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GROWTH AND PRODUCTION OF FABA BEAN CROPS EXPOSED TO SO_2 IN THE FIELD: EXPERIMENTAL DATA ANALYSED WITH A SIMULATION MODEL

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SUMMARY

SO_2 effects on growth and production of faba bean crops were studied with an open-air fumigation system in three years (mean concentration:164 µg SO_2 m^{-3} in 1985, 69 µg SO_2 m^{-3} in 1986 and 63 µg SO_2 m^{-3} in 1988). Total dry matter production was reduced with 17% in 1985, 7% in 1986 and 9% in 1988. Leaf injury, followed by abscission of the oldest leaves, was observed in the fumigated plots at the end of the growing period.

The effect of SO_2 on dry matter production was interpreted in terms of damage components using a mechanistic simulation model. Direct effects of SO_2 on photosynthesis and respiration both explained about 10% of the observed yield loss. A large part of the observed reduction in total dry matter production (69-86%) was caused by the reduction in leaf area at the end of the growing period in the exposed crops. This effect was due to leaf abscission and a reduction of the amount of absorbed radiation, causing reduced rates of canopy photosynthesis.

1. INTRODUCTION

The effect of SO_2 on plant growth has been the subject of many studies. Generally depressing effects on plant growth have been observed. Most experimental work on air pollutant effects on plants, has been carried out in laboratory, greenhouse, or open-top growth chambers, in which the microclimate strongly differs from the field situation. Since microclimatic factors can affect the uptake and effects of air pollutants, it is difficult to extrapolate these observed effects to field situations (1-3). A few systems for open-air fumigation of vegetation, without any form of plant enclosure, have been developed in the past decades, ranging from single point sources to computer-controlled squared or circular line sources (4).

In this study, SO_2 effects on growth and production of faba beans were analysed in a newly developed open-air fumigation system. Physiological and morphological backgrounds of observed effects on dry matter production were quantified with a mechanistic model for SO_2 effects on crop growth.

2. MATERIALS AND METHODS

2.1 The open-air fumigation system

A circular line source system was designed to obtain spatially uniform SO_2 concentrations over an area of at least 10x10 m^2, to have enough plants for growth analysis by periodical harvesting (5). Gas release was controlled by a computer on the basis of information on windspeed and gas concentrations in the sampling area. Predetermined concentrations of the pollutants were maintained with the system and peaks in concentration were avoided. Two circular tubings with a diameter of 30 m (at 0.6 and 2.1 m height) were connected by vertical gas release tubes with three emission holes of 1 mm per tube. The circular system was divided into 16 independent segments, each segment containing six vertical gas release tubes. All segments were connected with the main supply tube by computer directed valves.

Based upon the measured wind direction, the valves of three upwind segments were opened to release SO_2 gas. The SO_2 concentration was maintained at the desired concentration by computer controlled adjustment of the rate of SO_2 gas release. To prevent excessive SO_2 concentrations, a number of safety precautions were included in the hardware and software of the system. The fumigation system operated continuously and automatically throughout the growing season, except for periods in which the wind velocity was less than 1 m s^{-1} or during equipment failure.

2.2 Experimental procedure

Faba bean crops were exposed to elevated SO_2 concentrations in 1985,1986 and 1988. In the open-air fumigation system plots of 8x8 m2 were exposed to mean concentrations of 164 μg SO_2 m^{-3} in 1985 , 69 μg SO_2 m^{-3} in 1986 and 63 μg SO_2 m^{-3} in 1988. The control plot was located at 250 m distance from the system, far enough away to be exposed to background concentrations of SO_2 only (16 μg SO_2 m^{-3} in 1985, 7 μg SO_2 m^{-3} in 1986 and 9 μg SO_2 m^{-3} in 1988). Faba bean plants (Vicia faba, L., cv. Minica) were grown at a density of 20 plants per m^2 in plastic containers (55x22x25 cm) filled with a commercial potting mixture to avoid confounding effects of differences in soil conditions between the plots. Water was supplied by a commercially available drip-irrigation system. In 1985 the plants emerged at 16 April, in 1986 at 5 May and in 1988 at 15 May. Plant growth was determined up to 29 July in 1985, 21 July in 1986 and 25 August in 1988. Plant growth was analysed by frequent harvesting. In 1985 and 1986 the plots were divided into four blocks, each containing one subplot for each harvest. Five containers (2-4 plants) were harvested from each subplot. In 1988, three blocks were available. One container (5 plants) was harvested per block. After collecting the plants in the field, they were divided into leaves, stems, and pods. Leaf area and dry weights were measured.

2.3 Simulation analysis

The model was built up from an elementary model for crop growth (6-8), a submodel for the microclimate inside the canopy and a leaf submodel which calculates the uptake of SO_2 by the leaf, the metabolism of SO_2 in the leaf and effects on stomatal conductance and photosynthesis (9,10). The model operates with time steps of one day, but allows for the diurnal course of radiation. The core of the model is formed by the calculation procedure for canopy photosynthesis and respiration on the basis of processes at the organ level. The daily dry matter production is distributed over the different plant organs in dependence of the developmental stage. Numerical integration in time gives the time course of dry matter. In accordance with the observations, an effect of SO_2 on the allocation of dry matter to the different plant organs was not included in the model.

3. RESULTS AND DISCUSSION

3.1 Growth and production of faba bean crops exposed to SO_2

Total above ground dry-matter production was strongly reduced in the fumigated plots, which resulted in significant reductions of total above-ground biomass at final harvest (17% in 1985, 7% in 1986 and 9% in 1988). In view of a severe Botrytis infection in 1986 in the control crop in the pod filling period, final harvest was then conducted halfway the pod filling period. Pod yield in 1985 was reduced with 23% at final harvest and in 1988 with 10%. A marked effect was the leaf injury and leaf abscission of the oldest leaves in the fumigated plots, causing strong reductions in the Leaf Area Index (LAI).

An interesting observation in this study was the occurrence of a strong infection of the control plot in 1986 with the fungal pathogen Botrytis fabae (Chocolate spot). A slight Botrytis infection, in the control plot only, was also observed in 1985 and 1988. Similar interactions between SO_2 and pathogens were published by other workers (11,12). These findings may have considerable importance for disease control in agriculture.

The strong variability in published effects of SO_2 on the growth of different crops makes it difficult to derive dose-response relationships which can be used for prediction of air pollutant effects, since the response of crops varies with many factors, including species, varieties, microclimate in the fumigation system etc. (13,14). An explanation for the large variety of plant responses to SO_2 can only be achieved by defining the qualitative and quantitative basis for the final response of crops to air pollutants.

3.2 Damage components determined by simulation analysis

To allow a quantitative analysis of the physiological backgrounds of SO_2 effects on crop production, leaf area development was not simulated in the model, but the measured leaf area was used as input in the model. This procedure enables the evaluation of SO_2 effects on the carbon balance, without confounding errors due to errors in the simulation of leaf area development. Observed and simulated time courses of total above-ground dry matter in the control crops for the three experiments are presented in Fig. 1. With one set of parameters for species characteristics, growth and production of the control crop was simulated accurately for the three experiments.

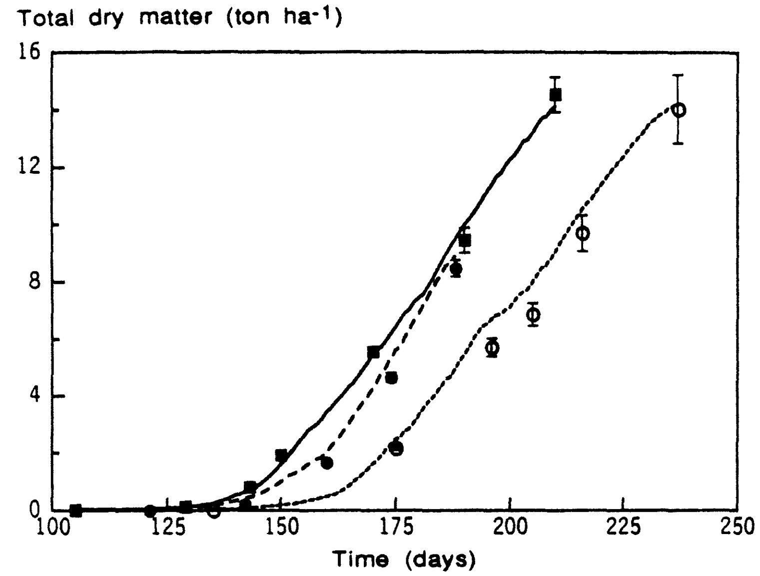

Fig. 1. Observed and simulated time course of dry matter production of the control crops in 1985 (■ observed and —— simulated), 1986 (● observed and ---- simulated) and 1988 (o observed and ······ simulated). Standard errors of means are indicated.

In the analysis of damage components, the effect of leaf injury and defoliation on crop production was analysed first. In all experiments leaf injury and leaf abscission were observed in the fumigated plots, which resulted in a reduced Leaf Area Index (LAI). Introduction of the measured time course of LAI of the fumigated crops, explained a large part of the reduction in final production of total dry matter in all three experiments: 69 % in 1985, 70 % in 1986 and 86 % in 1988 (Table 1). The simulated loss of total dry matter consisted of losses due to leaf abscission and a reduced absorption of photosynthetically active radiation, which caused depressed rates of canopy photosynthesis at the end of the growing period.

Introduction of the submodel for the uptake and direct effects of SO_2 on photosynthesis slightly improved the simulation results: an additional 8% in 1985, 11% in 1986 and 7% in 1988 on final total dry matter production was explained from direct effects of SO_2 on canopy photosynthesis (Table 1). The submodel for SO_2 effects on leaf photosynthesis is based upon observations from short term fumigation experiments. In order to analyse whether additional long term effects on photosynthesis play a role at the concentrations applied in the field, leaf photosynthesis was measured in the experiments of 1985 and 1986. In both years no effects on photosynthesis were detected after long term fumigations(15).

Table 1. Observed and simulated yield loss expressed in kg dry matter (total) ha^{-1} and expressed as percentages of observed yield loss in parentheses, at final harvest in three field experiments with faba beans exposed to ambient or elevated SO_2 concentrations in 1985 (164 μg SO_2 m^{-3}), in 1986 (69 μg SO_2 m^{-3}) and in 1988 (63 μg SO_2 m^{-3}). Three damage components were evaluated with the model: (1) the effect on leaf area development and leaf fall; (2) an additional effect of SO_2 on photosynthesis; and (3) an additional effect of an elevated maintenance respiration of the leaves.

	observed control yield kg ha^{-1}	observed yield loss kg ha^{-1}	simulated yield loss (kg ha^{-1}		
			Damage components included in the model		
			1	2	3
1985	14534	2528	1735 (69)	1947 (77)	2149 (85)
1986	8454	630	438 (70)	508 (81)	653 (104)
1988	13661	1240	1067 (86)	1159 (93)	1360 (110)

Dark respiration of the leaves at five different heights in the canopy was measured in 1988 around the pod filling period. A significant ($P<0.001$) increase of respiration with about 30% in the exposed leaves was observed, which appeared to be independent of leaf number. Introduction of an increased maintenance respiration of the leaves throughout the growing season in the model, slightly improved the simulation of the depression of dry matter and pod production (8-23% of observed reduction). However, the depression was overestimated in 1986 and 1988. No consistent effects of SO_2 on respiration have been reported in literature and both stimulating and inhibitory effects have been observed (16). More research on the interpretation of dark respiration measurements in terms of maintenance respiration and effects of air pollutants is needed.

The results of this study indicate that more quantitative insight in processes determining leaf injury (senescence), and effects of SO_2 on these processes is needed, before simulation models can be used for prediction of SO_2 effects on crops and forests.

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