EFFECTS OF FIELD EXPOSURES TO SO₂ ON DOUGLAS FIR, AGROPYRON SPICATUM AND LOLIUM PERENNE

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Agropyron spicatum, Lolium perenne (S23) and 2-year old Douglas fir (Pseudotsuga menziesii) were exposed to low SO₂ concentrations under field conditions for approximately eleven weeks. SO₂ was released continuously via manifold delivery systems, and provided treatment mean concentrations of 0.007 (ambient air), 0.042, 0.106 and 0.198 ppm. The concentrations in each treatment were approximately log-normally distributed, with standard geometric deviations ranging from 2.58 to 3.24. In both grass species, 0.198 ppm SO₂ caused substantial reduction of total growth. In L. perenne, this was largely the result of impaired root growth, whereas both shoot and root growth of A. spicatum were reduced. 0.106 ppm SO₂ had no significant effect on A. spicatum growth, but reduced root growth of L. perenne. Growth of Douglas fir was reduced in each of the three highest concentrations, with root growth being markedly diminished, particularly on trees which showed chlorotic and necrotic injury. However, in these trees the shoot and total leaf weights tended to increase at the highest SO₂ concentration, suggesting that in these plants injury to leaves stimulated further shoot growth at the expense of root development.

INTRODUCTION

Sulphur dioxide (SO₂) has been a major air pollutant for centuries, and an extensive literature has developed concerning its effects on vegatation, ranging from field observations in locations subjected to industrial and other emissions, to controlled fumigations in various types of exposure chamber (see USEPA, 1973; GUDERIAN, 1977). The need to obtain information as to the effects of controlled levels of SO2 on plants growing under field conditions led to the development of systems capable of generating SO₂containing atmospheres over field plots, such as the Zonal Air Pollution System (ZAPS) of LEE et al. (1975) and that of DE CORMIS et al. (1975). The extensive studies of Miller and his coworkers (MILLER et al., 1978 1979; SPRUGEL et. al., 1978; IRVING et al., 1979) on soybean using ZAPS attest to the value of

field-exposure studies. This paper presents some preliminary observations made using a modification of ZAPS to study the effects of SO₂ on the growth of young *Pseudotsuga menziesii* (Douglas fir) trees and the grasses *Agropyron spicatum* (Bluebunch Wheatgrass, an important rangeland species in central British Columbia) and *Lolium perenne* (perennial ryegrass). The latter has been the focus of considerable research, following the observations of Bell and Clough (1973) that the growth of the cultivar S23 was substantially reduced when subjected to prolonged exposures to 0.12 ppm SO₂

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METHODS AND MATERIALS

Field Exposure System

The field exposure system used in these studies is a scaled-down modification of ZAPS (LEE et al., 1975), in which gas is released over 10 x 12 m field plots, through apart (Fig. 1), with the choice of the plots over which the higher concentrations of SO, are to be established being selected so that they are in the prevailing wind direction, in order to minimize carry-over effects between the plots. The manifold over each plot consists of a network of ABS plastic tubing with 0.8 mm horizontal orifices at 1 m intervals (Fig. 2). study were season-long averages of 0.012, SO, diluted with compressed air is pumped through the manifold and relased over the "low", "medium" and "high" treatments. plots at predetermined rates in order to The first are the Canadian Maximum establish selected average SO2 concentrations, Desirable and Maximum Acceptable Objecafter mixing and dilution with the ambient tive levels respectively, while the highest air. Air was continuously sampled from two locations on each plot, and fed via a timesharing system to pulsed fluorescence SO,

analyser (Thermo Electron Corp., Model 43). Each sampling location was sampled at 24 min. intervals on a continuous basis. The data were recorded on a data logger (Hewlett-Packard) together with numerous meterological variables. A complete description of orifices in a distribution manifold suspended the system and an evaluation of its 1 m above ground level. The plots are 25 m characteristics and performance will be published elsewhere.

Selection of SO₂ treatment concentrations

The target concentrations for the present 0.026 and 0.065 ppm SO₂, referred to as the concentration was arbitrarily selected in order to ensure a measurable response in terms of plant growth.

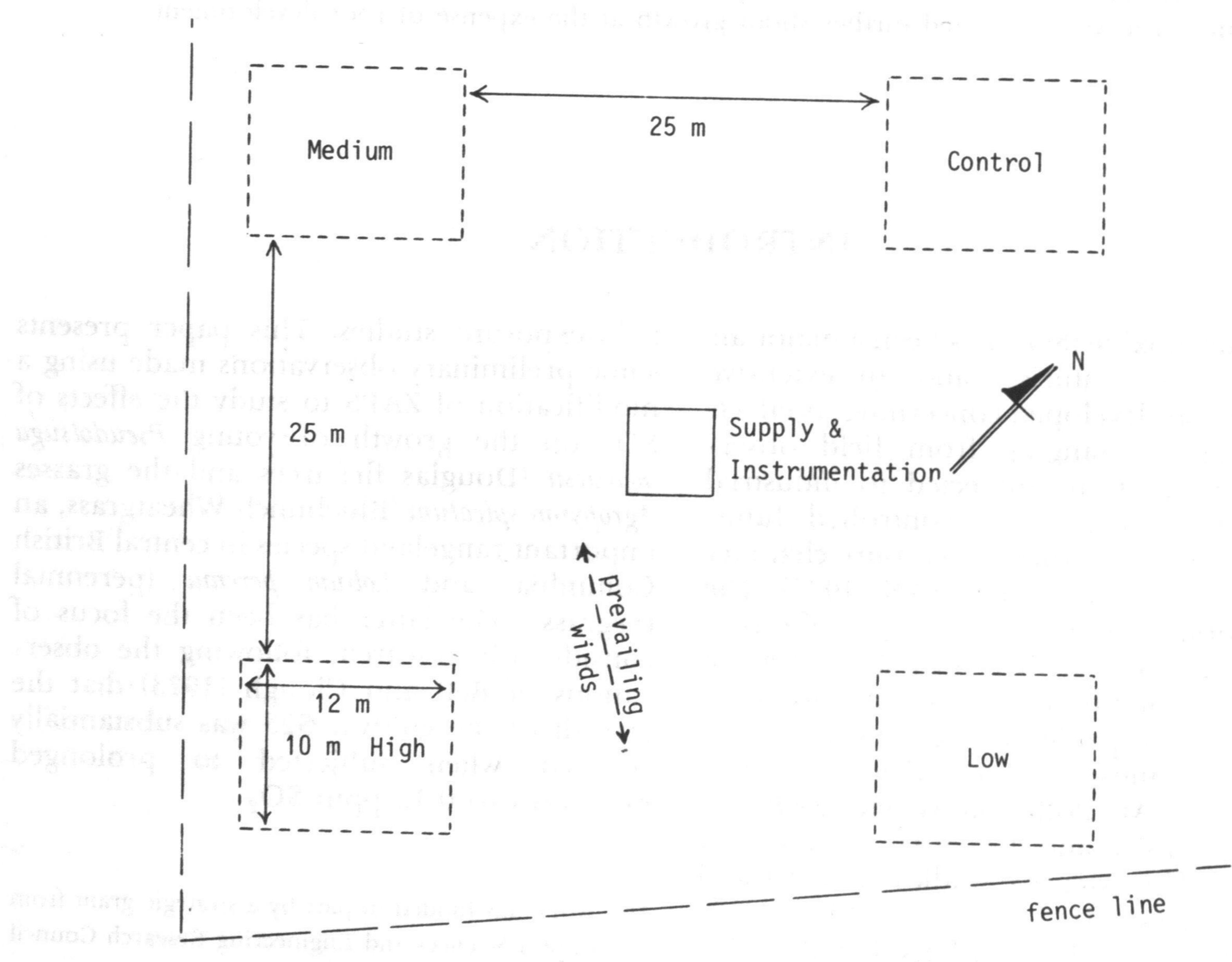


Figure 1. Layout of field-exposure plots.

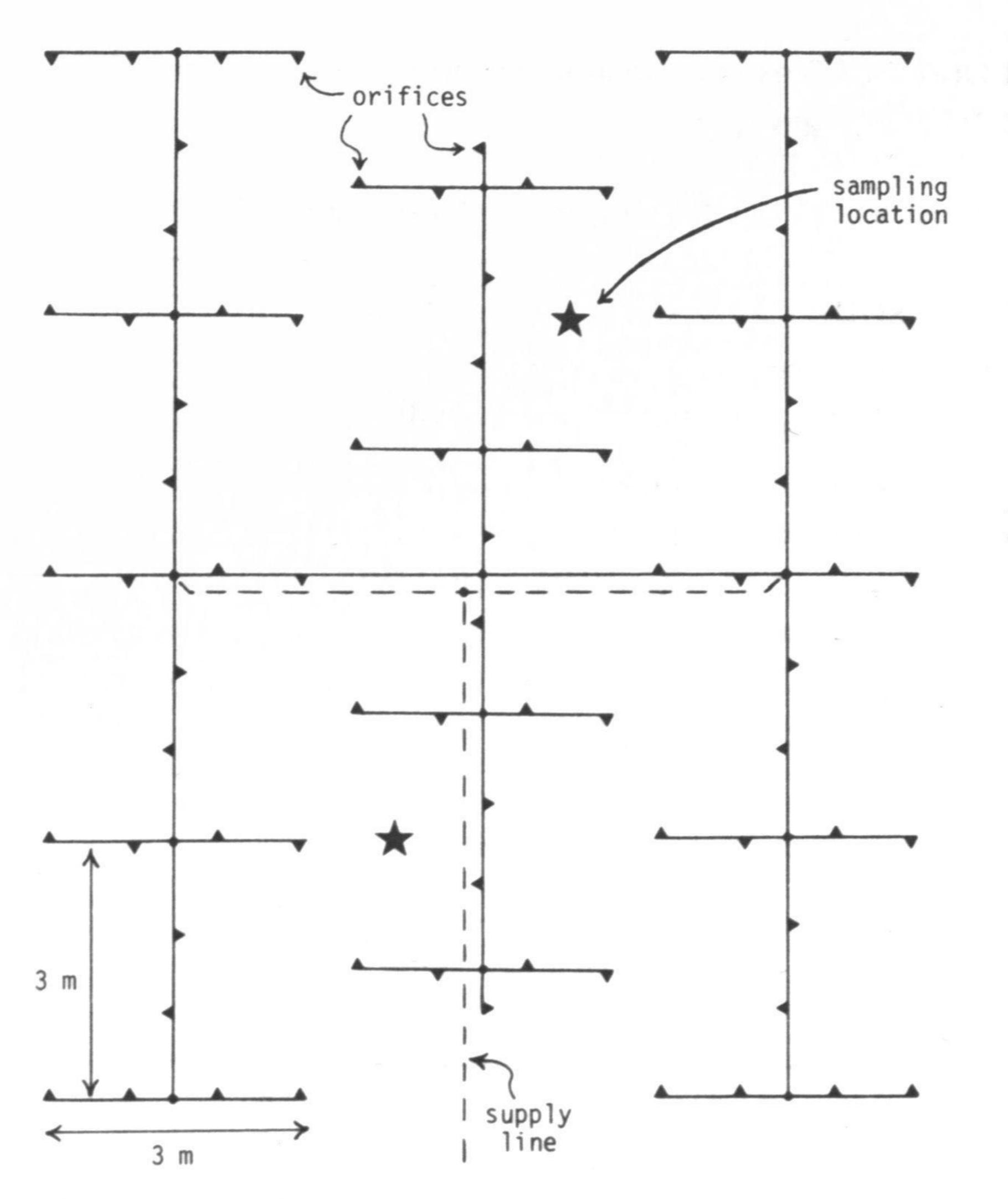


Figure 2. Gas distribution manifold and orifice location on each plot.

Plant materials

Two-year old Douglas fir seedlings were obtained from a single provenance supplied by MacMillan Bloedel Ltd. Agropyron spicatum was grown from a mixture of seed collected in the interior of British Columbia at several sites, provided by Dr. M.D. Pitt. of this Department. Lolium perenne, cultivar \$23, was at soil level, and separated into leaves and grown from seed provided by Dr. J. N. B. stems. In the case of A. spicatum, flowering Bell, Imperial College Field Station, Silwood heads were harvested separately, by clipping Park, Ascot, England.

Planting conditions

The grasses were grown in 17 cm plastic pots contining a 3:1 mixture of potting soil

and sand with general purpose fertilizer mixed in. Douglas fir was grown singly in 25 cm pots containing a 3:1 mixture of potting soil and coarse sand. The grasses were sown in the greenhouse and thinned to three seedlings per pot. All pots were plunged to soil level in the field plots.

Duration of experiments

All species were established in the plots in late June, at which time SO₂ treatments began. However, as a result of start-up problems, consistent SO₂ treatments only commenced in early August and continued to mid-October. The ages of the plants in relation to the SO₂ treatments were as follows:

A. spicatum: 17 weeks at harvest, treated continuously from weeks 7 to 17.

L. perenne: 14 weeks at harvest, treated continuously from weeks 3 to

P. menziesii: 21 weeks at harvest, treated

continuously from weeks 11 to

Observations and Growth Measurements

Plants were observed at regular intervals in order to record any symptoms of injury. At harvest, the shoots were collected by cutting at the point of insertion into the flag leaf. Roots were separated by washing. All samples were oven-dried and weighed. Totals of 96, 117 and 50 plants were harvested in each treatment of A. spicatum, L. perenne and P. menziesii respectively.

RESULTS

SO₂ treatments

Analysis of the data collected over a period of 74 days revealed considerable variablility both in terms of the individual concentrations

measured at each sampling location (Fig. 2) at 24-minute intervals, and in terms of 1-h, 3-h and 24-h average concentrations (Table 1). All distributions were essentially log-normal, as illustrated by the data for individual values

Table 1. SO2 Concentrations: Target Seasonal Mean and Obserbed Seasonal Mean Concentrations based on individual, 1-h, 3-h, and 24-h averages (ppm).

Treatment	Target Mean SO ₂	Arithemetic Mean SO ₂	3-min concns.		1-h averages	3-h averages	24-h averages
			GM*	SGD*	GM	GM	GM
Control	0	0.007	0.004	2.74	0.005	0.005	0.006
Low 1		0.040	0.019	3.24	0.020	0.022	0.028
2		0.044	0.021	2.97	0.023	0.024	0.030
Mean	0.012	0.042					
Medium 1		0.096	0.055	2.69	0.060	0.066	0.082
2		0.115	0.060	2.77	0.064	0.069	0.095
Mean	0.026	0.106					
High 1		0.170	0.090	300	0.097	0.106	0.138
2		0.225	0.135	2.58	0.144	0.154	0.203
Mean	0.065	0.198					

^{*} GM, geometric mean; SGD, standard geometric deviation

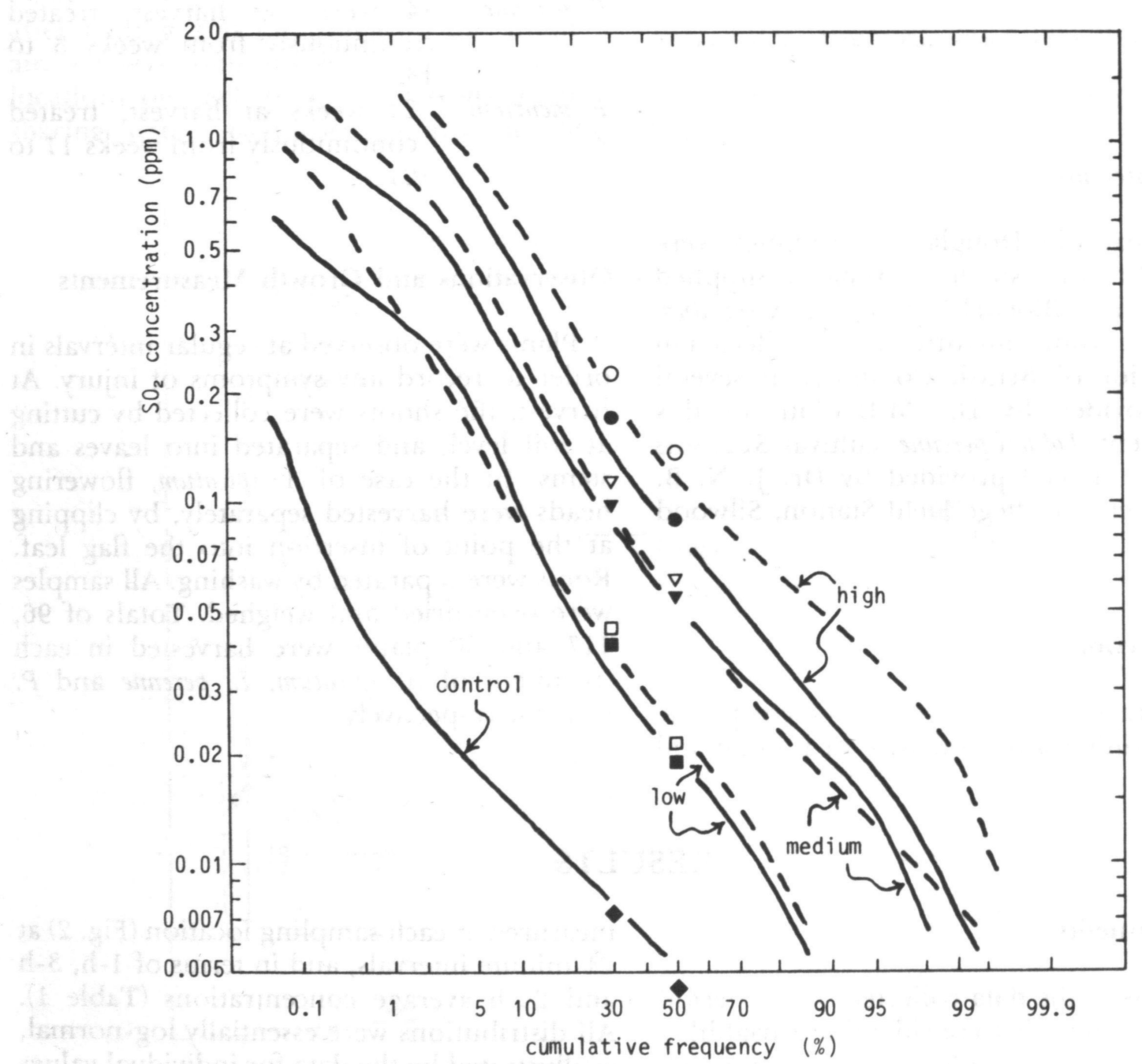


Figure 3. Freguency distribution of individual SO2 concentrations measured throughout the growing season.

(Fig. 3). In general, there was reasonable standard geometric deviations ranged argeement between the data for each pair of between 2.58 and 3.24 for the individual sampling locations per plot. The greatest readings. difference occurred in the "high" plot. In addition, the arithmetic average concentrations (30 percentile, Fig. 3) were consider- Effects on plant growth ably in excess of the target concentrations. Inspection on Table 1 shows that in each treatment, the observed average concentrations were greater than target by a factor of between 3 and 4, althoug the median significantly reduced in the high treatment (geometric mean) concentrations were only (Fig. 4). These reductions contributed to a greater by a factor of two. The causes for significant reduction in total growth in this these différences will be discussed below. The treatment. Growth in the medium concen-

a) Agropyron spicatum (wheatgrass)

Growth of both shoots and roots was

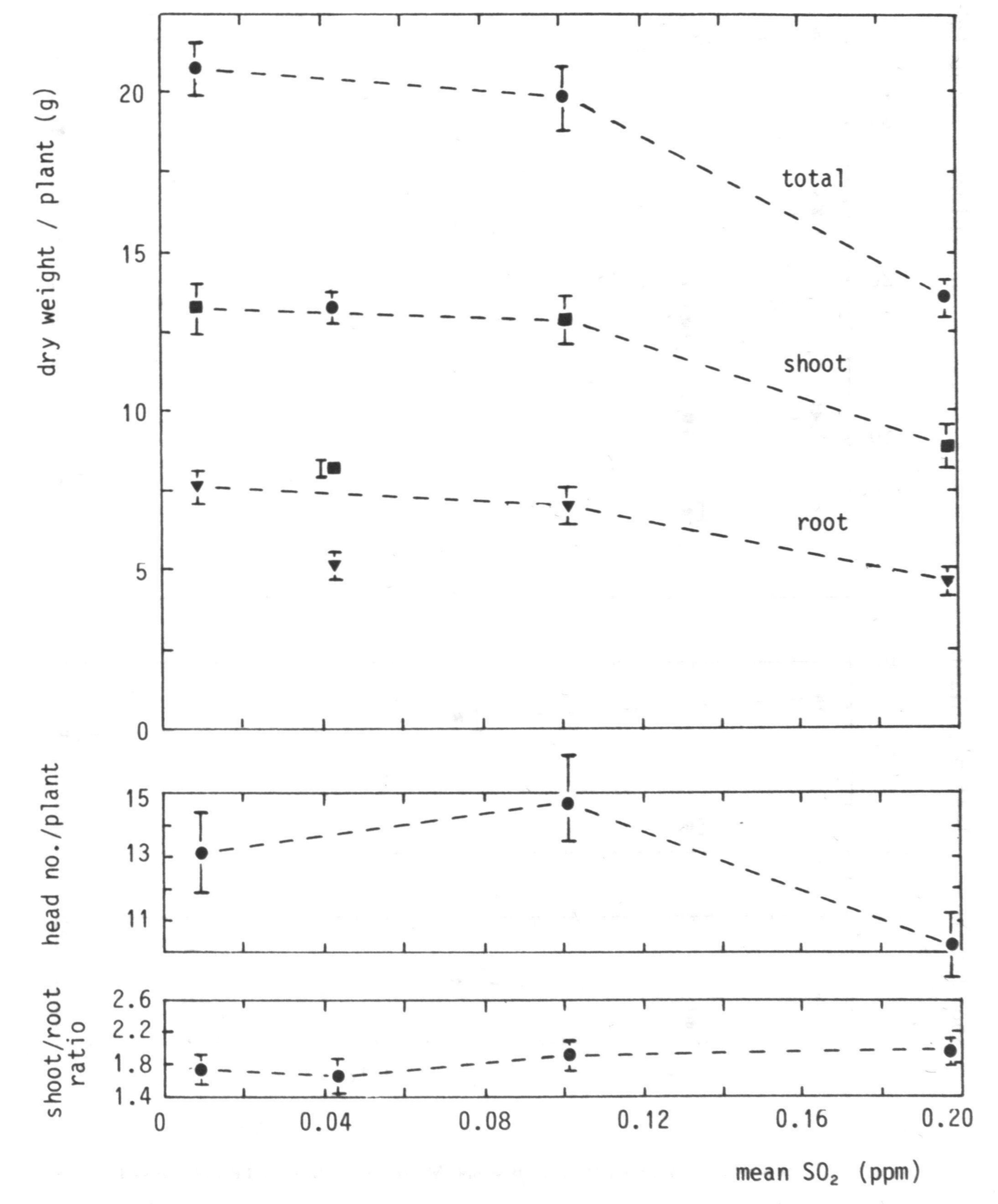


Figure 4. Effects of SO_2 on growth of A. spicatum. Means and standard errors; n = 96 per treatment.

tration, however, was not significantly affected as compared to that in the control (ambient air) treatment. The growth of plants in the low plot was also significantly reduced; however, as discussed further below, this reduction is probably the result of serious waterlogging of the plot which occurred early in the experiment, rather than an effect of SO₂.

The number of reproductive shoots (heads) was only reduced in the high treatment. In

spite of these growth reductions, there was no significant effect on shoot/root ratio (by weight).

b) Lolium perenne (ryegrass)

There was a significant but less marked reduction in ryegrass growth (Fig. 5) in the high treatment as compared with that of wheatgrass. However, here the effect was largely the result of root growth reductions in

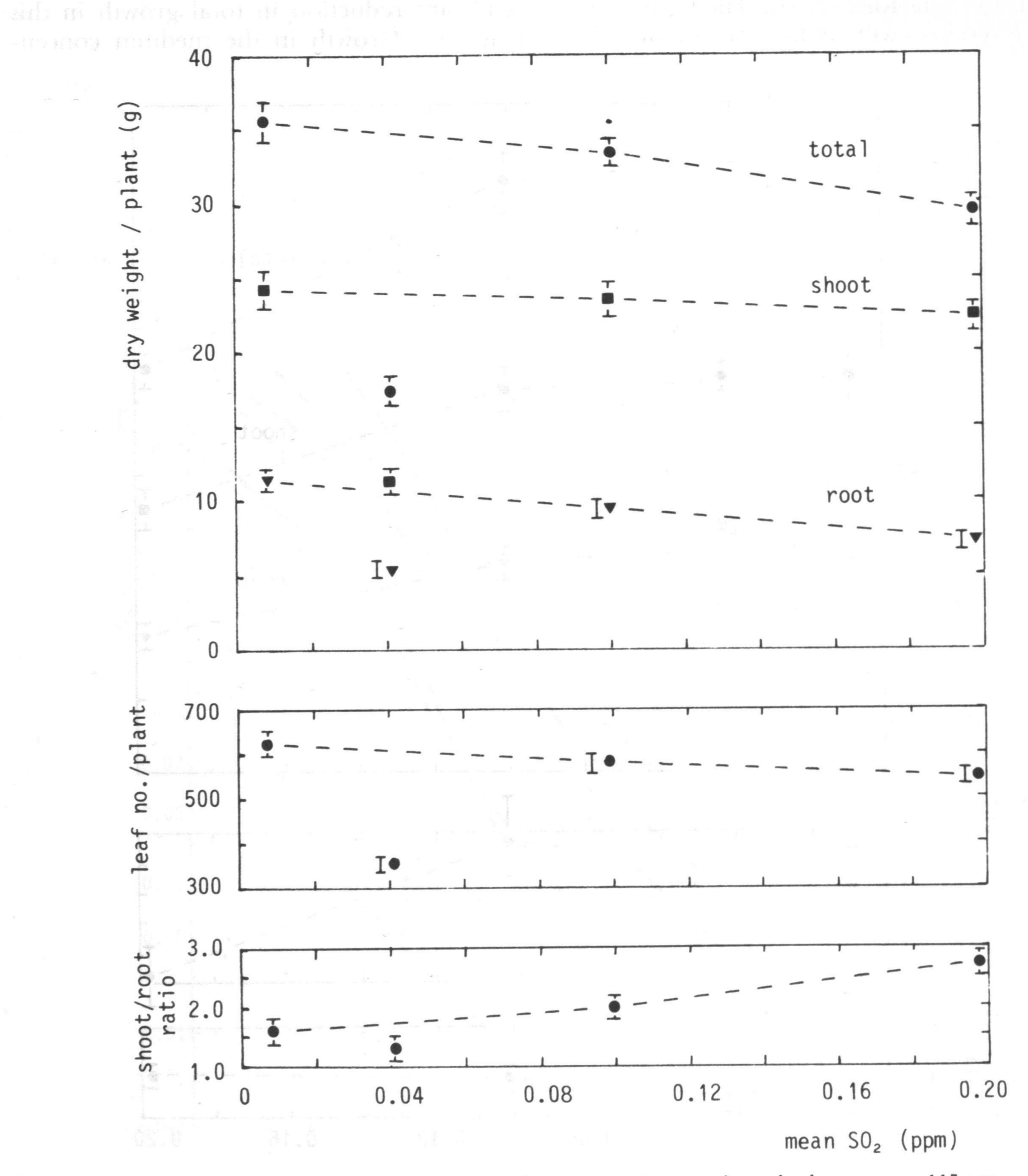


Figure 5. Effects of SO_2 on growth of L. perenne. Means and standard errors; n = 117 per treatment.

both the medium and high treatments, as shown by the significant increases in shoot/root ratios. Shoot growth showed a declining trend with increasing SO_2 concentration and the numbers of leaves per plant declined significantly. Again the weak growth in the low treatment should not attributed to SO_2 .

c) Pseudotsuga menziesii (Douglas fir)

In all treatments, the seedlings made appreciable growth, but again there was progressively less growth at higher SO₂ concentrations, especially of the roots (Fig. 6). In this case there is less reason to discount the data from the low treatment because of the considerably more porous soil mix used.

In the treatments receiving SO₂ there were appreciable numbers of plants on which

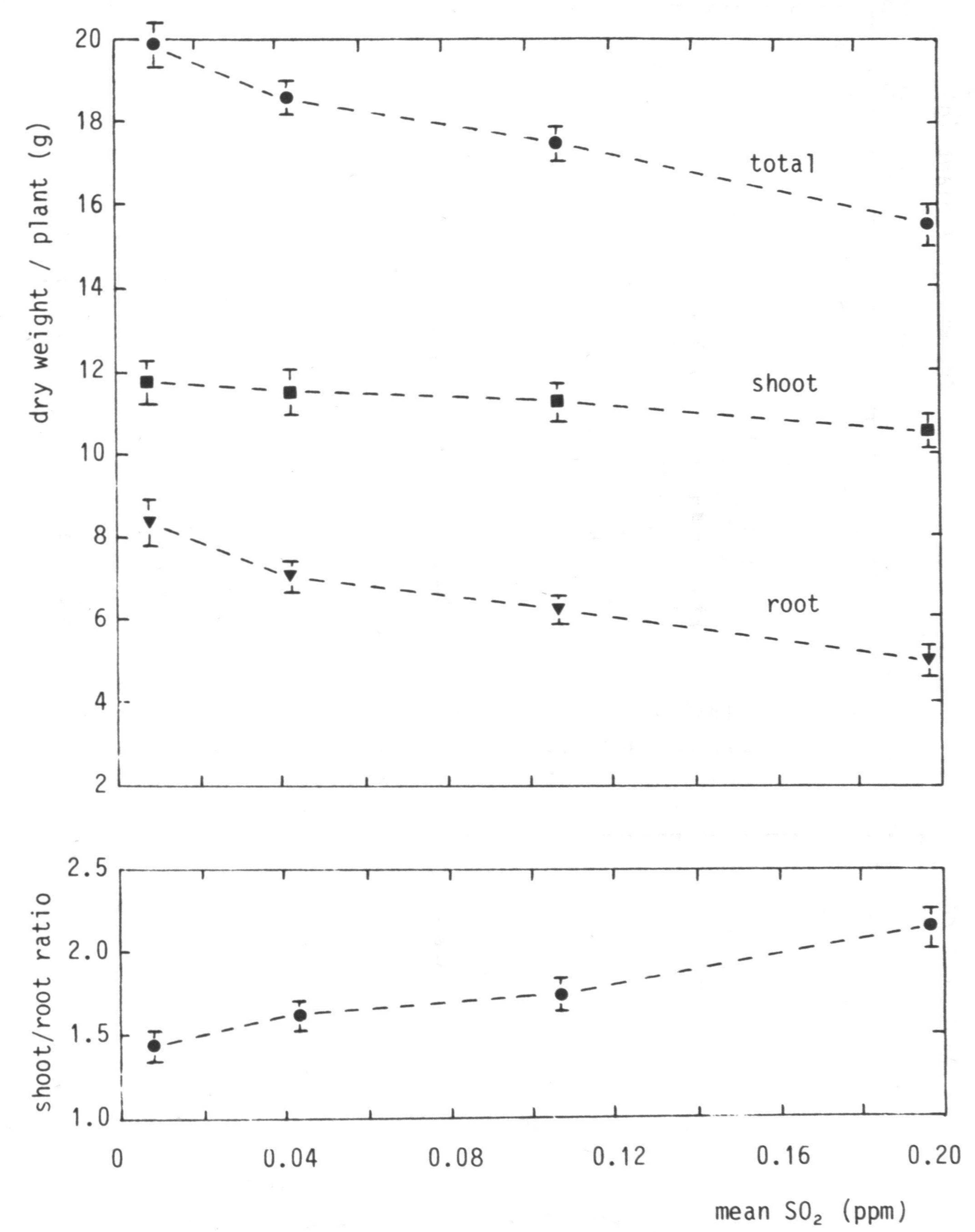


Figure 6. Effects of SO_2 on growth of P. menziesii. Means and standard errors; n = 50 treatment.

varying degrees of needle chlorosis and Visible symptoms of injury necrosis were observed, which symptoms appeared to be attributable to SO₂. These plants were analysed separately (Fig. 7), but, while again showing severe reduction in root growth, there was a clear indication of significantly greater needle growth, which resulted in an upward trend in total shoot weight with increased SO₂ concentration.

In no treatments were severe symptoms typical of aucte SO₂ injury observed on any species. However, there was a general trend towards greater numbers of chlorotic and necrotic leaves and needles at the higher SO₂ concentrations. In all species such symptoms typically became first apparent at the tips and progressed towards the stem to vayring degrees.

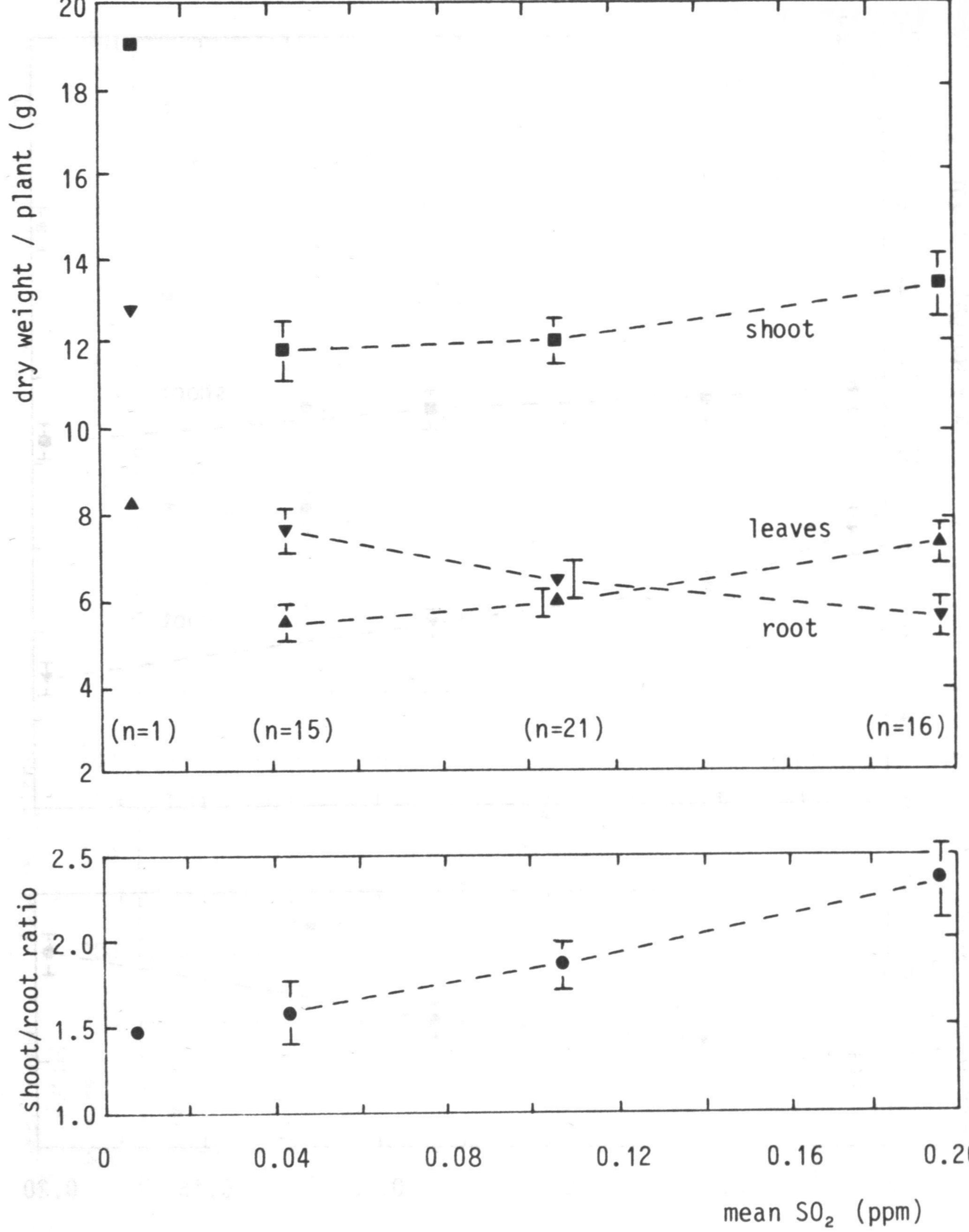


Figure 7. Effects of SO₂ on growth of P. menziesii plants showing distinct needle chlorosis or necrosis. Means and standard errors; numbers of plants in each treatment are shown in parentheses.

DISCUSSION

SO₂ treatments

The approximate log-normality of the distribution of concentrations obtained with ZAPS is in agreement with LEE et al. (1975) and MILLER et al. (1979). The lack of linearity at the lowest and highest concentrations undoubtedly derives from the theoretical impossibility of the variate, log (SO_2) , varying between $-\infty$ and ∞ . Transformation to the S_I or S_B distributions (IOHNSON, 1949) as discussed by MAGE (1980) would undoubtedly provide better linearity. Nevertheless, the distributions obtained illustrate the expected variability in terms of instantaneous values and averages over various intervals. In general, the highest concentrations on all plots occurred at times of lowest wind speeds (data not presented).

Two matters which need explanation are the lack of agreement between the observed and target SO₂ average concentrations and the difference between the data obtained from the two sampling locations in the "high" plot. Both of these are interrelated, and come about as a result of extensive road construction and earth-moving around the location of the plots. As a result, a large pile of soil was placed along the western fenceline (Fig. 1) which seriously affected the local meteorology. Although this pile essentially paralleled the direction of the prevailing winds, it acted as a wind break for crosswinds, and resulted in a decrease in the effect of increasing shoot/root ratios season-long mean wind speeds. Since the delivery rates to the individual plots had been calculated assuming a higher mean wind CRITTENDEN and READ (1978) and BELL speed, the net result was the higher concentrations observed, because at the time of the experiment, no provision had made for feedback control to limit the concentrations.

The disagreement between the data from the two sampling locations on the "high" plot was also attributable to the changed topography, which resulted in a greater frequency of still air conditions over part of species was quite low under the field the plot (that which gave rise to the higher C concentrations in Table 1).

Effects on plant growth

The anomalous results obtained for the grasses grown in the 'low' plot have been attributed to poor drainage in the plot. This too was caused in part by road building activities to the south of the fence-line (Fig. 1) which resulted in blockage of the drain tiles from this area. The fact that the effect of waterlogging was less marked on Douglas fir than on the grasses may be explained by the coarser soil mix used. However, the effects of water logging seriously confounded the effects of low SO₂, and may have masked any potentially beneficial effects of low SO, levels, such as those reported by COWLING et al. (1973) for L. perenne.

The two grass species revealed somewhat different responses to SO₂. A. spicatum, under the field conditions of the experiment, was somewhat more resistant at the lower SO₂ concentrations than L. perenne, but showed a steeper dose-response relationship, since at 0.198 ppm SO₂, its growth was reduced 36 percent, as compared with a 19 % reduction for ryegrass. Furthermore, the effect on wheatgrass appeared to be generally distributed, since both shoot and root growth were reduced without a significant effect on shoot/root ratio (Fig. 4). In contrast, the relative reduction of root growth of L. perenne. was progressively greater than that of shoot growth at the higher SO₂ concentrations. This occurring in plants under SO₂-stress is in agreement with the observations of et al. (1980). The significant but slight reduction in numbers of leaves of ryegrass (Fig. 4) has frequently been observed since BELL and CLOUGH (1973).

The reduction of growth of Douglas fir was 13 percent at 0.106 ppm SO₂ and 22 percent at 0.198 ppm SO₂, suggesting that the threshold for growth reductions in this conditions of this experiment. There are several conflicting reports in the literature concerning the sensitivity of P. menziesii to SO, (see DAVIS and WILHOUR, 1976, for review), and further studies are needed before this matter can be resolved.

The observation, that those Douglas fir trees which showed visible symptoms of injury tended to respond to SO₂ stress by replacing the injured leaves, probably reflects genetic differences within the population. However, the response also illustrates a subtle way in which SO₂ could ultimately result in serious growth impairment over a longer period. The increased diversion of assimilates from the roots (Fig. 6) would ultimately result in inadequate root system development of such plants.

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Dose-response relationships

relationships of the two grass species mentioned above is also reflected in the apparent threshold concentrations. In the case of A. spicatum, this appears to be between 0.1 and 0.2 ppm SO₂. The threshold for L. perenne appears to lie between 0.04 and 0.1 ppm. Many of the reports on growth reductions of ryegrass have been reviewed by HORSEMAN et al. (1079). It is noteworthy that the 19 percent growth reduction observed in the present study is considerably less than that reported by several workers for exposures to SO₂ amounting to comparable studies, suggests that the threshold SO₂ concentrations for adverse effects on the growth of ryegrass, based on chamber studies, probably lies well below 0.07 ppm (cf. BELL and CLOUGH, 1973). Hence it may also be that under field conditions, L. perenne has a somewhat higher SO₂ threshold than under chamber conditions, as a consequence of differences in environmental variables, such as the recently reported interactions between SO₂ and level of light intensity and day length for Phleum pratense (DAVIES, 1980).

long-term dosages up to the 15.3 ppm-h of the present study. All of these other studies, however, were conducted in growth chambers of various types, and the lower response found in the present study may therefore more accurately represent the situation to be expected under field conditions. Furthermore, the threshold of response of ryegrass found in the present field study appears to be somewhat higher than that observed by others in growth chamber studies. The recent UNSWORTH resolution MANSFIELD (1980) of the apparent discrepancies between the observations of BELL and CLOUGH (1973) and of COWLING et al. (1973) and these authors' more recent studies, suggests that the threshold SO, concentrations for adverse effects on the growth of ryegrass, based on chamber studies, probably lies well below 0.07 ppm (cf. BELL and CLOUGH, 1973). Hence it may also be that under field conditions, L. perenne has a somewhat higher SO₂ threshold than of differences in environmental variables, such as the recently reported interactions between SO₂ and level of light intensity and

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