in the day-time of approximately 5 mm s\(^{-1}\) to the Scots pine stand at Jädråks.

It should be pointed out that due to the weather conditions during the experimental period the stomatal conductance was rather low both in the exposed shoots and the controls. In the earlier part of the summer the mean values during the day was at least 50 % higher. If this would mean a proportional increase in \(\text{NO}_2\) uptake the result should be a 50 % increase in deposition rate.

To study this hypothesis field measurements on current and 1-year-old needles from two 18-year-old pine trees were continued in 1980. \(\text{NO}_2\) of 100 \(\mu\) g m\(^{-2}\) was introduced continuously for four weeks in July-August. Results evaluated so far show a tendency of quite a higher deposition rate at this time of the year compared to August-September.

From the field measurements 1979 there were no indications of any physiological effects of the used \(\text{NO}_2\)-concentrations. In the laboratory experiments the only effect found was a reduction in the transpiration rate in darkness when the seedlings were exposed to the highest \(\text{NO}_2\)-concentration.

The types of air pollution on the ultrastructure of spruce and pine needles have been studied during 1976–1980 in Finland in several polluted environments. The working group in the Ecological Laboratory of the Department of Environmental Hygiene of University of Kuopio has specialized in the structural approach. Earlier structural studies dealing with air pollutants included those made in fumigation chambers (e.g., WELLBURN et al. 1972) and some made in the field (GODZIK and KNABE 1978). Some of the questions which the structural studies as a whole aimed to answer were e.g., can the injuries be detected without visible symptoms, do the different pollutants cause different injuries, and if so, can these methods be used for diagnostic purposes. This paper summarises the ultrastructural injury types observed in spruce and pine needles growing in polluted environments.

LITERATURE


branches of mature spruces and pines at a height of 4-7 meters, mainly during winter. The condition of the trees varied from bad to rather good. The sampling methods and the fixation procedures as well as analysis of the material have been reported by Soikkeli (1978, 1981a).

The study is funded by the Academy of Finland. I wish to thank Prof. Lauri Kärenlampi, University of Kuopio, for his critical reading of the manuscript. Thanks are also due to Dr. Satu Huttunen, University of Oulu, for her support during the study.

Fig. 1. Study areas where the needles were collected. 1 = Tamminen, 2 = Valkeakoski, 3 = Kuopio, and 4 = Oulu.

ULTRASTRUCTURAL INJURY TYPES

At ultrastructural level four different types were observed and they differed with the origin of the material. The injury types were similar in the needles of spruce and pine, and could be observed in green needles. The types which appeared in S-polluted areas can best be characterized by the reduction of grana (Fig. 2) and by the lightening of plastoglobuli with simultaneous accumulation of lipid-like material in cytoplasm (Fig. 3). The types in P polluted needles showed stretched envelopes and swollen (Fig. 4) or curled (Fig. 5) lamellae. The curled lamellae injury appeared strongly during the coldest period of winter. When the injuries were slight-medium (the scale is slight-medium, severe, very severe, Soikkeli 1981a) usually only the injuries in chloroplast structure were distinguishable.

During the proceeding of the injury (severe injury), often observed in needles collected in late winter or spring, the injuries in chloroplasts became worse. E.g., the reduced grana lamellae got swollen and the envelopes began to rupture, the plastoglobuli were lightened and their shape changed and their amount and that of lipid-like material in cytoplasm increased. In F-polluted needles the swelling became worse and the lamellae of the other type were heavily curled with simultaneous appearance of hollows in stroma. Also in these two types the envelopes began to rupture.

In addition to the proceeding of the injury in chloroplasts also the other cytoplasmic organelles began to show injuries. E.g., cytoplasm became granulated, mitochondria injured, and the amount of ribosomes decreased (in samples collected during the growing period). In very severely injured cells all of the cell organelles were strongly disorganized and often the cell had an overall granular appearance. The portion of badly injured cells was the highest in nearly two-year-old needles collected during spring.

Fig. 2. Reduction of grana lamellae (arrow) at slight-medium stage of the injury in spruce needles collected from S-polluted areas. Mitochondria (M), plastoglobuli (P). Kuopio on May 2, 1979. X 24 000.

Fig. 3. Lipid-like injury (severe stage) in spruce needles collected from S-polluted areas. Plastoglobuli (P) are lightened and their shape is changed. Lipid-like material (star) in cytoplasm. Valkeakoski on January 31, 1978. X 51 000.
DISCUSSION

Because of their appearance in S-polluted areas, the injury types with reduced granae and with the lightening of plastoglobuli are thought to be caused by sulphur compounds. This conclusion is also supported by the observations that in areas with a high level of SO₂ (e.g., in Vakkekoski) the injuries were abundant and the stage of cell injury was more severe in needles of the same age if compared to areas with a low level of SO₂ (Kuopio) (SOIKKELI 1981a, 1981b). The reduction of granae in S-exposed material has been reported also earlier e.g., by GODZIK and SASSEN (1974).

One reason to the reduction of granae lamellae could be the disturbances in SH/SS status of lamellar porines caused by dissolved S-compounds (e.g., SUGHARA et al. 1980). On the other hand, the accumulation of lipid-like material can refer to disturbances in some stages of lipid metabolism.

The swelling and curling of the thylakoids with simultaneous stretching of the envelopes were typical injuries in needles exposed to fluorides not depending on the possible occurrence of other pollutants. Partly similar injuries have also been reported in HF-fumigated needles of Abies alba by BLIGNY et al. (1973). Curled thylakoids occurred during the coldest periods of winter and could be caused together by frost and pollutants. The curling lamellae have earlier been reported in some grass species at low temperatures by KIMBALL and SALISBURY (1973).

Swollen lamellae have been reported with many different pollutants in addition to fluoride, e.g., with SO₂ and NO₃, the concentrations of which have usually been high (e.g., WELLBURG et al. 1972, MŁODZIANOWSKI and BIALOBOK 1977). It is possible that the swelling of the thylakoids is not a specific reaction to some pollutant. It could better be a sign of an acute injury. On the other hand, the different species or even the same species under different conditions can react differently to the same pollutant. During the structural studies it became apparent, however, that the both Finnish conifers, Picea abies and Pinus silvestris, react similarly in similar pollutant situations.

The injuries become considerably worse during the second winter of the needles (SOIKKELI and TUOVINEN 1979). Also the extent of the damage is bigger then than in the younger needles collected during early winter or autumn (SOIKKELI 1981a, 1981b). The injury process during winter is due to many factors functioning together, e.g., the unsuccessful hardening during the preceding autumn which is likely to occur in environments with nitrogen oxides (HUTTUNEN et al. 1981). Higher concentrations of SO₂ in the air during winters (e.g., KARTASTENPÄÄ et al. 1979), accumulated and still accumulating pollutant in the cell, etc. All the harmful effects of pollutants together with the normal winter stresses lead to the disorganization of cell metabolism, even in the dormant trees (e.g., BÖRTIZ 1967). At ultrastructural level the events can be seen as an increasing injury, which begins from the most sensitive organelles such as chloroplasts spreading later to the entire cell.

REFERENCES


EFFECTS OF FIELD EXPOSURES TO SO2 ON DOUGLAS FIR, AGROPYRON SPICATUM AND LULIUM PERENNNE

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VET ZA2

Agropyron spicatum, Lulium 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 2.38 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 vegetation, 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 SO2-containing 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 Lulium perenne (perennial ryegrass). The latter has been the focus of considerable research, following the observations of Bell and Clough (1975) that the growth of the cultivar S23 was substantially reduced when subjected to prolonged exposures to 0.12 ppm SO2.

This work was funded in part by a strategic grant from the Natural Sciences and Engineering Research Council of Canada to V. C. R.