Chapter 15

AIR POLLUTION STRESS

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1. INTRODUCTION

The atmosphere surrounding a plant is a complex mixture of gases and particles, some common and some present in only trace amounts. In addition to naturally-occurring gases such as N\(_2\), O\(_2\), CO\(_2\), water vapor, and methane, the lower atmosphere also contains a wide array of natural and anthropogenic compounds whose presence in the air can strongly affect the growth of plants. Many of these potentially toxic compounds occur naturally in the lower troposphere, but when present at concentrations significantly in excess of background concentrations they are classified as air pollutants. Industrialization and urbanization over the past 200 years have greatly increased the concentrations of these toxic compounds in the atmosphere, increasing the potential for adverse effects of air pollution on the growth and productivity of crop plants and forests (Heck \textit{et al.}, 1988; Smith, 1990).

Primary air pollutants are those that are emitted directly into the atmosphere, often from industrial processes or combustion, and are usually highly local in origin and effects. Examples of primary gaseous air pollutants are sulfur dioxide (SO\(_2\)), from combustion of sulfurous coal or oil, and smelting and refining of metal ores; hydrogen fluoride (HF), emitted from aluminum refineries; ethylene (CH\(_2\)CH\(_2\)) emissions from polyethylene plants; or carbon dioxide (CO\(_2\)) and oxides of nitrogen (NOx) from a variety of combustion sources. Such pollutants can also arise from small local sources, such as accidental spills of liquid ammonia (NH\(_3\)) or chlorine compounds (Cl\(_2\), HCl). Primary particulate air pollutants include fugitive dust from exposed soil and roadways, abrasion products such as automobile tire and brake particles, construction and demolition dusts, and even salt from marine spray and industrial cooling towers.

Secondary air pollutants are those produced in the atmosphere by reactions among natural or anthropogenic precursor compounds. The most significant secondary air pollutant for vegetation is tropospheric ozone (O\(_3\)) produced by photochemical reactions among O\(_2\) and NO\(_x\) from natural sources and from autos and other combustion sources, and organic compounds emitted from auto exhaust, industrial processes, solvents, and vegetation. Ozone is produced in great quantities in the upper atmosphere through the photolysis of molecular oxygen, and in small amounts in the lower troposphere, by lightning or similar high-energy events. However, O\(_3\) is sufficiently chemically reactive that natural background concentrations in the lower troposphere are low, and without the presence of excess NO\(_x\) and hydrocarbons, O\(_3\) concentrations would be self-limiting (Finlayson-Pitts and Pitts, 1986). Other secondary air pollutants include peroxyacetyl nitrate (PAN), H\(_2\)O\(_2\), and a variety of other oxygenated compounds. These are less abundant than ozone, but mole for mole may be more phytotoxic.

Polluted atmospheres also contain aerosols, particles, heavy metal vapors, acid precipitation, pesticides, herbicides, and numerous other potentially toxic materials. With a few exceptions, the discussion of air pollution effects in this chapter will be confined to the major gaseous air pollutants, particularly O\(_3\) and SO\(_2\). Descriptions of injury, lists of susceptible plant species, and color photographs of injury symptoms produced by exposure to these and to the minor air pollutants can be found in \textit{Recognition of Air Pollution Injury to Vegetation: A Pictorial Atlas} (Flagler, 1998).
2. PLANT EXPOSURE TECHNIQUES

Our current state of knowledge of the effects of air pollutants on plants has been obtained from the integration of information derived across the spectrum of plant sciences applied to all levels of organization in the plant and its environment. The greatest progress in advancing the state of the science has come when techniques for the exposure of whole plants or plant parts have been applied at the appropriate level of organization within the plant. Information on the effects of acute (i.e., high concentration, short-term) exposures on biochemical or physiological processes, such as photosynthesis, has primarily been obtained using leaf cuvettes. In cuvettes, whole leaves can be exposed to known concentrations of pollutants, and photosynthetic rates can be measured under defined environmental conditions (Legge et al., 1979). Intermediate-term (days or weeks) exposures to study the effects of air pollutants on whole-plant processes, such as carbon partitioning or water relations can be carried out in growth chambers or in continuously-stirred tank reactor (CSTR) chambers, specifically designed for air pollution research (Rogers et al., 1977; Heck et al., 1978). Information on the effects of chronic exposures (several months or growing seasons) to low, medium, or high levels of pollutants to study effects on growth and yield of agronomic crops has been obtained primarily from open-top chamber studies, conducted in the field on plants growing directly in the ground or in large pots. One typical open-top chamber design (Heagle et al., 1973), widely used in the National Crop Loss Assessment Network (Heck et al., 1988), was 3 m in diameter, 3 m high, and was open at the top to allow natural precipitation and pollinators to enter (Fig. 15-1). Pollutant concentrations are controlled by filtering the air entering the chamber through activated charcoal to remove ambient pollutants, and then adding known amounts of pollutants such as O₃ or SO₂ to yield the desired concentrations and exposure regimes within the chambers.

All plant exposure systems come with a suite of advantages and disadvantages (Hogsett et al., 1987; Manning and Krupa, 1992). For example, temperature and humidity in open-top chambers are often slightly higher than field conditions, and light intensity a shade lower. To date, the open-top chamber is the most widely used and accepted technique for the exposure of plants to gaseous air pollutants in the field. Most studies of the effects of air pollutants on the growth and yield of cotton have used open-top chambers, while physiological studies have often been conducted in CSTR and closed field exposure chambers (Musselman et al., 1986).

3. OZONE

3.1 Origin and Distribution.

Ozone is a colorless, odorless gas that is only moderately soluble in water. As mentioned earlier, excess tropospheric O₃ is formed by photochemical reactions among O₂, NOₓ, and reactive hydrocarbons. Both NOₓ and hydrocarbons are produced by the combustion of gasoline, so the production of excess O₃ is often associated with dense automobile traffic. Other factors that contribute to the formation of high concentrations of O₃ include the presence of an inversion layer or stagnant air mass, which traps the precursor and reaction product pollutants, and high temperature and light intensity, which increase the rate of the photochemical reactions (Finlayson-Pitts and Pitts, 1986). Although these conditions are normally associated with Los Angeles-type smog, high O₃ pollution occurs in major parts of the cotton-growing regions of the U.S., including the southern San Joaquin Valley, south-central Arizona, southeastern and central Texas, and the Cotton Belt from Alabama to North Carolina (Lefohn, 1992).

No specific information is available on O₃ concentrations in other cotton-growing regions of the world. However, given the close association among O₃ formation, high temperatures and light, and stagnant air masses (Finlayson-Pitts and Pitts, 1986), the potential is present for production of phytotoxic concentrations of O₃ in cotton-growing areas downwind of major urban areas around the world (Schenone, 1993).

Other photochemical oxidant air pollutants, particularly peroxyacetyl nitrate (PAN) are produced in polluted urban atmospheres if sufficiently high concentrations of precursor molecules are available. Cotton is resistant to the effects of PAN (Taylor and MacLean, 1970), and no known instances of PAN injury to cotton have been recorded in the field.

3.2 Entry of Ozone into the Leaf and Initial Toxicity

3.2.1 Transport

Ozone moves from the bulk atmosphere to the sites of action inside the sub-stomatal cavity by eddy transport in turbulent air and by molecular diffusion near the leaves.