Atmospheric Pollutants in Forest Areas

Atmospheric Pollutants in Forest Areas

Their Deposition and Interception

edited by

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PREFACE

In November 1981 a first symposium with the topics of "Acid Deposition of Atmospheric Pollutants" was organised in Oberursel/Taunus to introduce the problems and first results of research-activities on wet and dry deposition of pollutants and on acid precipitation.

In the meantime the hazard to forest and vegetation became more dramatic and research-projects to investigate the input of pollutants to forest-ecosystems have been initiated by several interdisciplinary groups. The rapidly increasing interest in the problems of forest-decay and the many open questions with respect to the diagnosis of the forest-damage were the background for the organisation of a second symposium which was held in November 1985 at the same location in Oberursel/Taunus. It was mainly concerned with new techniques of sampling and analyzing pollutants in forest areas.
Besides deposition, one important pathway of pollutants in orographic terrain is the interception of fog-droplets by vegetation. Special emphasis was laid on the chemical composition of fog. The symposium successfully assembled scientists from the field of atmospheric research with those studying the effect of pollutants on trees and vegetation in order to reduce the many open questions in connection with forest desease. The proceedings presented in this volume are a substantial contribution to the understanding of deposition and interception of pollutants in forest-areas. Thanks to the authors the volume contains a lot of new research results and presents therefore a true picture of our present knowledge.

The success of the symposium was to a great deal due to the work of my associates and I would like to thank Mr. S. Grosch, Mr. G. Schmitt and Mrs. H. Wallenwein for their assistance.

Hans-Walter Georgii

Deposition in Forest-Ecosystems

DEPOSITION OF GASEOUS POLLUTANTS IN A DOUGLAS FIR FOREST

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ABSTRACT. This year a Dutch acid deposition monitoring program will be started in two stands of Douglas fir. The program includes continuous measurement of concentration profiles of the main gaseous pollutants SO_2, NO_x, NH_3 and O_3 as well as monitoring of physical and chemical parameters in the soil. To evaluate the response of the trees to air pollution stress there will also be photosynthesis measurements on single branches under controlled conditions. The first results are to be expected in the last months of 1986. In this contribution the experimental lay-out is described and some possible ways of interpretation of the measurements are discussed.

1. INTRODUCTION

On the first of July 1985 a Dutch National Research Program on acid rain was established. |1| The program will run for two and a half years and will have to provide scientific information, currently unavailable, on the "Acid Rain" problem to enable policy makers to take counter measures.

Main topics of the program are: research in exposure-effect relationships, research into NH_3-emission control techniques and study of the effectiveness of control measures, this in addition to the already existing projects on SO_2 and NO_x emission control. The exposure-effect studies will focus on forests, natural vegetation and agricultural crops and comprise experimental field studies, comparative field studies and studies under controlled conditions.

The contribution of our department, a research project called 'Air Pollution in Forest Canopies', is a part of the experimental field studies together with research on tree physiology, soil physics and chemistry, root growth and research on mycorrhiza. These studies will take place simultaneously at the same plots to enhance coherence of the program and to provide other research groups with additional information.

H.-W. Georgii (ed.), Atmospheric Pollutants in Forest Areas, 3–11.

2. AIMS OF THE PROJECT

One of the final aims of the research program on forests will be an estimate of the influence of air pollution, among other stress factors, on the vitality and growth rate of the Douglas fir (Douglas menziesii). Our part in the program will be the determination of air pollution levels above, within and below the forest canopy of two Douglas plantations, one with good and one with poor to moderate growth rate. Concentration profiles of the main gaseous pollutants SO_2, NO_x O_3 and NH_3 will be measured continuously.
As a further goal we will try to develop a model to quantify wet and dry deposition onto the trees and the soil under various meteorological conditions.

Finally we will have to determine exposure-effect relationships for the Douglas fir in regard to possible 'sensitive periods' for physiological damage and episodicity of the deposition. This will be done in close cooperation with research groups on tree physiology.

In addition to the continuous monitoring program over a period of about two years, other measurements will be taken during a few months each year. TNO (Netherlands Organisation for Applied Scientific Research) will determine levels of reactive hydrocarbons; ECN (Netherlands Energy Research Foundation) will sample acid gases and determine acids and photochemically active species in fog and dew. These measurements are intended to provide information about ohter components which can possibly play an important role in the decline of the Dutch forests.

The selection of the field stations has been rather difficult until now, due to the various requirements of the cooperating research groups, such as aerodynamic fetch, soil homogenity and stand vitality. Most Dutch forest plantations are rather small and generally surrounded by quite different environments, including industrial and agricultural areas with possible emissions of the pollutants of interest. Consequently parts of the research effort have to evaluate the influence of nearby sources, to quantify edge effects and to judge the representativity of the measuring sites.

3. EXPERIMENTAL LAY-OUT

In the central part of both Douglas stands a 30 m measuring tower will be erected with five arms bearing sensors. There will be two measuring levels above the canopy, two within and one below (see figure 1.). At all heights concentrations of SO_2, NO_x, O_3, NH_3, wind speed and direction, temperature and relative humidity will be measured. At the top level rainfall intensity and global radiation will be registered. If possible, the leaf wetness period will be monitored at the same levels.

Signal cables and Teflon tubing transport electrical signals and gases into a container next to the tower. The air entering the sampling lines is filtered from aerosols to avoid contamination of the tubing by aerosols. Filters will be renewed on a regular basis to avoid gas-

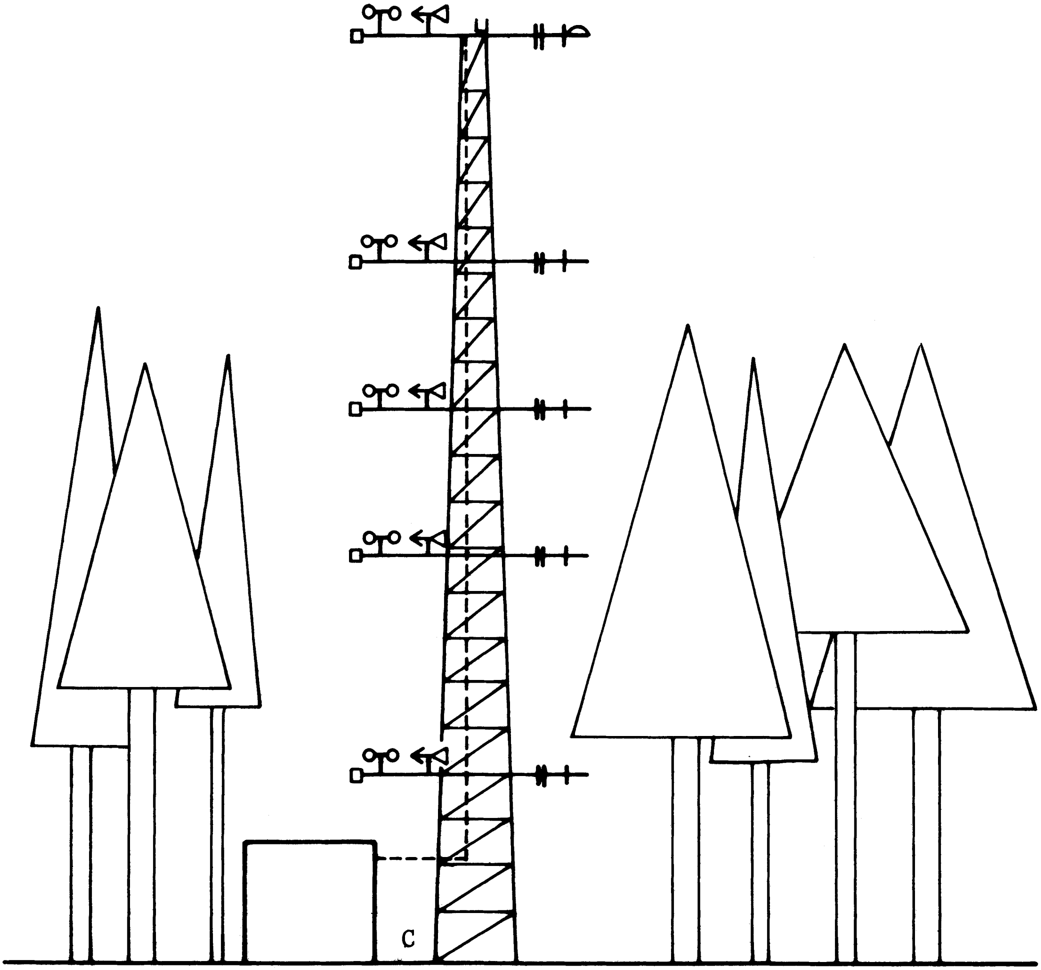


FIGURE 1. Lay-out of the measuring tower

C = Measuring container with NO_x, SO_2, NH_3 and O_3 monitors and data processing unit

= incoming solar radiation intensity

= temperature

= relative humidity

= rainfall intensity

= wind direction

= wind speed

= entrance filter for teflon tubing

particle interferences. Both tubing and filter housings will be heated slightly to keep all surfaces dry.

Within the measuring container, which is air conditioned, the instruments mentioned in table I analyse the incoming air by taking a small sidestream from the fast flowing mainstream of air. This is done to achieve a short residence time in the tubing. All other dimensions will be chosen so that an excessive pressure drop in the sampling system is avoided. Of course there will still be some sampling artifacts due to dissociation of ammonium salts on the filter, but we can avoid other severe artifacts such as differences between analysers or contamination of the tubing by retention of aerosols. The performance of the sampling system will be tested intensively in the laboratory and during the field experiments.

TABLE I. Gas analysis Equipment

Component	Analyser	Principle + Remarks
SO_2	Thermo Electron 43W	Fluorescence
$NO + NO_2$	Monitor Labs 8840 or Philips PW 9764/00	Chemoluminescence
O_3	Bendix 8002	Chemoluminescence + ethylene
NH_3	Monitor Labs 8840	Chemoluminescence + Tungsten oxide preconcentration units and SS catalyzer

Signal processing and steering of the equipment is done by an 'ARCOM'-system connected to a Digital PDP11 DTC 7367/WS computer, which also services equipment installed by other groups. The data will be stored on magnetic tape to obtain a central database, which can be used by all participants.

All instruments will be guarded against lightning as much as possible. For example, measuring towers and containers will be grounded thoroughly; for the incoming signals optical couplers will be used.

In addition to the continuous measurements our laboratory will organize measuring campaigns to characterize aerosol size-distribution and composition near the field site.

With the help of a mobile tower we will try to quantify the spatial variations in the concentrations of gaseous pollutants, especially near forest edges.

We are still considering direct measurement of deposition fluxes by exposure of surrogate surfaces. Due to differences in micrometeorological, physical and chemical properties between these and natural surfaces it will only give us an idea of the spatial variations in aerosol deposition and not the absolute amounts.

As we have already mentioned, ECN and TNO will sample acid gases, dew, fog and reactive hydrocarbons.

Bulk precipitation, wet-only precipitation, throughfall and litterfall will be sampled and analysed by the Department of Soil Science and Geology of the Agricultural University of Wageningen, in cooperation with the Laboratory of Physical Geography and Soil Science of the University of Amsterdam. They will also determine the soil water content, soil saturation pressures and soil temperature, as well as the chemical composition of the soil solution and the soil air.

Tree growth and leaf area index will be measured regularly by the Insitute for Forestry and Landscape Planning 'De Dorschkamp' (Wageningen). Needles of different ages and exposure to radiation will be analysed for composition. The Dorschkamp will also perform photosynthesis measurements in transparant cuvettes which will be mounted around twigs of a few selected trees. These measurements have to provide the link between the average gas concentrations and the direct effects on the needles. Therefore the twigs will be exposed to filtered air, (polluted) ambient air and air with a fixed level of one or more main pollutants (SO_2, NO_x, NH_3 or O_3). CO_2 and water vapour concentrations will be measured at the exit and entrance of the cuvettes.

Root growth will be monitored by another department of the Agricultural University (Forestry), using an endoscopic technique in prepunched holes in the forest floor. After the completion of the monitoring program some destructive samples of roots and trees will be taken.

4. INTERPRETATION

During the monitoring program a very large dataset will gradually become available. Analysis will not be easy, since many external factors can influence growth and vitality of a tree. A first step in determining the role of air pollution in this process will be the statistical evaluation of the concentration levels, e.g. calculating average concentration levels, frequency distributions, and their relation to the large scale meteorology above the forest.

As a next step we will try to estimate the pollutant fluxes to parts of the vegetation and the soil from the measured concentration profiles. A rough method of doing so is putting these fluxes equal to the measured concentration gradients times a turbulent diffusion constant: $F_c = K_c * dC/dz$. By using the analogy of electricity (Ohm's law) we can put the pollutant flux equal to the current, the concentration gradient to a potential difference and the reciprocal value of the diffusion constant to a resistance. Then we can treat the forest as an electrical circuit and calculate the fluxes, provided that we have the correct values for the resistances.

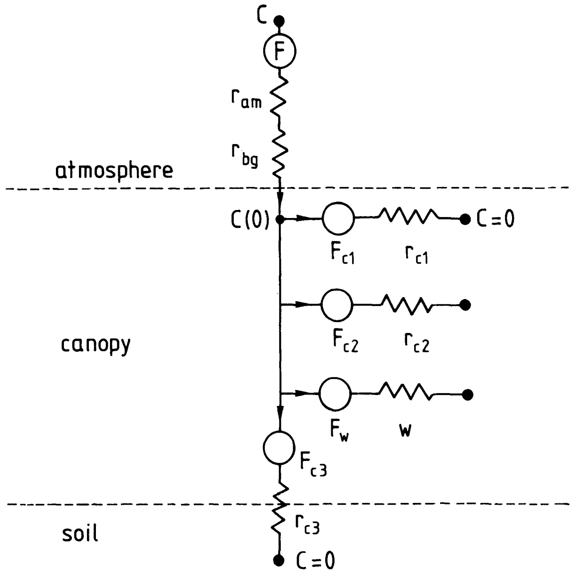
Such a 'resistance model' can have as many layers as desirable. An example of a simple one-layer model was given in Grace et al. |2| (figure 2.). As radiation intensity, stomatal resistances, wetness of the canopy and the amount of needles and twigs per unit volume show large variations within the canopy, we intend to use a multilayer model. |3| However, this still is a rather simple model, which in its present form can only be used for the calculation of vertical fluxes in a stationary situation. To include dynamic processes as interception, evaporation, dew formation, photosynthesis rate and stomatal responses to various factors, we need a micrometeorological model such as MICROWEATHER. (Goudriaan, 1977 & 1979) |4||5| Pollutant exchanges can be built in the same way as the CO_2 and water vapor exchange; uptake resistances for these processes can be calculated by this model. Nevertheless good care should be taken when modelling the uptake of reactive gases as HNO_3, for which stomatal resistance is essentially zero. Further exchange processes are quite different within a wet canopy, which can be a perfect sink for most gases until saturation of the water phase occurs. Therefore some of the modelling effort will concentrate on the uptake by and the chemical processes in droplets or layers of water. From laboratory experiments in a small wind tunnel and some model calculations we already know that SO_2 and NH_3 favour mutual deposition on a wet surface by alteration of the pH. |6| Measurements of throughfall composition in a Dutch forest by van Breemen et al. |7| have shown the deposition of equal amounts of NH_4 and SO_4, 5 - 20 times larger then in rainwater. This probably reflects the large capability of a wet canopy to store pollutants and emphasizes the important role of NH_3 in deposition processes in the Netherlands. Interpretation of the throughfall measurements will be done in cooperation with the participating soil research groups.

In a later stage of the project an attempt will be made to calculate aerosol size distributions and profiles within the canopy to compare them with results obtained during some measuring campaigns. Recently some modelling results were published by Wiman and Ågren |9|, showing a strong influence of particle size on aerosol dispersion and depletion in a forest.

If we succeed in estimating the fluxes of the main gaseous pollutants to the vegetation under various conditions, we still have to relate these fluxes or the measured concentrations to the observed effects such as e.g. photosynthesis reduction. We expect that the simultaneously running cuvette experiments will provide extra information on the physiological responses of a tree. Nevertheless there still is a significant gap in our knowledge as far as processes inside a tree are concerned. The redistribution of chemical species in tree parts and the modelling of biochemical cycles and growth remain subjects for additional research.

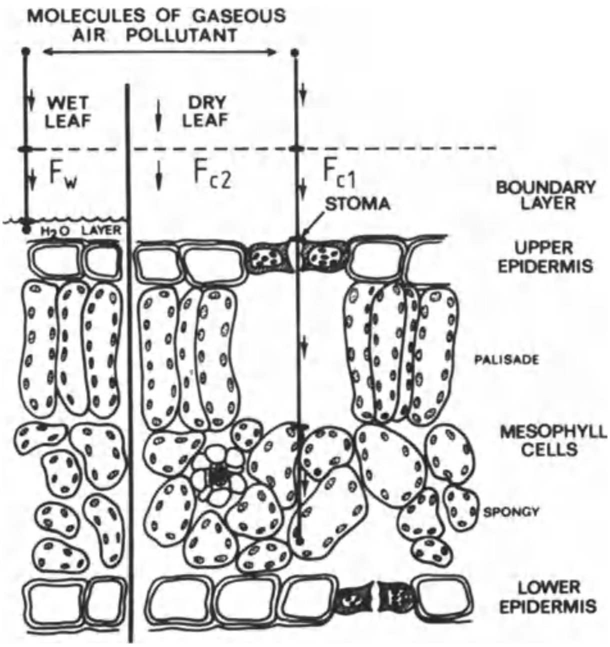
Another problem arises when we consider the representativity of our measurements. Dutch forest stands are rather small and often surrounded by other tree or vegetation types. Near the edges of our measuring site we will probably find quite different concentration profiles. Additional measurements with a mobile tower will have to provide more detail about the horizontal variations.

On the other hand the models we intend to use are only fit for a horizontally homogeneous situation. They will not be able to resolve concentration differences within a small and inhomogeneous forest stand. Even when we would have a large forest stand with a sufficient



(a)

FIGURE 2. (a) A one-layer resistance analogue for pollutant uptake by a crop canopy (Grace, 1981). |2| The canopy resistance is the result of the resistances in four parallel paths: stomata (R_{c1}), cuticle and dry surfaces (R_{c2}), soil (R_{c3}) and moisture trapped on leaves (w). Fluxes F_{c1}, F_{c2}, F_{c3} and F_w travel along each path.
(b) Cross-section of a leaf, showing parallel transport ways for gaseous air pollutants near and inside a leaf. (Smith, 1981). |8|



(b)

upwind fetch, we would find spatial differences in concentration profiles on the scale of the tree interspaces, due to an irregular distribution of up- and downdrafts, especially under buoyant conditions.

Aside from the spatial fluctuations there will be fast changes in time of the turbulent transport of momentum, mass and heat, which can not be detected by our 'slow' gas measuring techniques. There are even indications that in a forest a large part of the turbulent transport occurs during a few short events, due to gusts with a typical time constant of 20 to 40 seconds. (Shaw) |10| During these 'gusts' or 'sweeps' counter-gradient transport often occurs, as is evident from data presented by Denmead and Bradley |11|, who have compared fluxes, calculated from gradients, to direct eddy-correlation measurements. These sudden changes in the flow regime may be caused by large-scale eddies, generated by inhomogenities in the upwind surface roughness.

5. CONCLUSIONS

From the points stressed above it is clear that additional field research on flow characteristics as well as the dispersion of air pollutants in forests is needed badly. Especially intensive measuring campaigns during which both flux-gradient and eddy-correlation techniques are used at the right place and time are able to increase our understanding of transport processes in forests. Since the eddy-correlation method is a rather expensive technique and not always fit for continuous operation, the monitoring of pollutant concentrations under all conditions will be the first step to take.

As far as modelling is concerned we have to conclude that we are far away from a correct description of pollutant exchange in a forest. Therefore we shall, as a first approach, have to rely on the classical resistance models, often used for lower vegetation types, and make ad hoc adaptations whenever necessary.

During the next few years more information on this subject will gradually become available from this project and others of the same type in Canada, Germany, France and Switzerland.

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