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Growth Dynamics of Wheat (*Triticum aestivum* L.) Exposed to Sulfur Dioxide Pollution

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In recent years, several investigations have been conducted on the environmental effects of sulfur dioxide (SO_2), which is the most widespread air pollutant during the cold season. This is mainly due to the fact that the main sources of this pollutant are power plants and domestic heating. At present, there is general agreement on the fact that the most realistic scenario in rural areas is represented by long-term exposures of plants to relatively low or very low levels of pollution (*i.e.*, mixtures of gaseous pollutants). They may elicit both qualitative and quantitative reductions in productive performance, even in the absence of any other macroscopic symptoms in the plants.

It is known that SO_2 decreases the plant's photosynthesis and assimilate translocation (Hällgren, 1978), but little is known of the subsequent chain of events resulting in reduced yield. To follow these events, the growth of SO_2-polluted plants of four cultivars of wheat was compared with that of filtered-air plants (controls) using standard methods of growth analysis.

MATERIALS AND METHODS

Commercial seed of *Triticum aestivum* (cvs. Aurelio, Mec, Manital and Chiarano) was surface disinfested with NaOCl and put in black polyethylene containers filled with an organic compost. The number of replicate plants per treatment was 25.

Fumigations with SO_2 were carried out at the field station of San Piero a Grado (Pisa) in a set of Perspex chambers based upon the design of Farrar *et al.* (1977) and described in more detail by Lorenzini and Panattoni (1986). The chambers were placed inside a screenhouse and were exposed to normal environmental conditions, with the exception of solar radiation which was found to be reduced by 30%. Charcoal-filtered air was blown into the chambers (2.25 m^3 in vol.) in order to provide two complete air changes per minute. Seven days after emergence (February 18, 1986) the plants were transferred to the fumigation facilities, and were exposed

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continuously for 128 days to a constant concentration of 74 (± 1.9) ppb (parts x 10^{-9} in volume) SO_2 (1 ppb SO_2 = 2.67 $\mu g\ m^{-3}$ at 20°C, 101.3 kPa) or to charcoal-filtered air. The concentration of SO_2 in the test chamber was continuously sampled and monitored by a Monitor Labs 8850 automatic analyzer (Monitor Labs, San Diego, CA).

Non-destructive determinations were carried out at regular intervals and included the height of the main stem (measured from soil level to the base of the youngest leaf lamina), the number of leaves and culms and macroscopic toxicity symptoms. Sacrificial analyses were performed every three weeks and included the dry weight of the leaves, stems and roots (roots were separated from the soil by sieving and washing), leaf area (determined with a Licor LI 3000 electronic planimeter) and the weight of the air-dried kernels.

The relative growth rate (RGR), net assimilation rate (NAR), leaf area ratio (LAR), leaf weight ratio (LWR) and specific leaf area (SLA) were calculated according to the following formulae (Evans, 1972):

$$\mathrm{RGR} = (1/\underline{W})\ (dW/dt) = (\ln W_2 - \ln W_1)/(\underline{t}_2 - t_1)$$
$$\mathrm{NAR} = (1/\bar{F})\ (dW/dt) = [(W_2 - W_1)\ (\ln \bar{F}_2 - \ln \bar{F}_1)]/[(t_2 - t_1)\ (\bar{F}_2 - \bar{F}_1]$$
$$\mathrm{LAR} = \bar{F}/W$$
$$\mathrm{LWR} = F/W$$
$$\mathrm{SLA} = \bar{F}/F$$

where W_i and $\bar{F}_i$ are the dry weight of the whole plant and the leaf area at time t_i, respectively (i: 1 and 2), and F is the dry weight of the leaves.

A paired *t*-test was performed on all the data to verify the stastical significance of the differences between polluted and control plants.

RESULTS AND DISCUSSION

During the development of the plants, the only visible symptom attributable to the toxicity of SO_2 was a light foliar chlorosis which was observed only in the cv Mec plants, beginning from the third week of treatment.

The results of the last samplings are reported in Table 1. It is very evident that the four cultivars did not respond in the same way to long term exposure to the pollutant. Cv Mec plants showed significant reductions in several of the growth and yield parameters, while the other cultivars were only minimally affected. Fumigation with SO_2 reduced the yield of cv Mec plants by 33%.

The use of regular harvests, accompanied by growth analyses, permitted us to elucidate the effects of SO_2 on various growth attributes, as reported in Table 2.

Table 1. Growth parameters for the four cvs of <u>Triticum aestivum</u> L. grown for 84 days at 74 ppb SO_2 or filtered air (<u>above</u>) and final harvest data after 128 days (<u>below</u>).

Parameter	Treatment	Aurelio	Chiarano	Manital	Mec
Leaf No	Filtered air	8.6	9.2	9.4	10.4
	SO_2	8.0	11.2*	8.6	7.2**
Dead leaves No	Filtered air	8.2	12.2	5.4	7.2
	SO_2	6.0*	11.8	3.4*	6.0
Leaf Area (cm^2)	Filtered air	297	363	230	308
	SO_2	223	348	196	189***
Leaving leaves d.w. (g)	Filtered air	0.84	0.98	0.44	0.56
	SO_2	0.48	0.88	0.38	0.38***
Dead leaves d.w. (g)	Filtered air	0.69	0.18	0.05	0.06
	SO_2	0.30	0.19	0.03	0.07
SLA (cm^2 g^{-1})	Filtered air	385	389	510	549
	SO_2	463	431	517	509*
Shoot No	Filtered air	2.2	2.4	3.2	3.2
	SO_2	2.2	3.0	3.2	2.8
Shoot d.w. (g)	Filtered air	3.12	3.11	1.86	2.13
	SO_2	1.92	3.01	1.44	1.26**
Main stem height (mm)	Filtered air	924	852	685	786
	SO_2	896*	846	708	773
Root d.w. (g)	Filtered air	0.37	0.32	0.18	0.28
	SO_2	0.15*	0.32	0.09*	0.13**
Total d.w. (g)	Filtered air	3.46	3.43	2.05	2.41
	SO_2	2.05	3.33	1.53	1.39***
Ear No	Filtered air	2.6	3.0	3.2	3.4
	SO_2	2.2	2.6	2.8	2.2
Seed No	Filtered air	80	89	61	81
	SO_2	51	76	61	48*
Seed w. (g)	Filtered air	2.0	1.8	1.7	1.6
	SO_2	1.7	1.5	1.5	1.1*
1000 Seed w. (g)	Filtered air	26	23	29	16
	SO_2	36*	21	24	22*

*: $P < 0.05$; **: $P < 0.01$; ***: $P < 0.001$; no symbol: not significant (Paired t-test, $n = 5$).

The relative growth rates (RGR) of both the fumigated and control plants follow a bell-shaped profile, with minimal values shown at the sampling periods I (7-28 days from the sowing) and IV (70-91 days). The effect of the pollutant gas was not significant for all the samplings of cvs Chiarano and Manital, but it was statistically significant for sampling II (28-49 days) in cv Mec (40% reduction) and I in cv Aurelio (35% reduction).

With regard to the components of the RGR, namely leaf area ratio (LAR) and net assimilation ratio (NAR), the NAR increased quite rapidly in all the plants, and then tended to decrease in most of

Table 2. The effects of SO_2 treatments (74 ppb) in comparison with the control on Relative Growth Rate (RGR, g g^{-1} day^{-1}) Net Assimilation Rate (NAR, mg cm^{-2} day^{-1}), Leaf Area Ratio (LAR, cm^2 g^{-1}), Leaf Weight Ratio (LWR, g g^{-1}), Specific Leaf Area (SLA, cm^2 g^{-1}) and shoot/root dry weight ratio (S/R) in the four cultivars of Triticum aestivum L., during successive samplings (21, 42, 63 and 84 days of fumigation).

	Treatment	Aurelio				Chiarano				Manital				Mec			
		21	42	63	84	21	42	63	84	21	42	63	84	21	42	63	84
RGR	Filtered air	0.05	0.09	0.09	0.02	0.03	0.08	0.07	0.04	0.04	0.09	0.07	0.01	0.02	0.11	0.07	0.03
	SO_2	0.03	0.08	0.07	0.03	0.03	0.08	0.07	0.04	0.04	0.08	0.07	0.02	0.03	0.07	0.08	0.03
		*													*		
NAR	Filtered air	0.29	0.37	0.45	0.12	0.19	0.33	0.35	0.36	0.20	0.36	0.29	0.09	0.06	0.47	0.25	0.20
	SO_2	0.18	0.29	0.31	0.19	0.12	0.31	0.31	0.28	0.19	0.32	0.38	0.09	0.08	0.25	0.35	0.18
		*		**							**						
LAR	Filtered air	177	251	205	127	190	245	212	134	212	250	187	129	243	285	223	159
	SO_2	201	289	241	156	213	272	242	161	198	246	196	143	244	289	236	172
			*	*	*	*		*	*				*				
LWR	Filtered air	0.32	0.48	0.49	0.35	0.37	0.51	0.53	0.39	0.40	0.50	0.48	0.33	0.44	0.52	0.52	0.37
	SO_2	0.36	0.55	0.55	0.38	0.44	0.58	0.56	0.41	0.40	0.50	0.49	0.36	0.46	0.55	0.55	0.41
		*	**	*	*	**	**		**				***				
SLA	Filtered air	534	536	411	365	463	484	392	357	524	503	384	423	579	562	425	465
	SO_2	530	536	435	410	491	472	437	404	506	494	394	432	527	524	407	442
				*				*									
S/R	Filtered air	2.40	4.73	4.56	8.87	3.51	5.24	4.18	10.04	2.94	5.97	6.22	10.76	4.39	4.49	5.76	7.68
	SO_2	5.76	4.90	6.86	13.31	7.36	4.43	8.75	9.51	4.42	5.99	7.98	16.77	6.12	5.65	8.18	9.96
		*		*		*		*		*		*		*		*	**

*: $P < 0.05$; **: $P < 0.01$; ***: $P < 0.001$; no symbol: not significant (Paired t-test, n = 5).

them; the LAR was quite stable over time. In cvs Manital and Chiarano, the NAR was never affected by the t leaf weight ratio (LWR) and the specific leaf area (SLA) showed only minimal changes over time. SO_2 caused increases in the LWR in cv Aurelio (7-12% during all the stages of growth) and in cv Chiarano (5-17% at harvests I, II and IV); the LWR of cv Mec was unaffected, and that of cv Manital was slightly (8%) changed by the pollutant gas at sampling IV. The SLA was not influenced by SO_2 in cvs Manital and Mec, but was increased (6-10%) at harvest III in cvs Aurelio and Chiara leaf weight ratio (LWR) and the specific leaf area (SLA) showed only minimal changes over time. SO_2 caused increases in the LWR in cv Aurelio (7-12% during all the stages of growth) and in cv Chiarano (5-17% at harvests I, II and IV); the LWR of cv Mec was unaffected, and that of cv Manital was slightly (8%) changed by the pollutant gas at sampling IV. The SLA was not influenced by SO_2 in cvs Manital and Mec, but was increased (6-10%) at harvest III in cvs Aurelio and Chiarano.

The behaviour of cv Aurelio is worth noting. The final yield parameters in the SO_2-treated plants did not differ from those of the controls, even if at sampling I we observed an overall reduction in both the RGR and the NAR. The increases in LAR (which is the product of SLA and LWR) observed in the fumigated plants provide an explanation of the compensatory processes which take place in Aurelio under SO_2 pollution and explain why the reduction in NAR induced by the pollutant gas at the sampling III is not reflected in a reduction in the RGR. LAR is the total leaf area of the plant divided by the dry weight of the whole plant, while SLA is the leaf area divided by the leaf dry weight. LAR provides an indication of the proportion of the plant's dry weight that is committed to assimilation, and SLA indicates how the dry weight allocated to the leaves has been used to provide assimilatory area. Changes in SLA almost invariabily involve inverse changes in leaf thickness. The LWR increased in the treated plants in all the samplings; since LWR is the ratio of the dry weight of the leaves to that of the whole plant, an increase in the LWR would reflect a decrease in the distribution ratio of photosynthates to the other organs, *i.e.* the stem and roots. It appears that there is a plant response whose effect is to minimize the consequences of SO_2 exposure, but at an appreciable cost in terms of the allocation of dry matter - *i.e.* there is a much greater allocation of dry matter towards producing leaves. It is well known that both LAR and SLA are very flexible parameters, and their flexibility plays an important role in the plant adjusting the form which growth takes in relation to environmental variables. Studies on the dynamic response of plants have already been reported (Walmsley *et al.*, 1980).

Fumigated plants of cv Mec gave a yield (weight of air-dried kernels) which was considerably lower than that of the controls, and this may be associated with the reduction in RGR (due to a drop in the NAR) at sampling II, which was not followed by any significant recovery. This strongly suggests that for the response of cv Mec to SO_2 there is a sort of single 'critical' stage - tillering (stage 25 in the scale of Zadocks, Chang & Konzak -

Tottman, 1987).

The yield parameters of the fumigated cvs Chiarano and Manital plants were almost unaffected; only some of their growth parameters showed increases.

The shoot:root ratios illustrate that the partitioning of dry weight in the polluted plants differed from that of the controls. There were reductions in the proportion of dry matter allocated to the root system while that allocated to the leaves was maintained (or increased) in the fumigated plants. In other words, the treatment with SO_2 caused an increase in the relative leafiness of the plants - a larger proportion of dry weight was contained in the leaves. This was not unexpected, since such behaviour is in fact very common in polluted plants (Kasana and Mansfield, 1986) as well as in plants otherwise stressed (Last, 1962; Ryle and Powell, 1976). Air pollutants are usually considered in terms of their effect on the leaf, with little thought being given to possible root effects. Root development slowed very soon after the beginning of fumigation, and these effects probably underline the dependence of root growth on the supply of carbohydrates. The greater loss of roots in comparison to the one of the above ground portions is also relevant when considering the 'indirect' effects of environmental pollutants - a drastic reduction in the root system may bring about a reduced resistance to drought as well as to other stress factors.

From these results and speculations, we can conclude that the response of wheat cultivars to long-term SO_2 pollution is not homogeneous, and different mechanisms may be involved. This makes much more difficult the job of quantifying the economic impact of air pollution on crop plants and demonstrates the danger involved in drawing conclusions from experiments carried out with a limited number of cultivars or genotypes.

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