation and the distribution of ^{14}C among the first products of photosynthesis will be reported later. The aim of these investigations was to study the mechanisms of injuries caused by SO_2 during winter depression of photosynthesis and during emergence from it on the arrival of warmer spring temperatures. The studies were conducted in January on detached shoots rapidly transferred from the outside into laboratory conditions.

MATERIAL AND METHODS

The experimental material consisted of current year shoots, i.e. grown during the preceding summer. The shoots were taken from three Scots pine (*Pinus sylvestris* L.) clones aged 18 years differing in susceptibility to SO_2. These clones are designated in the Institute of Dendrology by the symbols K-08-02 (tolerant of SO_2 – T), PSI-6 (relatively tolerant – I) and K-01-16 (susceptible – S). Their degree of sensitivity has been determined earlier (Lorenc-Plucińska 1978, 1982). Shoots were collected from the trees in the first days of January when air temperature was +5°C after a thaw. The shoots were exposed to sulphur dioxide at a concentration of 1.0 ppm for 1, 2 and 3 days, 6 h a day by the method described by Karolewski and Białobok (1979). The controls were similarily collected shoots left in an atmosphere free of SO_2. Air flow rate (15 m^3h^{-1}) temperature (18-20°C), relative humidity (60-70%) and irradiance (240 Wm^{-2}) were kept constant during the fumigation. The exchange of CO_2 has been measured directly after each 6 hours of fumigation. An IRGA (Infralyt III, Junkalor) in a closed-circuit system was used. The CO_2 exchange rate was measured in one cycle of light and darkness. P_N, R_L and R_D were determined as described earlier (Lorenc-Plucińska 1978). Light intensity, temperature and humidity were the same as during fumigation but the air flow rate was 0.18 m^3h^{-1}. The data presented below are average values based on 10 shoots.

RESULTS

Regardless of the degree of SO_2 sensitivity of the three studied clones of pine P_N in the needles increased during the 55 consecutive hours after the shoots have been transferred to the laboratory from natural conditions (Fig. 1). The increase was greatest during the first 7 h. Throughout the duration of the experiment P_N was greater in tolerant clones relative to the remainder.

Also R_L increased towards the end of the experiments (Fig. 1). On the other hand R_D attained highest values in the first hour after transfer of shoots from the field into the laboratory and this was followed by a declining tendency over the successive hours (Fig. 1). Directly after detaching the shoots R_D in needles was almost twice as large as R_L and 1.5 to 2.0 times as large as P_N. It needs to be stressed that in the

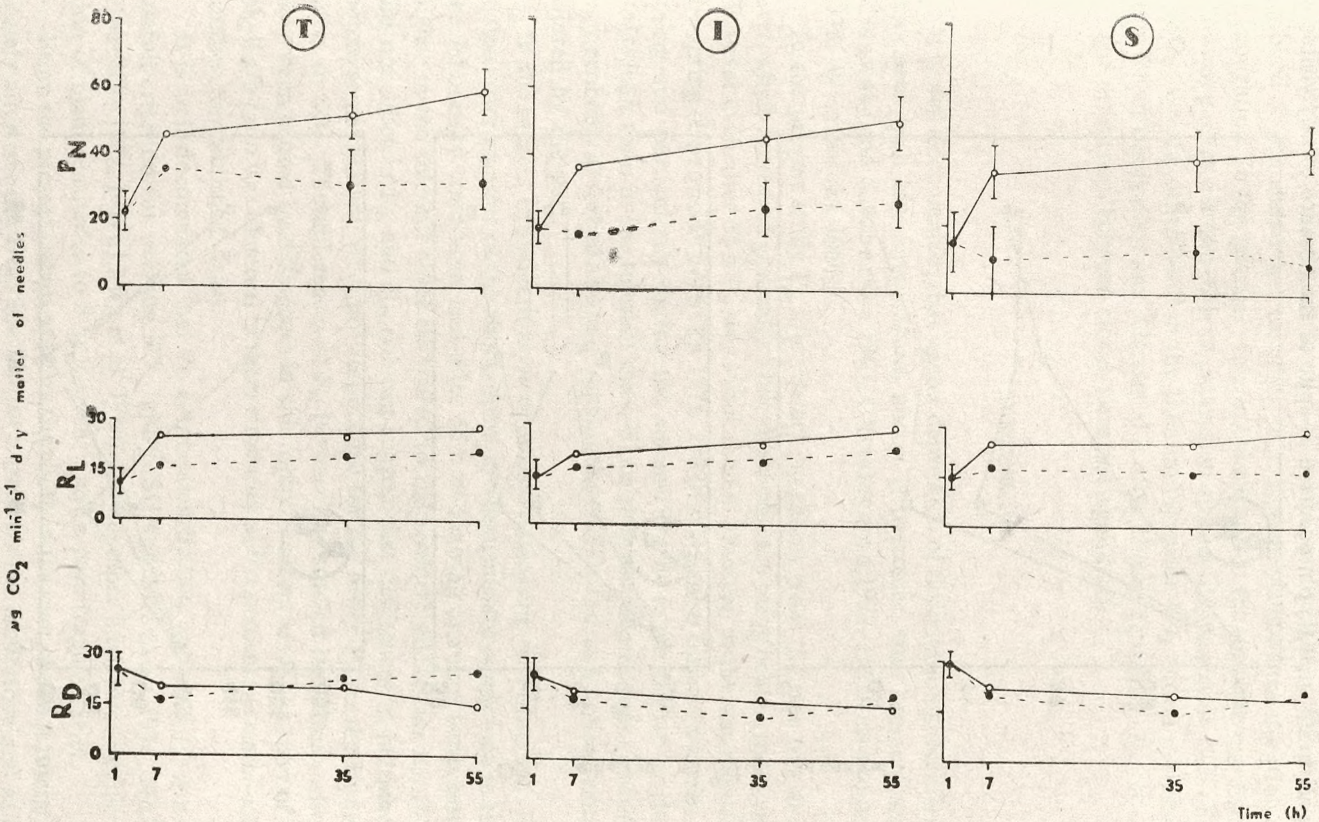

Fig. 1. Rates net photosynthesis (P_N), photorespiration (R_L) and dark respiration (R_D) of pine needles over a 55 h period after transfer of shoots to the laboratory from natural winter (January) conditions. ○ – controls, ● – after fumigation with 1.0 ppm SO_2, T – clone tolerant to SO_2, I – clone relatively tolerant to SO_2, S – SO_2 sensitive clone. Bars indicate one standard deviation.

non-fumigated conditions no differences were found between the pine clones in R_L and R_D levels.

The significant changes in the rate of CO_2 exchange after 6, 12 or 18 hours of fumigation with SO_2 at 1.0 ppm occurred in spite of the absence of any visible in-

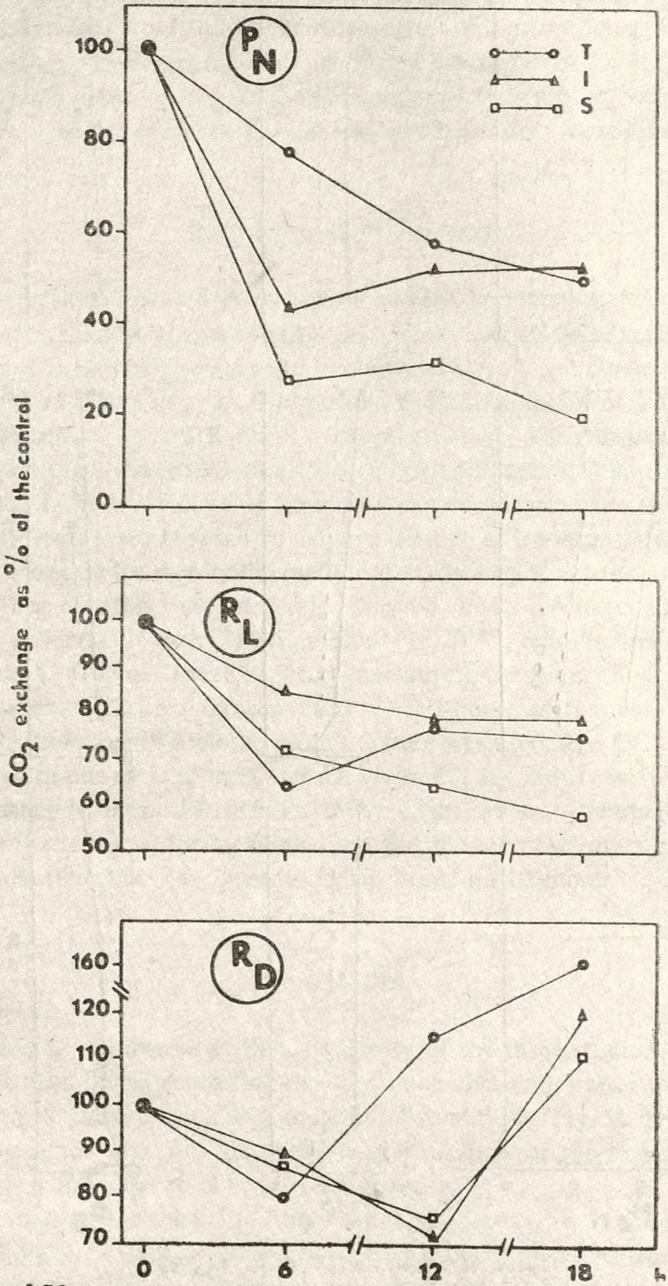

Fig. 2. Effect of SO_2 on the rates of net photosynthesis (P_N), photorespiration (R_L) and dark respiration (R_D) in pine needles after 6, 12 and 18 h of fumigation with SO_2 in January, comparing tolerant (T) relatively tolerant (I) and sensitive (S) clones.

juries to needles. Both P_N and R_L were inhibited (Fig. 2) the more so the longer was the fumigation. Inhibition of P_N and R_L was strongest in the SO_2 sensitive clone.

In contrast to the processes of CO_2 exchange in light, sulphur dioxide either inhibited or stimulated the rate of R_D (Fig. 2), depending on the duration of the time of fumigation. In the relatively tolerant clone and in the sensitive one R_D underwent a lowering after 6 h and 12 h of exposition and an increase after 18 h of exposition to SO_2. On the other hand in the tolerant clone the SO_2 action inhibited R_D only after 6 h of fumigation and stimulated it after 12 and 18 h (Fig. 2).

The differences between clones were not significant.

DISCUSSION

It is well documented, that winter depression of assimilation in coniferous trees is associated with low temperatures and it is overcome after temperature increases (Żelawski and Kucharska 1967, Christersson 1972, Hashimoto and Suzuki 1978, Wierzbicki 1980).

In the present study P_N after detaching shoots from the tree was at a very low level, which increased gradually while the shoots are being held at room temperature. However even after 55 h P_N was lower than is observed in the same material during the spring (Lorenc-Plucińska 1978, 1982). It was also observed earlier that in the spring and particularily during the summer P_N is much higher in the sensitive individuals than in the tolerant ones. Since they assimilate large quantities of CO_2 they probably absorbed also larger quantities of SO_2 and as a consequence are more injured by the gas.

In the present investigations as opposite relationship was observed. Both immediately after transfer of the shoots from low temperature conditions in the forest to the laboratory conditions and after 55 h of thawing at room temperature P_N was higher in the tolerant clone compared to the sensitive one. Since the studied pines did not differ in R_L and R_D one can suggest that differences in mitochondrial and peroxysomal activity were not responsible for the lower P_N in the clone more sensitive to SO_2. The differences in P_N between the studied individuals also could not have been caused by differences in chlorophyll content since the level of the chlorophyll a/b ratio was identical in them similarity as the percentage water content in the needles (unpublished data).

It is well documented that P_N is inhibited by SO_2 and that P_N is a potentially usefull criterion for defining SO_2 injury (Sij and Swanson 1974, Hällgren and Gezelius 1978, Furukawa et al. 1980). On the other hand intraspecific differentiation of plant sensitivity to SO_2 is so far known only fragmentarily.

From the present data it appears that both in the case of shoot fumigation immediately after transfer from low temperatures into the laboratory and as duration of warm conditions as well as the time of fumigation are extended, SO_2 causes an increase in the extent of injuries to the process of CO_2 exchange in sensitive clones compared to the more SO_2 tolerant clones. To summarize, in the more tolerant individuals, SO_2 lowers P_N and R_L. However as the duration of warm conditions is extended, (in spite of the longer fumigation) the inhibition of CO_2 exchange in light is lowered and this is coupled with an increase in R_D. The stimulation of R_D may be a consequence of a higher energy need to compensate losses and to regenerate injuries. Le Blanc and Rao (1975) suspect that the energy produced as a consequence of increased respiration is being used by the plants for a rapid oxidation of SO_3^{-2} to SO_4^{-2}. In this connection it should be mentioned that sulphate ions are about 30 times less toxic than the sulphite ones (Thomas and Hendricks 1956) and the increased R_D may be a defence reaction of the organism against SO_2.

On the other hand in the sensitive individuals, SO_2 causes a greater inhibition of P_N and R_L during the winter, which deepens with time of exposition to warmer temperatures and to fumigation. At the same time changes in R_D are not significant which excludes the potential existence of a defence reaction to SO_2 injury as suggested above. Since P_N in unfumigated controls was also lower in the sensitive individual compared to the tolerant individual one can suggest that the higher sensitivity of the former is caused by a lower activity of chloroplasts and photosynthetic enzymes or by their decline under the influence of SO_2.

I wish to thank Dr. P. Karolewski fo r his help with the SO_2 fumigation of plants and laboratory assistants U. Fober and U. Chrabąszcz for technical help.

SUMMARY

The rates of carbon dioxide exchange were studied during winter depression and emergence from it in shoots of three Scots pine clones, a SO_2-tolerant one, a SO_2-relatively tolerant one and a SO_2-susceptible one, following exposure to 1.0 ppm SO_2 for 1, 2 or 3 days, 6 h a day. The CO_2 exchange rates were measured using an infra-red CO_2 analyser. The rates of photosynthesis (P_N) and photorespiration (R_L) were inhibited by SO_2 much more in the susceptible clone than in tolerant one over a 55 h period following transfer from natural winter (January) conditions into the laboratory. On the other hand dark respiration rate (R_D) was either stimulated or inhibited by SO_2 depending on the duration of warm conditions and fumigation with SO_2.

Accepted for publication 1985

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Wpływ SO_2 na metabolizm sosny zwyczajnej podczas zimy. I. Wpływ na fotosyntezę i oddychanie

Streszczenie

Badano wpływ SO_2 w stężeniu 1,0 ppm podczas zimy (styczeń) na wymianę CO_2 odciętych pędów trzech klonów sosny zwyczajnej różniących się wrażliwością na ten gaz. Ekspozycję na dwutlenek siarki przeprowadzono 1, 2 lub 3 dni po 6 godz. dziennie. Natężenie wymiany CO_2 oznaczano za pomocą gazowego analizatora CO_2 w podczerwieni. Wykazano, że działanie SO_2 hamuje natężenie fotosyntezy netto (P_N) i fotooddychania (R_L) silniej w klonie wrażliwym w porównaniu z klonem o względnej wrażliwości i tolerancyjnym podczas pierwszych 55 godz. od przeniesienia odciętych pędów sosny ze środowiska zewnętrznego (+5°C) do laboratorium (+20°C). Z drugiej jednak strony, natężenie oddychania ciemniowego (R_D) było wzmagane lub obniżane przez SO_2 w zależności od czasu przetrzymywania pędów w temperaturze pokojowej i czasu oddziaływania gazu.

ГАБРИЕЛЯ ЛОРЕНЦ-ПЛЮЦИНЬСКА

Влияние SO_2 на метаболизм углерода сосны обыкновенной в зимний период. 1. Влияние на фотосинтез и дыхание

Резюме

Исследовали влияние SO_2 в концентрации 1.0 частей/млн в зимний период (январь) на обмен CO_2 у отрезанных ветвей трех клонов сосны обыкновенной отличающихся чувствительностью по отношению к этому газу. Газацию сернистым ангидридом проводили 1, 2 или 3 дня по 6 часов в день. Интенсивность обмена CO_2 определяли с помощью инфракрасного газоанализатора CO_2. Было доказано, что SO_2 тормозит нетто фотосинтез (P_N) и фотодыхание (R_L) более значительно у чувствительного клона, нежели у относительно толерантного и толерантного, в течение первых 55 часов после перенесения срезанных побегов сосны из внешней среды (+5°C) в лабораторию (+20°C). Однако, с другой стороны, интенсивность темнового дыхания (R_D) стиммулировалась или уменьшалась SO_2 в зависимости от периода содержания побегов в комнатной температуре и времени воздействия газа.