REGIONAL COPPER-NICKEL STUDY

INTERACTIONS BETWEEN AIR POLLUTANTS AND PLANT DISEASES CAUSED BY BIOTIC AGENTS

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Stands of vegetation, whether native, introduced, or agricultural species, are subject to a wide range of diseases caused by biotic agents (fungi, bacteria, mycoplasma-like agents, viruses and nematodes). Often, individual plants and stands of plants are found to be affected by several of these pathogens. Similarly, plant diseases can be caused by a multitude of abiotic factors, or agents, such as air pollutants, either singly or in combinations. The role of abiotic agents and air pollutants in plant disease has been documented since the 19th Century and detailed explanations of their effects upon plants are found in other portions of this study. It is well known, however, that abiotic factors and agents can also interact with biotic agents and plants, and can influence the development of biotically caused plant diseases.

The study of the interactions between air pollutants and plant diseases caused by biotic agents is a relatively new area of investigation. There are two measurable interactions that may occur, and most published reports fall into two catagories:

1. Air pollutants such as sulfur dioxide, ozone, or fluoride may be toxic to disease-causing biotic agents, impair their growth and reproduction and thus partially or fully control the plant diseases they cause.

2. Air pollutants may injure plants and/or otherwise alter them, making them more susceptible to infections by certain biotic agents.

Thus, air pollutants, like the chemical oxidants sulfur dioxide and ozone, have been reported to both increase and decrease the incidence of plant disease caused by biotic agents. The ability of these air pollutants to either increase or decrease (the most easily measured events) the incidence of plant disease caused by biotic agents may at first glance appear confusing and contradictory, unless accompanied by a brief explanation of parasitism caused by biotic agents.

Biotic agents causing plant disease vary greatly in their abilities to parasitize plants. Certain fungi (rusts, powdery mildews, etc.), bacteria, and viruses are termed obligate parasites. Obligate parasites require living host cells and tissues for their growth and reproduction, and although they may persist outside of living cells in dormant forms they can only colonize and reproduce in living host cells. As a rule obligate parasites prefer well-nourished, actively-growing plant hosts. Other biotic plant parasites, mainly certain fungi and bacteria, are termed facultative parasites. Facultative parasites can live on dead organic matter and generally attack living plants only when particularly unfavorable conditions have predisposed the plant in such a way that it is unusually suceptible to the pathogenic properties of the facultative parasite. Thus obligate parasites attack normally healthy plants, whereas facultative parasites attack slightly weakened stressed or physiologically altered plants (Walker, 1957).

Two broad generalizations emerge when extensive reviews of the literature (Heagle 1973, Treshow 1975) pertaining to interactions between air pollutants and plant diseases caused by biotic agents are evaluated. First, air pollutants tend to decrease the incidence and severity of plant diseases caused by obligately parasitic biotic agents (rust, downy and powdery mildew fungi, many bacterial diseases, and viruses). Presumably the decrease in disease caused by obligate parasites is due to the fact that the host plants are altered by the air pollutants in such a way as to make them unsuitable for the obligate parasite, or the obligate parasite itself is very sensitive to the particular pollutant. Second, air pollutants tend to increase the incidence and severity of plant diseases caused by facultative biotic parasites. Presumably the increase in disease caused by the facultative parasites is due to the fact that the host plants are altered and/or stressed by the air pollutants in such a way as to make them more favorable hosts for the facultative parasites, and/or that the facultative parasites are not sensitive to the particular pollutants involved. As will be shown later, certain root rots, trunk rots and leaf diseases that normally occur at low levels in young actively-growing vegetation are the most likely to increase in incidence due to interaction with air pollutants like sulfur dioxide and ozone. Although there are exceptions to the above-mentioned generalizations, they are rare and pertain mainly to very specific situations found with agriculturally important, annual plant species.

The Influence of Sulfur Dioxide on Plant Diseases Caused by Biotic Agents

Sulfur dioxide (SO_2) is released into the atmosphere from point sources during ore smelting, fossil fuel combustion, petroleum refinement and from non-point sources through the natural sulfur cycle. Generally, SO_2 concentrations at ground level, (e.g. from point sources such as smelters) decrease rapidly with distance from the source. Thus, most investigations of the interactions between SO_2 and biotic plant disease agents have been conducted at various distances from point sources. Many of these have been at distances of 1-75 miles from large industrial sources of SO_2.

In reviewing SO_2-biotic disease interactions, it should be noted that most studies relied upon field observations; some were well planned and documented and others were rather casual obsrevations. Most studies have resulted from observations when mixtures of pollutants occurred but in which the principal pollutant was SO_2. With field studies there is always the possibility that something other than SO_2 caused the effects, although most published observations, whether carefully or casually done, tend to support each other and point to the fact that SO_2 emissions affect biotic diseases of plants. Although this discussion of the influence of SO_2 on plant diseases caused by biotic agents will be restricted to interactions with gaseous emissions, it should be noted that the oxidation and dissolution of SO_2 in water can increase the acidity of precipitation, soils, and surface waters (Swedish Royal Ministry Report for United Nations, 1971), and these alterations can also affect the course of plant diseases.

Decrease in incidence and severity of plant disease caused by biotic agents is the most commonly reported interaction with SO_2-containing emissions. Scheffer and Hedgcock (1955), in the United States, found decreased parasitism of fungal diseases (mainly rust fungi) caused by Cronartium, Coleosporium, Melampsora, Peridermium, Pucciniastrum, and Puccinia where trees were injured by SO_2. Scheffer and Hedgcock report that SO_2 injury decreases the incidence of fungal disease close to the SO_2 source but that fungal disease increases with increasing distance from the SO_2 sources. Linzon (1958), who studied the effect of smelter emissions in the Sudbury, Ontario region of Canada, reports a decrease in the incidence of white pine blister rust (caused by the fungus Cronartium ribicola). He reports that white pine showed white pine blister rust symptoms on less than one percent of the trees examined within 25 miles of the smelter complex, whereas 4 and 5 percent showed symptoms at 43 and 71 miles away, respectively. In the industrialized Ore Mountain region of Czechoslovackia, Jancarik (1961) reports observations on the occurrence of sporocarps (fruiting structures) of 40 species of fungi in both a severly polluted and a "clean" area. Six fungal species, Poria sp., (3) Mycena spp., Schizophyllum commune and Polyporus verisicolor were apparently absent from the severly polluted area. Heagle (1973), when reviewing the world literature on SO_2-biotic plant-disease interactions, reports that SO_2 decreases the incidence of fungal foliar diseases caused by the following Ascomycetes; Hypodermella laricis, Lophodermium pinastri, Hypodermella sp., Lophodermium juniperi, Hysterium pulicare, and Venturia inaequalis. Since Heagle's (1973) review, Treshow's (1975) review added further documentation to the reduction of certain foliar diseases, especially those caused by powdery-mildew fungi, and, in an original work, Domanski (1976) reports similar observations from Poland. Without going into greater detail about specific fungi, it is sufficient to state that the reduction of certain fungal diseases by SO_2 exists. It should be remembered, however, that in the great majority of cases cited, the plant hosts were already damaged and showed symptoms of SO_2 injury. Thus it would appear that in order to decrease the incidence of biotic disease agents, the plants must be exposed to phytotoxic levels of SO_2.

Sulfur dioxide has been reported to increase the incidence of shoestring root rot (caused by the fungus Armillaria mellea), primarily in trees injured by SO_2 (Domanski, et al. 1976, Donaubauer 1968, Grzywacz and Wanzy 1973, Jancarik 1961, Kudela and Novakova 1962, Schaeffer and Hedgecock 1955). The reports of an increase in A. mellea are not unexpected, for this is a facultative fungal pathogen that usually invades weakened trees. The importance of shoestring root rot should not be underestimated, for the causal fungal agent attacks a wide variety of tree species and has a worldwide distribution. In addition to A. mellea, three other wood-rotting fungi (Glocophyllum abietinum, Trametes serialis and Trametes hetermorpha) were reported by Jancarik (1961) to be frequently associated with SO_2-damaged trees. Jancarik (1961) also found a higher incidence of Lophodermium piceae on spruce needles injured by SO_2. A similar association is suspected for Lophodermium pinastri on pine (Kowalski and Budnik 1976). Chiba and Tanaka (1968) found an increased incidence of needle blight of Japanese red pine caused by the otherwise weakly pathogenic fungus Rhizosphaera kalkhoffii in an industrialized area of Japan. The fungus infected only injured needles. Lophodermium on junipers and Rhytisma tar spot of maples may also become more severe following exposure of plants to SO_2 (Barkman, et al. 1969). Recently, the incidence of tar spot of maple and sycamore leaves caused by the fungus Rhytisma acerinum has been noted to change dramatically enough in SO_2 interactions that the disease has been considered for field use as a biological indicator of SO_2 pollution (Bevan and Greenhalgh 1976, Vick and Bevan 1976).

In addition to influencing plant disease, SO_2 may affect mycorrhizal associations (Heagle 1973). Mycorrhizal fungi associate with plant roots and assist in the uptake of nutrients. They rarely cause disease and are very important to the normal growth of many woody plant species. Heagle (1973) reports that certain mycorrhizal associations in spruce were abnormal in polluted areas. Fungi were adversely affected or even absent where trees were injured by SO_2. Thus, SO_2-injured vegetation may be further weakened due to abnormal mycorrhizal development.

Because studies to date indicate that biotic diseases of plants have only been influenced when SO_2 concentrations reach phytotoxic levels, it may be that if concentrations do not exceed these levels then there will be little or no influence upon biotic diseases. With SO_2, as with all air pollutants, the threshold concentration required to injure plants is affected by the pollutant dose (duration of exposure x concentration of pollutant) and a multitude of interacting biological and meterological variables. Plant species and clones within species vary widely in sensitivity to a given pollutant. In general, plants are most sensitive during daylight hours when humid conditions with moderate temperatures and adequate soil moisture exist (i.e. conditions favorable for maximum stomatal opening and gas exchange in plants).

Plant species have been grouped into three classes; sensitive, intermediate, and resistant in terms of SO_2 sensitivity. Table 1 shows the concentrations of SO_2 necessary to cause threshold injury (visible symptoms) to these various sensitivity groupings of plants.

The major dominant tree species found in the Copper-Nickel Study Area are discussed in ________________ and their major diseases and biotic disease agents are listed in Table 1 of ____________________. Based upon published sensitivity listings these dominant species are ranked in the following SO_2 sensitivity classes:

Sensitive: Jack Pine (Pinus banksiana); Red Pine (Pinus resinosa); White Pine (Pinus strobus); Paper Birch (Betula papyrifera);

Black Ash (Fraxinus nigra); Quaking Aspen (Populus tremuloides); and Bigtooth Aspen (Populus grandidentata).

Intermediate: Balsam Fir (Abies balsamea); Balsam Popular (Populus balsamifera); and Basswood (Tilia americana).

Resistant: White Spruce (Picea glauca); Black Spruce (Picea mariana); White Cedar (Thuja occidentallis); Red Maple (Acer rubrum); Red Oak (Quercus borealis); and Bur Oak (Quercus macrocarpa).

Should mining and smelting operations begin in the Copper-Nickel Study Area, the major gaseous pollutant would be SO_2. Thus, in terms of possible interactions between this pollutant and biotic diseases, the most SO_2 sensitive tree species and their obligate and facultative parasites would most likely be those in which interactions would occur, should SO_2 levels (during the growing season) exceed the threshold injury concentrations listed in Table 1. Should the SO_2 not exceed the threshold injury concentrations it is unlikely that interactions between SO_2 and biotic diseases should ever become noticeable, for the measurable interactions have, to date, been restricted to areas in which the vegetation is already adversely affected (showing symptoms of SO_2 damage). What is not known, and can not be logically predicted, are interactions that occur due to long-term, sub-threshold levels of SO_2 that may or may not add to the acidity of precipitation, soils, and surface waters. Should SO_2 levels, both local (near sources) and regional, be kept in compliance with state and federal standards (which are based upon sensitivity of plants to SO_2), it is highly unlikely that any appreciable and measurable interactions between SO_2 and biotically caused disease agents would occur.

The Influence of Other Air Pollutants on Plant Diseases Caused by Biotic Agents.

Although SO_2 is the primary gaseous air pollutant of concern, it should be briefly pointed out that air pollutants most often occur as mixtures, and pollutants other than SO_2 have been shown to interact with plant diseases caused by biotic agents. For example, fluoride can be a gaseous product of ore smelting, and ozone and its precursors (produced by photochemical reactions with nitrogen oxides) may be transported many hundreds of miles from its source of production (mainly urban areas) and can interact with locally produced air pollutants. Both Heagle (1972) and Treshow (1975) have recently reviewed the interactions of these pollutants with biotic disease agents and their effects on the course of certain plant diseases. In general, the interactions of fluoride and ozone (considered separately in the reviews and in subsequent published reports) are similar to those caused by SO_2 (i.e., diseases caused by obligate parasites may be decreased in severity, whereas those caused by facultative parasites may, under certain conditions, be increased in severity).

Because the Copper-Nickel Study Area is remote from large urban areas, episodes of air pollutants transported from great distances (e.g., ozone) should not occur frequently and most likely would never have enough effect upon vegetation to influence the course of plant diseases caused by biotic agents. It is highly unlikely that air pollutants other than SO_2 will become a significant factor in influencing the course of biotic diseases in the Study Area.

Table 1. Sulfur dioxide concentrations causing threshold injury to various sensitivity groupings of vegetation[a,b,c]

Maximum Average Concentration	Sensitivity Grouping		
	Sensitive ug/m^3	Intermediate ug/m^3	Resistant
Peak	2,620 to 3,930 (1.0 to 1.5 ppm)	3,930 to 5,240 (1.5 to 2.0 ppm)	5,240 (2.0 ppm)
1 hr	1,310 to 2,620 (0.5 to 1.0 ppm)	2,620 to 5,240 1.0 to 2.0 ppm)	5,240 (2.0 ppm)
3 hr	786 to 1,572 (0.3 to 0.6 ppm)	1,572 to 2,096 (0.6 to 0.8 ppm)	2,096 (0.8 ppm)
8 hr	262 to 1,310 (0.1 to 0.5 ppm)	524 to 6,550 (0.20 to 2.5 ppm)	unknown

a/ Peak, 1-hour and 3-hour concentrations based on observations of visible injury occurring on over 120 species growing in the vicinities of SO_2 sources in the southeastern United States and on other field observations. Adapted from Jones, et al. 1974.

b/ Eight-hour concentrations based on Heagle 1973.

c/ Parts per million converted to micrograms per cubic meter ($\mu g/m^3$) by the multiplication of ppm x 2,620. Adapted from Stern, et al. 1973. Conversion factor assumes that the ideal gas law is accurate under ambient conditions and is based on a temperature of 25°C and a pressure of 760 mm Hg. Thus, conversions of ppm (from the literature) to $\mu g/m^3$ are only approximations and would vary slightly with changes in temperature and air pressure.

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