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The effect of ozone on photosynthesis and respiration in Scots pines differing in resistance to this gas*

1. INTRODUCTION

One of the physiological effects of the action of ozone on higher plants is that the processes of CO_2 exchange are altered. These changes depend on the concentration and duration of action of the gas (Dugger and Ting, 1970; Rich, 1964). Ozone reduces the intensity of photosynthesis (Barnes, 1972; Botkin et al., 1972; Furukawa and Kadota, 1975; Hill and Littlefield, 1969; Miller and Parmeter, 1967; Stolzy et al., 1964; Ziegler, 1973) and stimulates or reduces the dark respiration (Erickson and Wedding, 1956; Konig and Jegier, 1968; Todd, 1958).

Hill and Littlefield (1969) suggest that as a result of the action of ozone stomata close which causes a reduction in photosynthesis. Furukawa and Kadota (1975) further indicate that ozone may directly affect the light and dark reactions of photosynthesis. Coulson and Heath (1974) claim that ozone inhibits photophosphorylation.

In experiments with *Pinus elliottii, P. serotina, P. strobus* and *P. taeda* Barnes (1972) found that exposition of seedlings to ozone at a concentration of 5 and 15 pphm for a period of 5 - 18 weeks has caused a reduction in photosynthesis and a stimulation of dark respiration, these changes being greater with the higher (15 pphm O_3) concentration and longer period of fumigation.

Miller et al. (1969) reports that the treatment of seedlings of *Pinus ponderosa* with ozone at a concentration of 15, 30 or 45 pphm for three days inhibited the intensity of net photosynthesis by 10, 70, and 80% respectively.

Treating with ozone at a concentration of 50 pphm for 4 hours individuals of *Pinus strobus*, sensitive, medium resistant and resistant to this gas Botkin et al. (1972) have observed a progressively greater

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inhibition of net photosynthesis the more sensitive were the individuals to this gas.

So far data is lacking on the effect of ozone on CO_2 in Scots pine (*Pinus silvestris*). Also we do not know the effect of this gas on the process of photorespiration. For this reason it was the purpose of this study to establish the effect of ozone on CO_2 exchange taking place in light, i.e. photosynthesis and photorespiration and in the darkness, i.e. dark respiration in two individuals of Scots pine differing in the degree of resistance to this gas. These studies were conducted over four seasons of the year.

2. MATERIALS AND METHODS

For the experiment one year old shoots were used from two individuals (grafts) of Scots pine, growing in a seed orchard aged about 15 years, which are known to differ from each other in their resistance to ozone. These individuals are labelled in the Institute of Dendrology as K-08-02 III (the more resistant on to ozone) and K-01-16 I (the less resistant one). They were selected on the basis of selection experiments described earlier (Lorenc-Plucińska, 1978).

2.1. MEASUREMENT OF CO_2 EXCHANGE

For the experiment each season 20 shoots were taken from individuals K-08-02 III and K-01-16 I. One year old shoots taken from the upper, non-shaded whorls of the three were treated with ozone for 3 days (6 hours daily) at a concentration of 1.0 ppm. The control consisted of similarily cut shoots left for the same three days in bottles with water in an atmosphere free of ozone. CO_2 exchange in light and in darkness has been measured directly after detaching the shoots and after 3 days either left untreated (control) or immediately after treatment with ozone. Measurements of CO_2 exchange have been made using an infra red gas analyser Infralyt III, operating in a closed system. The intensity of net photosynthesis and true photosynthesis, photorespiration and dark respiration have been determined according to the formulae given earlier (Lorenc-Plucińska, 1978). Measurements of CO_2 exchange have been performed in the following seasons:

October - November — autumn
January - February — winter
April - May — spring
July - August — summer

The results obtained have been verified statistically using the variance analysis and the Scheffe's tests of multiple contrasts (Oktaba, 1972).

Table 1

CO_2 exchange in light and in darkness. Net photosynthesis (NPS), photorespiration (PR), true photosynthesis (TPS) and dark respiration (DR) in detached shoots of Scots pine subjected to the action of ozone at 1.0 ppm for 3 days 6 hours daily. K-08-02 III is the more resistant individual and K-01-16 I is the lese resistant individual

		Autumn								Winter								Spring								Summer							
		µg CO_2/g dry wt. needls/min								µg CO_2/g dry wt. needls/min								µg CO_2/g dry wt. needls/min								µg/CO_2/g dry wt. needls/min							
		TPS		NPS		PR		DR		TPS		NPS		PR		DR		TPS		NPS		PR		DR		TPS		NPS		PR		DR	
		C	O_3	C	O_3	C	O_3	C	O_3	C	O_3	C	O_3	C	O_3	C	O_3	C	O_3	C	O_3	C	O_3	C	O_3	C	O_3	C	O_3	C	O_3	C	O_3
K-08-02 III	$\bar{x}$	97	92	59	56	32	29	22	20	61	102	27	42	30	53	21	28	100	84	61	51	29	24	16	14	99	69	71	48	19	17	13	25
	α_1									××		××															×		×				××
K-01-16 I	$\bar{x}$	105	70	64	38	39	28	22	22	69	85	27	26	40	57	25	19	86	88	54	53	23	25	18	16	149	78	95	49	41	19	18	15
	α_1		××		××		×																				××		××		××		
	α_2																										××		×		××		
	α_3		××		××								××														××		××		×		××

α_1 – minimal level of significance at which the null hypothesis about lack of differences between the control and the fumigated material is rejected.
α_2 – minimal level of significance at which the null hypothesis about lack of differences between the controls of both individuals is rejected.
α_3 – minimal level of significance at which the null hypothesis about the absence of interaction between treatments and individuals is rejected.
×× – $\alpha = 0.01$.
× – $\alpha = 0.05$.
C – control
O_3 – ozone treated

The null hypothesis H_o that there are no differences between the different elements of the experiment was verified at the $\alpha=0.05$ level of significance.

3. RESULTS

As can be seen from Table 1 treatment of detached pine shoots with ozone affects the intensity of processes of CO_2 exchange. Changes in these processes depend on the season in which the detached shoots were treated with ozone and on the degree of resistance of trees to this gas.

In the more resistant individual (K-08-02 III) fumigation with 1.0 ppm of ozone for 3 days (6 hours daily) significantly lowered in the summer and increased in the winter the intensity of net and true photosynthesis and stimulates the intensity of dark respiration in the summer (Tab. 1 α_1). In the other seaons changes in these processes were slight. Photorespiration is little affected by the treatments throughout the year.

A similar treatment of detached shoots of the less resistant individual (K-01-16 I) to ozone significantly lowers the intensity of net photosynthesis, photorespiration and true photosynthesis during the summer and autumn (Tab. 1 α_1). In the other seasons, i.e. in the spring and winter, and in the case of dark respiration throughout the year ozone does not affect these process significantly.

It needs to be pointed out that non-fumigated shoots of the two individuals differing in resistance to ozone differ also in the intensity of CO_2 exchange processes in light i.e. photorespiration, net and true photosynthesis (Tab. 1 α_2), but only in the summer. At that time the intensity of these processes is higher in the individual less resistant to ozone.

4. DISCUSSION

The results presented indicate that ozone has a substancial influence on the intensity of CO_2 exchange in light and in darkness by detached Scots pine shoots. The extent of injuries to the CO_2 exchange system are different depending on the degree of resistance of individuals to this gas and on the season when the shoots were treated with the gas. This latter relationship appears to be associated with the age of the shoots, both calendar and physiological. Ozone at a concentration of 1.0 ppm inhibited the intensity of net photosynthesis and of true photosynthesis in both the individuals least in the spring and most intensively in the summer. The great sensitivity of the individuals to ozone during the summer appears to be associated with the physiological activity of photosynthesis in that part of the season. A maximum of photosynthesis in

Scots pine occurs in August or even in June (Żelawski and Góral, 1966), depending on the weather. Besides the shoots of Scots pine used in the summer were shoots of the current season formed in the spring and therefore they were the youngest and thus presumably most sensitive to ozone. On the other hand in the spring the young shoots were only beginning to form and the shoots of the previous season were becoming two-year-old ones, and thus were more resistant to ozone.

In the experiments with *Pinus elliottii*, *P. echinata*, *P. taeda*, and *P. viriginiana* fumigated with ozone at a concentration of 2.4 ppm Berry

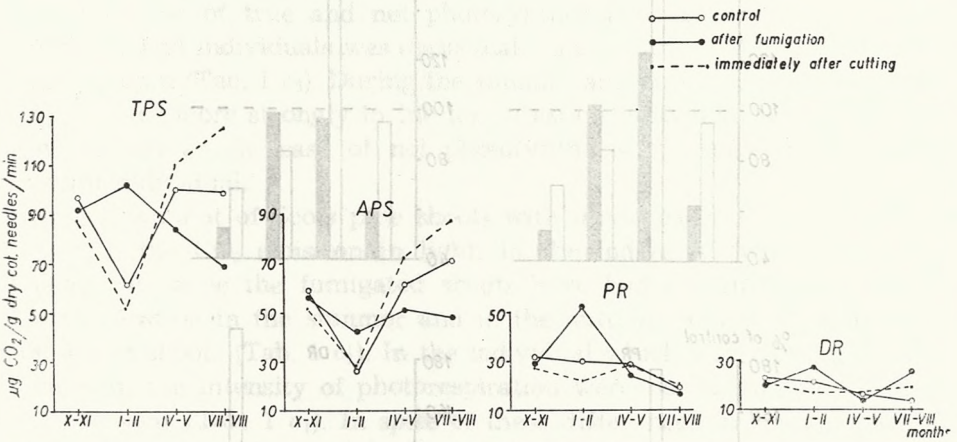

Fig. 1. CO_2 exchange in light and in darkness. Net photosynthesis (NPS), photorespiration (PR), true photosynthesis (TPS) and dark respiration (DR) of detached pine shoots from a more resistant individual of Scots pine, subjected to the action of ozone at 1.0 ppm for 3 days 6 hours daily

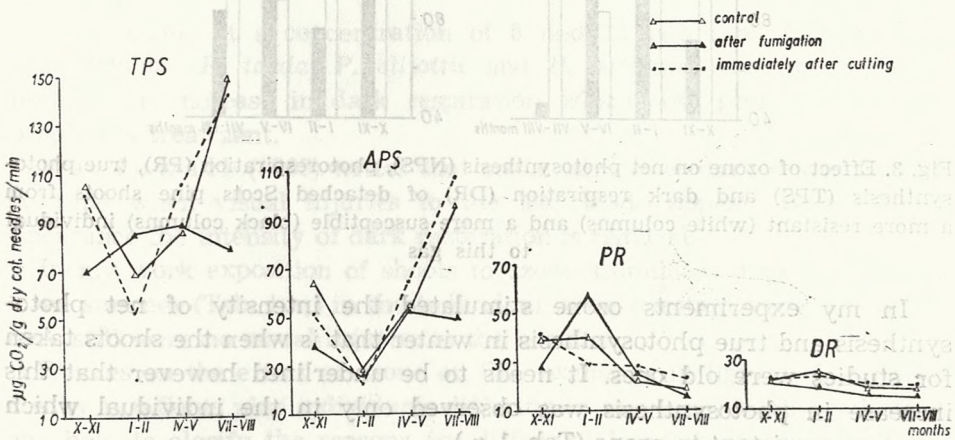

Fig. 2. CO_2 exchange in light and in darkness. Net photosynthesis (NPS), photorespiration (PR), true photosynthesis (TPS) and dark respiration (DR) of detached Scots pine shoots, from the less resistant individual, subjected to the action of ozone at 1.0 ppm for 3 days, 6 hours daily

(1974) also observed that the injuries to the plants were the greater the younger was the material.

Also Barnes (1972) when studying the effect of ozone at a concentration of 5 ppm on *Pinus elliottii*, *P. serotina* and *P. taeda* reports that ozone inhibits photosynthesis most strongly in young needles and in the oldest the reduction in assimilation is only slight or even the intensity of photosynthesis increases under the influence of this gas.

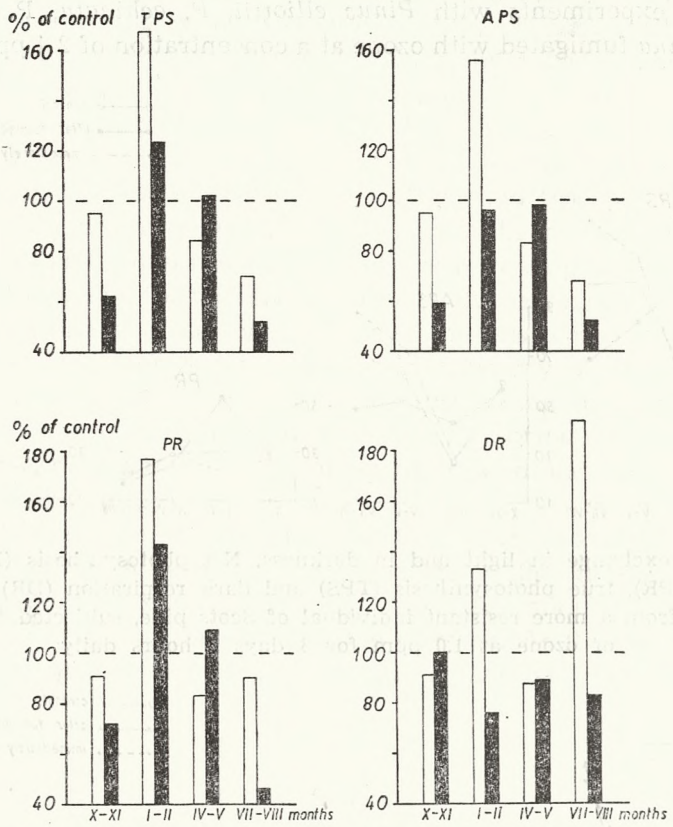

Fig. 3. Effect of ozone on net photosynthesis (NPS), photorespiration (PR), true photosynthesis (TPS) and dark respiration (DR) of detached Scots pine shoots from a more resistant (white columns) and a more susceptible (black columns) individual to this gas

In my experiments ozone stimulated the intensity of net photosynthesis and true photosynthesis in winter that is when the shoots taken for studies were old ones. It needs to be underlined however that this increase in photosynthesis was observed only in the individual which was more resistant to ozone (Tab. 1 a_1).

Acting with ozone at a concentration of 90 - 100 pphm for 8 hours on 5 year old trees of white pine *Pinus strobus* originating from regions with a high concentration of impurities in the atmosphere, Botkin et al.

(1972) have found that, that changes in photosynthesis depended on the degree of resistance of the trees to this gas. In susceptible individuals ozone has reduced photosynthesis 100%. In less sensitive individuals the reduction of photosynthesis was only of the order of 50% compared with the control. In resistant individuals ozone either did not affect the intensity of photosynthesis or stimulated it only.

In my experiments the treatment of detached shoots of Scots pine with ozone at a concentration of 1.0 ppm also caused a stronger depression of the processes of CO_2 exchange in light in the less resistant individual compared with the more resistant individual.

In the case of true and net photosynthesis the interaction between treatments and individuals was statistically significant in the summer and in the autumn (Tab. 1 α_3). During the summer and autumn ozone inhibited the processes more strongly in the less resistant individual. In the winter ozone caused an increase of net photosynthesis but only in the more resistant individual.

The treatment of Scots pine shoots with ozone bad also caused aberrations in the CO_2 emission in light. In the individual which was less resistant to ozone the fumigated shoots have had a significantly lower photorespiration in the summer and in the autumn compared with non-fumigated shoots (Tab. 1 α_1). In the individual which was more resistant, changes in the intensity of photorespiration were not significant throughout the year (Tab. 1 α_1). In spite of these differences in the changes of CO_2 emission in light in the two individuals the variance analysis has shown that the interaction between treatments and individuals is significant only in the summer (Tab. 1 α_3), and this differentiation is caused by a much higher sensitivity of photorespiration to ozone in the less resistant individual.

Using ozone at a concentration of 5 and 15 pphm on seedlings of *Pinus strobus*, *P. taeda*, *P. elliottii* and *P. serotina* Barnes (1972) observed an increase in dark respiration which was greater with the 15 pphm O_3 treatment.

Macdowall (1965) writes that ozone stimulates dark respiration at the time when visual injuries to the leaf blade appear. Before their appearance the intensity of dark respiration is reduced.

In my work exposition of shoots to ozone stimulated dark respiration in the summer (Tab. 1 α_1) in the individual more resistant to ozone. When there still were no visual injuries to the needles.

Studies on the effect of ozone on CO_2 exchange in light and in darkness by two Scots pine individuals differing in resistance to this pollutant may help to clarify the reasons for differential sensitivity of pine trees to ozone. On the basis of the results presented here it can be concluded that lower resistance to ozone is associated with greater sensitivity of photosynthesis and respiration to this gas.

SUMMARY

Studies were made on the effect of ozone acting 6 hrs a day for 3 days at a concentration of 1.0 ppm on the CO_2 exchange of detached pine shoots from a more resistant and a more susceptible individual to ozone. Net photosynthesis, photorespiration, true photosynthesis and dark respiration were estimated using an infra red CO_2 analyser. It was shown that in summer and autumn zone significantly inhibits net and true photosynthesis and photorespiration in the less resistant individual. On the other hand in the more resistant individual CO_2 assimilation is significantly reduced in the summer and increased in the winter. Changes in photorespiration were not significant throughout the year. It was shown however that ozone stimulates dark respiration during the summer in the more resistant individual.

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GABRIELA LORENC-PLUCIŃSKA

Wpływ ozonu na fotosyntezę i oddychanie sosny zwyczajnej o różnej odporności na ten gaz

Streszczenie

Badano wpływ trzydniowego działania ozonu (po 6 godzin dziennie) w stężeniu 1,0 ppm na wymianę CO_2 odciętych pędów sosny, osobnika bardziej i mniej odpornego na ten gaz. Oznaczano natężenie fotosyntezy netto, fotooddychania, fotosyntezy rzeczywistej i oddychania ciemniowego za pomocą analizatora CO_2 w podczerwieni. Wykazano, że latem i jesienią ozon istotnie hamuje natężenie fotosyntezy netto, rzeczywistej i fotooddychania u osobnika mniej odpornego na ten gaz. Natomiast u osobnika bardziej odpornego asymilacja CO_2 jest istotnie obniżana latem, a zimą zwiększana. Zmiany w fotooddychaniu są statystycznie nieistotne w ciągu całego roku. Stwierdzono, że ozon stymuluje latem oddychanie ciemniowe u osobnika bardziej odpornego na ozon.

ГАБРИЕЛЯ ЛОРЕНЦ-ПЛЮЦИНЬСКА

Влияние озона на фотосинтез, фотодыхание и темновое дыхание сосны обыкновенной, характеризующейся различной степенью устойчивости к действию этого газа

Резюме

Исследовалось влияние трехдневного действия озона (по 6 часов в день) в концентрации 2,7 мг/м³, на обмен CO_2 отрезанных побегов сосны у особей в большей и меньшей степени устойчивых к действию этого газа. Была обозначена интенсивность фотосинтеза нетто, фотодыхания, действительного фотосинтеза и темнового дыхания

с помощью инфракрасного газоанализатора CO_2. Оказалось, что летом и осенью озон существенно тормозит интенсивность действительного и нетто фотосинтезов и фотодыхания у особи менее устойчивой. У особи более устойчивой ассимиляция CO_2 существенно снижается летом, а зимой она увеличивается. Изменения в фотодыхании оказались статистически несущественными на протяжении всего года. Отмечено, что озон вызывал уменьшение интенсивности темнового дыхания у особи менее устойчивой, в то время как у особи более устойчивой, в особенности летом, этот процесс стимулировался.