WORLD HEALTH ORGANIZATION
REGIONAL OFFICE FOR EUROPE

WELTGESUNDHEITSORGANISATION
REGIONALBÜRO FÜR EUROPA

ORGANISATION MONDIALE DE LA SANTÉ
BUREAU RÉGIONAL DE L'EUROPE

ВСЕМИРНАЯ ОРГАНИЗАЦИЯ ЗДРАВООХРАНЕНИЯ
ЕВРОПЕЙСКОЕ РЕГИОНАЛЬНОЕ БЮРО

14044

ECOLOGICAL EFFECTS OF AIR POLLUTANTS

Working Group

Neukirchen, Austria,
24-28 June 1985

ICP/CEH 002/m71
0576i
ENGLISH ONLY
UNEDITED REPORT

1985

CONTENTS

1. Introduction

The meeting was held at the office of the Austrian National Park "Hohe Tauern" in Neukirchen am Grossvenediger with the State of Salzburg and the Austrian Government as hosts. Mr Kremser, Director of National Park, Hohe Tauern, welcomed the participants and conveyed greetings of the State of Salzburg, and Professor Donaubauer welcomed participants on behalf of the Federal Government. The meeting was opened by Dr R. Türck on behalf of Dr J.E. Asvall, Regional Director, WHO Regional Office for Europe.

The WHO Regional Office for Europe is in the process of establishing air quality guidelines with relevance to the countries of the European Region. A planning meeting held in early 1984 produced an agreement to evaluate a group of pollutant substances, divided into five categories, one of which included, among other substances, SO_2, NO_x and ozone/photochemical oxidants. These substances were evaluated by a Consultation group with regard to their ecological effects, particularly on terrestrial vegetation. The group comprised 13 temporary advisers from the European Region and the United States.

2. Scope and purpose

Although the main objective of the Regional Office's project on establishing air quality guidelines is the protection of human health, the planning meeting decided that the ecological effects of air pollutants should also be considered. The effects of air pollutants on the natural environment are of special concern when they occur at concentrations lower than those that damage human health. In such cases, air quality guidelines based simply on effects on human health would allow for environmental damage that might indirectly affect human health.

The pollutants selected for consideration (SO_2, NO_x and ozone/photochemical oxidants) form only part of the vast range of air pollutants; furthermore, the effects which were discussed are only part of the spectrum of ecological effects. Nevertheless, the examination by the group indicates the importance attached to such pollutants and to their effects on terrestrial vegetation in the European Region. Moreover, both the human health and ecological effects of these pollutants are relatively well documented.

In a later phase of the air quality guidelines project, recommendations for ecologically based guideline values will be combined with those concerning direct health effects in order to provide more comprehensive recommendations for Member States.

After the presentation of scope and purpose Mr Goerke as chairman and Dr Johnsen as rapporteur of the meeting were elected.

3. Discussion

The distinction between guidelines and actual air quality standards (which can be promulgated only by the Member States), was made.

The group agreed that ecological aspects should be included in air quality guidelines because human health was ultimately dependent on a healthy environment.

The various issues before the Working Group were framed in the form of following topics:

Definition of the pollution scenario to be dealt with.

Concept of concentration-based guidelines versus dose-related considerations.

Determination of pollutant fluxes to ecosystems.

Relation between effects due to single pollutants and effects due to actually occurring pollutant mixtures; the necessity of considering mixture problems when deciding upon guidelines concerning single pollutants.

Feasibility of developing NAEL (no adverse effect level) guidelines, in consideration of the problem concerning combination effects and the limited adequacy of the present database for such an exercise.

Pollutant distribution in time and space.

Identification of particular sensitive ecosystems to be used in worst thinkable case scenarios.

Formulation of long-term goals for air quality.

3.1 Definition of the pollutant scenario to be dealt with

Any living organism exposed to ambient air may react more or less strongly to all the components cooccurring in the ambient air. In spite of this, the meeting agreed to confine itself to the effects of SO_2, NO_x and ozone/photochemical oxidants on terestrial plant life.

The development of air quality guidelines for the above gaseous pollutants was considered very useful as a first step towards regulations that also protect ecosystems. When the further review of such guidelines is necessary, it must be based on a more extensive database than the present one, and in particular must take the following interactions into account:

Direct versus indirect effects;

Primary versus secondary pollutants;

Synergism and antagonism;

Climatic conditions versus pollutant impact and

Biotic versus abiotic stress factors.

a) Direct versus indirect effects

The direct effects are those due to gaseous foliar uptake, primarily through the stomata, thereby influencing photosynthesis negatively. Indirect effects are, e.g. changes in growing conditions due to alterations of soil properties (edaphic factors), such as decreased nutrient content and increased mobility of toxic ions. These two types of effect are not well separated in the environment, and any ecosystem will be subject to both types of impact. Therefore, guidelines for air quality should include deposition rates in the future. This is particularly important with respect to nitrogen and sulfur.

b) Primary versus secondary pollutants

Primary pollutants emitted to the air are, e.g. SO_2, NO, NO_2 and simple hydrocarbons. These compounds may affect all plants and animals directly. By atmospheric chemical reactions, often of a complicated nature, these primary pollutants are converted into other compounds. Sulfates, nitrates and photochemical oxidants (including ozone) are formed, the so-called secondary pollutants. The process of sulfate and nitrate formation goes along with the production of hydrogen ions. When aiming at guidelines for the primary pollutants mentioned above, the formation of secondary pollutants from these precursors must be considered. The compounds NO_x - hydrocarbons - ozone/PAN (peroxyacetyl-nitrate), form a particularly important multifactorial regulation problem and have to be dealt with in an integrated fashion. Another example of a complex problem is the connection between hydrogen ion formation, and thus pH of rain water (acid precipitation), and the ambient air levels of SO_2 and NO_x.

c) Synergism and antagonism

Experiments have shown that simultaneous fumigation of plants with combinations of gases such as SO_2, NO_2 and ozone, lead to results which differ from what might be expected from fumigation experiments with the same gases individually. Plants often do not react in an additive fashion to exposure against two more pollutants, but either synergistically, i.e. the combined effect is larger than expected, or antagonistically, i.e. the combined effect is smaller than expected from experiments with the individual pollutants. Even though experimental observations on combined effects are rather scanty, the mere occurrence of synergism and antagonism constitutes a major problem when setting air quality guidelines for single pollutants. Ozone, SO_2 and NO_x may all occur together or sequentially, and the combined influences may thus change plant response considerably. The guideline values should help to protect most plant species from such combined effects. At this time, data in Europe are inadequate to deliver a quantitative and qualitative picture of pollutant co-occurrencies and their geographic distribution and therefore air quality guidelines for pollutant combinations cannot be produced at this time.

d) Climatic conditions versus pollutant impact

Climatic conditions vary strongly throughout Europe. Large areas are subject to prolonged winter stress, which may accentuate the adverse effects of air pollutants. The relief of the European surface further adds to the complexity. Mountain slopes receive more moisture from condensation of water than do the neighbouring valleys, and concentrations of SO_2, NO_x and ozone vary with height. Extensive forest die-back in central Europe at altitudes about 1000 m.ab.s.l. has been assigned to the higher ozone concentrations occurring at these altitudes, where the deposition of acidic substances dissolved in water also reaches a maximum. The seemingly greater sensitivity of forests at high altitudes may be paralleled with the general assumption that boreal forests are believed to be particularly sensitive to air pollution due to severe climatic stress during winter.

In conclusion, the most sensitive ecosystems are often those adapted or confined to extreme climatic habitats, and the selection of such early warning systems may partly be based, therefore, on bioclimatic considerations. Particularly sensitive ecosystems may serve as an indicator for the effectiveness of environmental management.

e) Biotic versus abiotic stress factors

Forest die-back as a result of strong attacks by parasites (fungi, insects etc.) has been known for centuries. The present die-back syndrome also includes biotic factors of more or less well-known nature. The natural defense system in plants and animals against pest infection may be disturbed or weakened by air pollution, indicating a relation between biotic and abiotic stress in ecosystems. The confounding biotic factors should also be taken into account when setting air quality guidelines, but this represents a large problem. Too little is known about basic defence mechanisms against parasites and thus even less about the interaction of air pollution with these organisms.

3.2 The concept of concentration-based guidelines versus dose-related considerations

The concept of expressing guideline values in terms of air pollution concentrations was accepted. However, this approach does not totally reflect dose-effect relationships; very different doses may result from identical averages of air concentrations. Since the reaction of a plant to a given pollutant is related to dose rather than concentration in the recipient, the concentration limits to protect plants must be defined according to knowledge of dose-effect relations. This means that air quality guideline may need to be adjusted, as the understanding of concentration with time variations and their implications for plant and animal life is improved.

3.3 Determination of pollutant fluxes to ecosystems

Some air pollutants may accumulate in ecosystems as a result of increasing anthropogenic emissions to the atmosphere. The accumulation takes place when input exceeds output for an element or a chemical compound. Ozone and other photochemical oxidants do not accumulate; they are rapidly broken down upon contact with organic matter, thus causing damage to e.g. membranes, a direct type of effect. In the case of SO_2 and NO_x, the present input to natural ecosystems in most cases exceeds the output. To some extent, the excess nitrogen and sulfur are incorporated in living tissue. Excess nitrogen and sulphur may induce higher growth rates in plants, in particular in the case of nitrogen, which in many unpolluted ecosystems is at a minimum. At a later stage of higher air pollution, which probably already has been reached in many natural European ecosystems, the accumulation of nitrogen is believed to cause problems for the functioning of plants. Sulfur compounds, which are not so efficiently taken up by plants as nitrogen compounds, may impose a different problem when supplied in excess amounts. Sulfate leaches easily through the soil profile and is always accompanied by equivalent amounts of cations, e.g. Ca^{2+} and Mg^{2+}, which eventually are removed from the topsoil, thus causing nutrient deficiency.

In conclusion, deposition of SO_2 and NO_x need to be regulated in addition to air quality guidelines, only based on concentrations in air. Low air quality guidelines shall, of course, to some extent ensure low deposition rates, but this is not always the case, as deposition rates are determined by the average levels over long time periods and not by short-term peak concentrations in the air.

3.4 The relation between effects due to single pollutants in comparison with the actually occurring pollutants mixtures

Besides the difficulty to evaluate the combined effects of NO_2, SO_2 and ozone, there is the problem of how to take into account the multitude of other pollutants predisposing the ecosystem to impact from the above three gaseous pollutants. This is possible only when the specific nature of such abiotic factors is known. Perhaps the most important pollutants in this respect are the heavy metals. They are known to interfere with a number of processes in ecosystems and may easily accumulate. The deposition rates of heavy metals and their compartmental concentrations have to be measured before safe statements can be made about the influence of the above three gaseous pollutants. The same situation probably exists for a number of other pollutants.

3.5 The feasibility of developing NOAEL-guidelines including combined effects; the adequacy of present data

From the above-mentioned confounding circumstances, identification of NOAEL's is problematic. The air quality guidelines are based on lowest observed adverse effect levels (LOAEL's). To search for "safety factors" for ecosystems (factors reducing the LOAEL to NOAEL) was not believed to be feasible. However, from data on direct effects of gases on plants it should be possible to find levels below which adverse effects are highly improbable.

3.6 Pollutant distribution in time and space

A problematic aspect of pollutant distribution with time, i.e. the concentration time pattern is: how do ecosystems react to sudden changes of concentrations in contrast to gradual changes between two different average levels? It was the general opinion that while short term variations may be camouflaged in the overall ecosystem reaction, long-term trends pose a more serious problem. Therefore, the reaction pattern in an ecosystem differs from that of an individual higher plant. As regards the spatial distribution, the three gaseous pollutants in question have characteristic vertical and horizontal patterns. Values for SO_2 and NO_x are normally well correlated, and their concentrations decrease steadily with distance from the source area. Furthermore, the highest levels of these pollutants occur close to the ground. In contrast, ozone reaches peak values in the outer periphery of larger urban areas but may indeed also be transported over long distances. This latter point is documented by elevated levels of ozone over large areas of Europe during periods with conditions especially favourable for ozone formation in the lower troposphere. Ozone levels are highest between 500 and 1000 m.ab.s.l. in central Europe in remote regions during the summer time. This fact has stimulated the hypothesis that ozone plays a role in forest die-back, which is particularly severe at these elevations.

3.7 Identification of particular sensitive ecosystems representing the worst thinkable case with respect to adverse ecological effects

Sensitivity may be defined in a number of ways. Sensitive ecosystems shall be understood as ecosystems which, by their species composition and/or overall structure, either accumulate certain elements strongly or react directly in a negative way at low pollution levels. With respect to NO_x, SO_2 and ozone, the following systems were mentioned:

a. Epiphytic communities with a high percentage of lichen. These communinities are highly sensitive to SO_2, while their sensitivity to NO_x and ozone are within the normal range of plant sensitivity.

b. Ombrotrophic mires. These unique ecosystems, supplied exclusively with nutrients from the air, accumulate heavy metals and show a high sensitivity to SO_2 and NO_x, causing changes in the composition of *Sphagnum* species.

c. Heathlands dominated by dwarf shrubs, lichens and mosses growing on land. These ecosystems are mainly sensitive to increased eutrophication, in particular from increased deposition of nitrogen in rural areas.

d. Oligotrophic lakes with clear, shallow water and containing species like *Lobelia dortmanna*, *Isoëtes echinospora* and *I. lacustris*, *Litorella uniflora* and *Pilularia globulifera*. These are normally situated in nutrient-poor areas. They are sensitive to pH decrease of rain water, which may stimulate invasion of *Sphagnum* species, and also to eutrophication, which may enhance growth of planktonic communities. In both cases, the characteristic flora of such lakes will become subject to stronger competition for available light and nutrients.

These ecosystems constitute examples of early warning indicator systems. Success in protecting the environment from negative effects of SO_2, NO_x and ozone may be inferred from the behaviour of these ecosystems. As they will react before most others, their state of health is a good measure of environmental quality.

One of the most sensitive ecosystems towards ozone may be the European coniferous forest. With respect to ozone, experimental methods, comprising controlled environments ("open top chambers", laboratory growth chambers, etc.) and especially sensitive plant varieties must still be applied.

3.8 Formulation of long-term goals for air quality

Knowledge about long-term affects is very limited and, most problematic, the natural variation with time in long-lived ecosystems such as forests is not known. Too few long-term baseline studies have been undertaken. Consequently, a solid reference is needed for the fluctuations so readily assigned to anthropogenic factors. Therefore, as our knowledge increases, air quality guidelines may have to be amended. The main problem is that a point of no return may be reached, where a real possibility to change the situation no longer exists. Two cases in point are heavy metal deposition and soil changes due to input of nitrogen and sulfur compounds from the atmosphere. Therefore, appropriate steps should be taken forward in emission control today, when our scientific knowledge justifies such action.

Following the general discussion, three subgroups were formed dealing with ozone/photochemical oxidants, SO_2 and NO_x respectively. The subgroups' findings were discussed by the participants in plenary session and the following conclusions and recommendations were formulated.

Conclusions

SO_2

SO_2 results from combustion of sulfur-containing fossil fuels, the smelting of sulfur containing ores, and other industrial processes.

It is mainly deposited to the earth's surface by dry processes, but with increasing distance from source, it is converted to sulphate, which is removed by various forms of precipitation. Ultimately nearly all sulfur deposition results from the emission of SO_2 and thus recommendations made here are based on ambient levels of the gas.

Natural SO_2 concentrations are less than 5 ug/m^3, but in Europe most rural areas experience annual means of 5-25 ug/m^3. However, means above 25 ug/m^3 are fairly common in agricultural and forested regions, while urban values range between 50 ug/m^3 and 130 ug/m^3; even higher values are recorded in certain places.

The uptake, and subsequent impact of SO_2 are determined by the concentration and duration of exposure as well as genetic sensitivity of the plant. The response also is influenced, in large measure, by environmental parameters including windspeed, temperature, relative humidity, light intensity, elevation and soil moisture and chemistry, as well as the presence of other air pollutants. SO_2 can also predispose plants to other environmental stresses, including frost, drought and biotic agents.

Although SO_2 can cause visible injury on foliage, growth is often reduced and metabolic processes disturbed in the absence of such symptoms. This emphasizes the difficulty in readily evaluating impacts of SO_2 in the field.

The lowest SO_2 concentrations shown in controlled long-term fumigations to affect agricultural field crops are between 40 ug/m^3 and 60 ug/m^3.

The lowest SO_2 concentrations in fumigation experiments which have reduced forest tree growth are between 60 ug/m^3 and 80 ug/m^3 over a period of approximately two years. However, this period covers only a small fraction of a tree's lifetime and in field studies growth reductions have been observed in the SO_2 concentration range of 20-30 ug/m^3 (yearly averages) in areas with severe climatic stresses. The highly sensitive lichen component of forest ecosystems is not protected from damage at these levels.

Filtration experiments that compare plant growth in ambient and purified air have shown that mean SO_2 levels as low as 34 ug/m^3 over 28 days are capable of reducing plant growth. In such cases NO_2 and ozone are very probably contributing factors.

There are currently insufficient data on the combined impact of wet and dry deposition on ecosystems to permit the establishment of an appropriate air quality guideline.

NO_x

Oxides of nitrogen are only a part of the total nitrogen-based atmospheric pollution. Emissions by combustion processes consist mainly of nitric oxide (NO) and nitrogen dioxide (NO_2). In combination with hydrocarbons, oxides of nitrogen are also precursors of ozone. Soils may emit dinitrogen oxide (N_2O) which is very stable in the troposphere and unreactive towards vegetation. As the most abundant oxide of nitrogen, it may ultimately have significant global effects by promoting enhanced destruction of ozone in the stratosphere. Both NO and NO_2 take part in many atmospheric reactions to form secondary pollutants such as gaseous nitric acid (HNO_3), and nitrite (NO_2) and nitrate (NO_{-3}) in aerosol form. Ammonia (NH_3), emitted mainly by agricultural activities as well as the ionic product ammonium (NH_4+), are also important components of nitrogen-based atmospheric pollution and are associated with problems of eutrophication and acidification as well as having their own direct effects.

Within the last 20 years ambient air levels of oxides of nitrogen have increased continuously. In Europe today, for example, levels of NO and NO_2 on the basis of annual averages reach 10-40 ug/m^3 in rural areas, whereas in urban and industrial areas 40-200 ug/m^3 are often experienced. Near busy roads concentrations can reach 300 ug/m^3. Levels of oxides of nitrogen are still rising in most parts of Europe and are expected to continue to do so in the absence of stringent emission controls.

The flux of nitrogen compounds from the atmosphere to terrestrial and aquatic ecosystems depends on the atmospheric concentration of these compounds, the climatic conditions and the properties of the receiving surfaces. Thus similar concentration levels in the atmosphere of, say, NO_2 in two geographically separate areas do not necessarily imply similar fluxes of NO_2 in these areas. Furthermore, the total deposition of all the nitrogen compounds from the atmosphere to different ecosystems is the sum of the individual fluxes. In conclusion, when establishing air quality regulations not only ambient concentrations but also variations in individual deposition fluxes should be considered.

Nitrogen-containing compounds in the atmosphere are many; consequently, guideline concentrations must take into account the various nitrogen-containing compounds as well as combinations with sulfur dioxide and ozone which are more likely to occur together in Europe than elsewhere in the world.

NO_2 is the most phytotoxic oxide of nitrogen. Foliar injury is often caused by mixtures of NO_2 with SO_2 and /or ozone at threshold concentrations much lower than for individual pollutants. However, the foremost consequence of pollutant mixtures is reflected by reductions in plant growth. To protect sensitive plants against direct effects of NO_2, the ambient concentrations should not exceed 30 ug/m^3 (in the presence of levels of SO_2 and O_3 not higher than 40 ug/m^3 and 60 ug/m^3 respectively) as a yearly average of 24 h mean values (preferably measured using chemoluminescent techniques).

Limiting the one year average level of a pollutant does not effectively protect the environment against peak values. Therefore, proposals for limiting peak concentrations should be included. Sensitive plants are protected against the adverse effects of NO_2 if the average concentration over four hours does not exceed 95 ug/m^3 (in the presence of similar concentrations of SO_2).

It is not possible to define no-effect levels of nitrogen-based air pollutants with respect to deposition because even small changes in nitrogen fluxes in some ecosystems may induce major changes. Therefore, guidelines for total nitrogen deposition would be an effective approach for the protection of sensitive ecosystems. Unfortunately, methods for determining total nitrogen deposition are not widely available at present.

Oligotrophic ecosystems are threatened by the increasing deposition of nitrogen and ombrotrophic[a] mires are among the most sensitive ecosystems with regard to nitrogen-based air pollutants. For the survival of these mires total deposition of nitrogen should be below 3g $m^{-2} y^{-1}$. Although it is difficult to relate atmospheric concentrations to these inputs, long-term levels of NO_2, NO and NH_3 should each be below 10 ug/m^3. Since wet deposition of NH_4^+, NO_3 and organic nitrogen contributes significantly to eutrophication of these systems, this wet deposition should be reduced below 1g $m^{-2}y^{-1}$.

---

[a] ombrotrophic = supplied with nutrients from rainfall only

The proposed guidelines for air quality cannot adequately protect sensitive ecosystems from nitrogen enrichment. Thus a long-term goal for levels of total nitrogen deposition should be below 3g $m^{-2} y^{-1}$ noting that depositions of nitrogen upon forests are several times higher than to open areas.

Ozone/photochemical oxidants

Ozone occurs naturally in high concentrations in the stratosphere but is present in the lower atmosphere at concentrations in the range of 40 to 80 ug/m^3 based on hourly averages. These values may vary somewhat over different parts of Europe. Anthropogenic ozone is formed from the reaction of nitrogen oxides and hydrocarbons in the air during periods of sunshine when uv-radiation is high. These precursors are formed largely from combustion processes.

Elevated concentrations of ozone have been reported to occur in urban areas of North America and Europe within the range of 300-750 ug/m^3 per hour. The highest 30-minute average reported for Europe was 664 ug/m^3 in Mannheim (Federal Republic of Germany). Ozone is regionally distributed; its non-urban concentrations may be of the same magnitude as those in urban areas but may persist over longer periods of time. Over the past 20 years there has been a substantial increase in ozone concentration over central Europe. Recent evidence shows that, contrary to previous belief, ozone is a regional problem in Europe. Peak concentrations of peroxyacetylnitrate (PAN) (another photochemical oxidant) in Europe are less than half of the 100-150 ug/m^3 (hourly average) measured in California.

The uptake, and subsequent impacts, of ozone and other photochemical oxidants are determined by the concentration and duration of exposure as well as by the genetic and environmentally conditioned sensitivity of the plants. The response also is influenced, in large measure, by environmental parameters including windspeed, temperature, relative humidity, light intensity, elevation and soil moisture and chemistry, as well as the presence of other air pollutants. Interactions with fungus and insect pests can also be important where ozone has predisposed the plant to infection.

Photochemical oxidants, especially ozone, damage leaves and needles of sensitive plants, largely by disrupting membrane integrity, but metabolic processes such as photosynthesis are also affected. Visible features such as leaf-yellowing, necrosis, defoliation and premature senescence may also become apparent. Characteristic symptoms of ozone pollution such as chlorotic and necrotic flecking have been observed in Europe on plants such as clover, vines, potatoes, peas and beans. Clovers are among the most sensitive native plants to ozone in Europe.

In addition to visible, morphological responses, impaired physiological processes may inhibit yield and reproduction, and reduce growth and quality at lower concentrations than those causing visible symptoms. In ecosystems such as forests, the more sensitive individuals and species may be eliminated, giving way to more tolerant (and sometimes less desirable) species, thus changing the sociobiology.

The time-concentration patterns of ozone exposure are critical to plant responses, as are site conditions and the stage of plant development. Characterization and representation of plants' exposure to ozone continues to be a major problem. Most studies have characterized exposure by the use of mean ozone concentrations, although various averaging times have been used. Some studies have also used the cumulative ozone dose.

Data on exposure thresholds have been derived largely from exposures of plants less than one year old and exposed in greenhouse or field chambers. The plant responses evaluated ranged from visible injury to growth and yield reductions. These data suggest that the lowest effective (i.e. threshold) concentrations of ozone during the growing season are 200 ug/m^3 for 1 hour, 65 ug/m^3 for 24 hours and 60 ug/m^3 for the growing season (100 days). The attainment of mean ozone concentrations below these levels should be adequate to protect the most sensitive plant species and ecosystems. These concentrations are only slightly higher, or may even overlap, background ozone concentrations. Nevertheless, the elevated ozone concentrations reported in Europe are harmful to plants and pose a risk to both agriculture and forests. Since the total exposure period is important to plant response, the life expectancy of the species becomes critical. Thus, the lowest effective concentration for conifers having an 80-100 year rotation may be lower than for annual, agricultural crops.

PAN primarily effects herbaceous crops, not trees, and consequently is not likely to be involved with forest decline. Furthermore, concentrations reported for Europe are not likely to pose a risk to agricultural crops. Data for PAN indicate the lowest effective concentrations to be 310 ug/m^3 for 1 h and 80 ug/m^3 for 8 h.

General

Ozone, SO_2 and oxides of nitrogen may all occur sumultaneously or sequentially, and their combined influence may change plant response considerably. The resulting effects may be greater than the sum of the effects of the individual pollutants and, if the concentrations of the co-occurring components are not higher than the recommended guideline values for individual components, most plant species will also be protected from negative effects due to such co-occurrences; however, the most sensitive ecosystems, including their lichen components, may not be completely protected. Data for Europe are at present inadequate to show the extent or frequency of pollutant co-occurrences.

Recommendations

SO_2

The maximum annual mean SO_2 concentration should be 30 ug/m^3, with 100 ug/m^3 as the 95th percentile. This guideline may, however, be insufficient in the case of extreme environmental conditions and/or the presence of other pollutants.

NO_x

In the presence of levels of SO_2 and ozone not higher than 30 ug/m^3 and 60 ug/m^3 respectively, the atmospheric concentration of NO_2 should be no higher than 30 ug/m^3 as a yearly average of 24-hour means and no higher than 95 ug/m^3 as a 4-hour average.

In order to protect sensitive ecosystems, the total nitrogen deposition should not exceed 3 $g\ m^{-2} y^{-1}$.

Ozone/photochemical oxidants

Mean ozone concentrations should stay below 200 ug/m^3 for 1 hour, 65 ug/m^3 for 24 hours and 60 ug/m^3 for the growing season.

The concentrations of PAN should stay below 300 ug/m^3 for 1 hour and 80 ug/m^3 for 8 hours.

General

Research should focus on exposure-response relationships for significant compartments of ecosystems on the basis of validated investigation and data-handling methods in order to improve assessment of the long-term impacts of total nitrogen and sulfur deposition on sensitive ecosystems.

Information concerning the effects of ozone in combination with SO_2 and nitrogen-based air pollutants on European plant species under actually occurring concentration patterns should be improved.

Research should be extended to determine the extent to which various pollutants predispose plants to biotic and abiotic stresses. More work is strongly in host-parasite relations and symbiotic interactions is strongly needed.

More efficient methods, emphasizing statistical design and analysis to determine the parameters that best characterize the exposures, are needed in order to extrapolate the results of experimental studies to ambient air conditions. These methods are also needed to separate the effect of air pollutants on plants from potentially confounding climatic and edaphic[a] factors in field studies.

A guideline for wet and dry deposition of sulfur and nitrogen should be developed as soon as possible as a major step towards the protection of sensitive ecosystems.

---

[a] edaphic = produced or influenced by the soil

ANNEX

TEMPORARY ADVISERS

Dr J.N.B. Bell
Centre for Environmental Technology, Imperial College
London, United Kingdom

Dr J.B. Bucher
Eidg. Anstalt f.d. forstliche Versuchswesen
Birmendorf, Switzerland

Professor E. Donaubauer
Forstliche Bundesversuchsanstalt
Vienna, Austria

Mr W. Goerke
Bundesministerium des Innern
Bonn, Federal Republic of Germany

Dr S.O. Huttunen
Department of Botany, University of Oulu
Oulu, Finland

Dr I. Johnsen
Institute of Plant Ecology, University of Copenhagen
Copenhagen, Denmark

Dr G.H.M. Krause
Landesanstalt für Immissionsschutz des Landes Nordrhein-Westfalen
Essen, Federal Republic of Germany

Dr K. Meijer

Ministry of Housing, Physical Planning and Environmental Management

Leidschendam, Netherlands

Dr A.C. Posthumus

Department of Phytotoxicology, Research Institute for Plant Protection

Wageningen, Netherlands

Dr D.T. Tingey

US Environmental Protection Agency

Corvallis, United States of America

Professor M. Treshow

University of Utah

Salt Lake City, Utah, United States of America

Dr A.R. Wellburn

Department of Biological Sciences, University of Lancaster

Lancaster, United Kingdom

Dr H. Werner

Ministry of Public Health of the German Democratic Republic

Berlin, German Democratic Republic

WORLD HEALTH ORGANIZATION

Regional Office for Europe

Dr R. Türck (Secretary), Project Coordinator, Air Quality Guidelines