



Air Pollution Damage to Plants

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The annual losses of food and fiber crops, ornamental plants, turfgrasses, and trees in the United States caused by air pollution are estimated to be more than a billion dollars. Injury caused by air pollution is often evident on plants before it can affect humans or other animals.

This circular discusses the more important pollutants, including the inorganic pollutants--sulfur dioxide, fluoride, chlorine, and ozone--and the organic pollutants--peroxyacetyl nitrate (PAN) and ethylene. It describes their symptoms and the concentration likely to cause plant injury. It also lists plants which are very sensitive to the pollutant and plants which are somewhat resistant.

Symptoms Of Air Pollution Damage To Plants

The effects of pollution on plants include mottled foliage, "burning" at leaf tips or margins, twig dieback, stunted growth, premature leaf drop, delayed maturity, abortion or early drop of blossoms, and reduced yield or quality (Figure 1). In general, the visible injury to plants is of three types: (1) collapse of leaf tissue with the development of necrotic patterns, (2) yellowing or other color changes, and (3) alterations in growth or premature loss of foliage. Injury from air pollution can be confused with the symptoms caused by fungi, bacteria, viruses, nematodes, insects, nutritional deficiencies and toxicities, and the adverse effects of temperature, wind, and water.



Figure 1. Dark pigmented stipple on upper surface of yellow poplar leaves exposed to ozone.

Factors Influencing Air Pollution Injury To Plants

Plant injury caused by air pollution is most common near large cities, smelters, refineries, electric power plants, airports, highways, incinerators, refuse dumps, pulp and paper mills, and coal-, gas-, or petroleum-burning furnaces. Plant injury also occurs near industries that produce brick, pottery, cement, aluminum, copper, nickel, iron or steel, zinc, acids, ceramics, glass, phosphate fertilizers, paints and stains, rubbers, soaps and detergents, and other chemicals. Damage in isolated areas occurs when pollutants are spread long distances by wind currents.

Factors that govern the extent of damage and the region where air pollution is a problem are (1) type and concentration of pollutants, (2) distance from the source, (3) length of exposure, and (4) meteorological

conditions. For some pollutants, damage can occur at levels below Environmental Protection Agency standards.

Other important factors are city size and location, land topography, soil moisture and nutrient supply, maturity of plant tissues, time of year, and species and variety of plants. A soil moisture deficit or extremes of temperature, humidity, and light often alter a plant's response to an air pollutant.

Damage caused by air pollution is usually most severe during warm, clear, still, humid weather when barometric pressure is high. Toxicants accumulate near the earth's surface when warm air aloft traps cooler air at ground level. This is called air inversion.

Sulfur Dioxide

The exposure of succulent, broad-leaved plants to sulfur dioxide (SO₂) and its by-product sulfuric acid usually results in dry, papery blotches that are generally white, tan, or straw-colored and marginal or interveinal (Figure 2). On some species, chronic injury causes brown to reddish brown or black blotches (Figure 3). Both the upper and lower leaf surfaces are affected. The leaf veins normally remain green. Chlorosis (yellowing) and a gradual bleaching of the surrounding tissues is fairly common. Injured grass blades develop light tan to white streaks on either side of the midvein. A tan to reddish brown dieback or banding occurs on conifer leaves, with adjacent chlorotic areas. Growth suppression, reduction in yield, and heavy defoliation may also occur. Middle-aged leaves and young plants are most susceptible to sulfur dioxide.



Figure 2. Marginal and interveinal necrosis on American beech leaves exposed to sulfur dioxide.

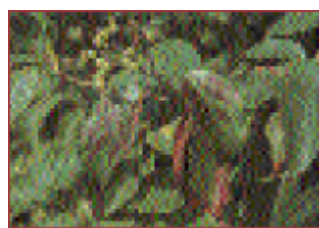


Figure 3. Dark, reddish pigmentation on dogwood leaves exposed to sulfur dioxide.

Sulfur dioxide injury can be severe 30 miles or more from its source. Injury, however, is usually greatest in the vicinity of the source (less than 1 to 5 miles away). Sources of sulfur dioxide include electric power plants, copper and iron smelters, oil refineries, chemical factories, and other industries that burn soft coal, coke, or high-sulfur oil as fuel.

Concentration

The degree of injury increases as both the concentration of sulfur dioxide and the length of exposure increase. Sensitive plants are injured by exposures of 0.5 parts per million (ppm) for 4 hours, or 0.25 ppm for 8 to 24 hours. Plants are most sensitive to sulfur dioxide during periods of bright sun, high relative humidity, and adequate plant moisture during the late spring and early summer.

Very Sensitive Plants

Alfalfa, amaranthus, apple, apricot, ash (green and white), aspen, aster, bachelor's button, barley, bean (broad and garden), beech, beet (table and sugar), begonia, bindweed, birch, blackberry, bluegrass (annual), broccoli, bromegrass, brussels sprout, buckwheat, carrot, catalpa, centaurea, chickweed, China aster, clovers, columbine, cosmos, cotton, crabapple, curly dock, dahlia, dandelion, Douglas fir, eggplant, elm, endive, fir (white), fleabane, forsythia, four o'clock, hawthorn (scarlet), larch, lettuce (garden and prickly), mallow, morning glory, mulberry, mustard, oat, okra, orchardgrass, Pacific ninebark, peach, pear, pecan, pepper (bell and chili), petunia, pine (Austrian, jack, loblolly, ponderosa, Virginia, white), plantain, polygonum, poplar, pumpkin, quince, radish, ragweed, raspberry, rhubarb, rockspirea, rose, rye, ryegrass, safflower, saltbush, smartweed, soybean, spinach, spruce, squash, strawberry, sumac, sunflower, sweet pea, sweet potato, Swiss chard, tomato, tulip tree, turnip, velvetweed, verbena, violet, wheat, and zinnia.

Somewhat Resistant Plants

Arborvitae, box elder, canna, castor bean, celery, chrysanthemum, citrus, corn, cucumber, ginkgo, gladiolus, gourds, hibiscus, honeysuckle, horseradish, iris, Johnsongrass, lilac, maple, milkweed, mock orange, muskmelon, most oaks, onion, potato, privet, purslane, shepherd's purse, snowball, sorghum, tulip, viburnum, Virginia creeper, willow, and wisteria.

Fluorides

Fluorides are compounds containing the element fluorine (F). The typical injury by gaseous or particulate fluorides is either a yellowish mottle to a wavy, reddish brown or tan "scorching" at the margin and tips of broad-leaved plants or a "tipburn" of grasses and conifers (Figures 4 and 5). A narrow, chlorotic to dark brown band often occurs between living and dead tissue. Citrus, poplar, sweet cherry, and corn foliage exhibit a chlorotic mottling, streaking, or blotching prior to the development of the typical "burned" area. On apple, apricot, citrus, fig, peach, plum, and prune, leaves and fruit may fall prematurely. Injured areas in stone fruit leaves may become brittle and drop out, leaving shot-holes. Young, succulent growth is injured the easiest. Fruit may soften or become necrotic at the blossom end. Fluoride-contaminated forage that is eaten by cattle or sheep may cause fluorosis.



Figure 4. Yellowish mottle and marginal chlorosis on sweetgum leaf exposed to fluorides.

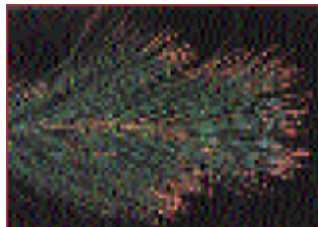


Figure 5. Tip necrosis on needles of eastern white pine exposed to fluorides.

Fluorides are produced by glass, aluminum, pottery, brick, and ceramic industries and by refineries, metal ore smelters, and phosphate fertilizer factories.

Concentration

Accumulated leaf-fluoride concentrations of 20 to 150 ppm often injure sensitive plants, although

resistant varieties and species of plants will tolerate leaf concentrations of 500 to 4,000 ppm or more without visible injury. A 4-week exposure of susceptible gladiolus to an air concentration of 0.0001 ppm, or less than 24 hours at 10 parts per billion, produced leaf concentrations of 150 ppm and definite tissue necrosis. Susceptibility to fluorides varies tremendously among varieties or clones of the same plant, such as apricot, begonia, corn, gladiolus, grape, peach, ponderosa and white pines, and sweet potato. The extent of tissue damage is related to the dosage and the quantity of fluoride accumulated.

Very Sensitive Plants

Alfalfa, apple, apricot (Chinese, Moorpark, Royal, Tilton), azalea, barley, blueberry, box elder, buckwheat, canna, cattail, cherry, chickweed, citrus, corn (sweet), crabgrass, cyclamen, Douglas fir, gladiolus, grape (European), hypericum, iris, Jerusalem cherry, Johnsongrass, larch (western), mahonia, maple, mulberry, nettleleaf goosefoot, some oaks, oxalis, peach, peony, most pines, plum, poplar, prune (Italian), smartweed, sorghum, spruce (blue and white), sweet potato, and tulip.

Somewhat Resistant Plants

Ash (European and Modesto), asparagus, bean, birch (cutleaf), bridal wreath, burdock, Canterbury bell, cauliflower, celery, cherry (flowering), chrysanthemum, citrus, columbine, cotton, cucumber, currant, dandelion, dock, dogwood, eggplant, elderberry, elm (American), fir (grand), galinsoga, hemlock, most junipers, laurel, lettuce (Romaine), linden (American), lobelia, locust, marigold, mountain ash (European), nightshade, onion, orchardgrass, parsnip, pear, pepper, petunia, pigweed, planetree, plum (flowering), plantain, privet, purslane, pyracantha, ragweed, rhododendron, rose, snapdragon, soybean, spinach, squash, spruce (Engelmann), strawberry, sweet pea, tobacco, tomato, tree-of-heaven, Virginia creeper, willow (weeping), wheat, and zinnia.

Chlorine

Injury caused by chlorine (Cl₂) is somewhat similar to that caused by sulfur dioxide and fluorides, in that it is marginal and interveinal. On broad-leaved plants, necrotic, bleached, or tan to brown areas tend to be near the leaf margins, tips, and between the principal veins. Injured grass blades develop progressive streaking toward the main vein in the region between the tip and the point where the grass blade bends. The streaking usually occurs alongside the veins. Middle-aged leaves or older ones are often more susceptible than the young ones. Bleaching and tissue collapse can occur. Conifers may show tipburn on the current season's needles.

Hydrogen chloride and chlorine are emitted from the stacks of glassmaking factories and refineries. These gases are also produced by incineration, scrap burning, and spillage, such as from chlorine storage tanks. Chlorine-injured vegetation is often observed near swimming pools, water-purification plants, and sewage-disposal facilities.

Concentration

Very susceptible plants show symptoms when exposed for 2 hours or more at concentrations of chlorine ranging from 0.1 to 4.67 ppm. Chlorides do not accumulate in plant tissues after exposure to chlorine.

Very Sensitive Plants

Alfalfa, amaranthus, apple, ash, azalea, barberry, basswood, bean (Pinto and Scotia), birch (gray), blackberry, bluegrass (annual), box elder, bridal wreath, buckwheat, catbrier, cherry, chickweed, chokecherry, coleus, cosmos, cucumber, dandelion, dogwood, gomphrena, grape, honeysuckle, horse chestnut, hydrangea, Johnsongrass, Johnny- jump-up, juniper, lilac, mallow, maple (Norway, silver, sugar), May apple, morning glory, mulberry, mustard, oak (pin), onion, peach, peony, petunia, phlox, pine (jack, loblolly, shortleaf, slash, white), poison ivy, primrose, privet, radish, rose (tea), sassafras, spruce (Norway), sunflower, sweetgum, tomato, tree-of-heaven, tulip, Venus's looking-glass, violet, Virginia creeper, witch hazel, and zinnia.

Somewhat Resistant Plants

Arborvitae, begonia, ivy (Boston), day lily, eggplant, hemlock, holly (Chinese), iris, lamb's-quarters, maple (Japanese), oak (red), oxalis, pepper, pigweed, polygonum, Russian olive, soybean, and yew.

Ozone

Ozone (O₃) is probably the most important plant-toxic air pollutant in the United States. It is a very active form of oxygen that causes a variety of symptoms on broad-leaved plants: tissue collapse, interveinal necrosis, and markings on the upper surface of leaves known as stipple (pigmented yellow, light tan, red brown, dark brown, red, black, or purple), flecking (silver or bleached straw white), mottling, chlorosis or bronzing, and bleaching (Figures 6 and 7). Ozone stunts plant growth and depresses flowering and bud formation. It also causes marginal rolling and scorching of leaves on lilac. Affected leaves of certain plants, such as citrus, grape, and tobacco, commonly wither and drop early.



Figure 6. Bronzing of lower surface of potato leaf exposed to ozone.

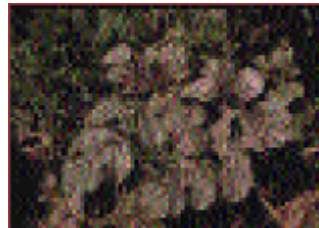


Figure 7. Bleaching of upper surface of watermelon leaves exposed to ozone.

Conifers frequently show a yellow to brown mottling and tipburn, or a yellow to brown or orange-red flecking and banding of the needles (Figure 8). Susceptible white pines are stunted or dwarfed and chlorotic. The injury pattern in small grains and forage grasses generally occurs as a scattering of small, yellowish or white to tan flecks on one or both leaf surfaces. The flecks may later merge to form larger, bleached white to yellowish dead areas. Ozone usually attacks nearly mature leaves first, progressing to younger and older leaves. Young plants are generally the most sensitive to ozone; mature plants, relatively resistant. Ozone-killed tissues are readily infected by certain fungi, such as *Botrytis*.



Figure 8. Tipburn on eastern white pine exposed to ozone.

Ozone is brought down from the stratosphere by vertical winds or produced during electrical storms; more importantly, it is produced when sunlight reacts with nitrogen oxides and hydrocarbons formed by refuse burning and combustion of coal or petroleum fuels, especially the exhaust gases from internal-combustion engines. When oxidant levels in the air are high, more than 90 percent is ozone. These levels are usually at their highest point in the afternoon and relatively low at night.

Concentration

The exposure of sensitive plants for 4 hours at levels of 0.04 to under 1.0 ppm of ozone will produce injury patterns. Susceptible tobacco plants are injured when concentrations of ozone reach or exceed 0.04 ppm. (Ozone injury on tobacco is called weather fleck.) Ozone susceptibility differs greatly between varieties of the same plant, for example, bean, grape, oat, onion, petunia, pine, potato, spinach, squash, sweet corn, and tobacco. The extent of the injury depends on the plant species and environmental conditions prior to and during exposure. Ozone and sulfur dioxide often combine to cause plant injury before either of these pollutants alone would cause damage.

Very Sensitive Plants

Abutilon, alder, alfalfa, apricot, ash (green and white), aspen, aster, avocado, barley, bean (green and Pinto), beet (table and sugar), begonia, bentgrass, birch, bluegrass (annual), box elder, bridal wreath, broccoli, bromegrass, brussels sprout, carnation, carrot, catalpa, celery, chicory, chickweed, Chinese cabbage, chrysanthemum, citrus, clover (red), corn (sweet), crabapple, crabgrass, dahlia, dill, duckweed, eggplant, endive, fuchsia, gourds, grape, hemlock, honeylocust, hypericum, larch (European), lilac, linden, locust (black), maple (silver and sugar), marigold, mint, mimosa, muskmelon, oak (gambel and white), oat, onion, orchardgrass, parsley, parsnip, pea, peach, peanut petunia, pine (ponderosa, scotch, white), potato, privet, pumpkin, radish, rye, salvia, scallion, smartweed, snowberry, spinach, squash, strawberry, sweet potato, Swiss chard, sycamore, tobacco, tomato, tulip tree, turnip, verbena, walnut, wheat, and willow (weeping).

Somewhat Resistant Plants

Coleus, cotton, cucumber, dogwood, euonymus, geranium, gladiolus, impatiens, juniper (Pfitzer), kalanchoe, most maples, most oaks, pepper, poinsettia, tolmiea, and yew.

Peroxyacetyl Nitrate (PAN)

The most plant-toxic oxidant, next to ozone, is PAN. PAN causes a collapse of tissue on the lower leaf surface of numerous plants. The typical leaf marking is a glazing, bronzing, or silvering that commonly develops in bands or blotches. On some plants, such as petunia, Pinto bean, tomato, and tobacco, the collapse may be through the entire thickness of the leaf blade. In grasses, the collapsed tissue has a bleached appearance, with tan to yellow, transverse bands. Conifer needles turn yellow. Early maturity or senescence, chlorosis, moderate to severe stunting, and premature leaf drop may also occur. PAN is most toxic to small plants and young leaves. The very young and most mature leaves are highly resistant.

Like ozone, PAN is produced when sunlight reacts with various exhaust gases. PAN is formed by oxides of nitrogen reacting with unsaturated hydrocarbons (simple olefins) in the presence of light. Other

PANs, such as peroxypropionyl nitrate and peroxybutyryl nitrate, may also be present in urban air and may produce symptoms that are indistinguishable from those caused by peroxyacetyl nitrate.

Concentration

Typical damage to susceptible plants occurs with PAN at levels of 0.01 to 0.05 ppm for an hour or more. Plant injury requires light before, during, and after exposure. Injury is increased by any factor contributing to maximum plant growth. PAN is best known in the Los Angeles basin area, with injury occurring on vegetation from Seattle to San Diego. Little is known about the concentration of PAN in the Midwest or the eastern United States. PAN is unstable, particularly at temperatures above 90 degrees F.

Very Sensitive Plants

African violet, alfalfa, aster, bean (Pinto), beet (table and sugar), bluegrass (annual), carnation, celery, chickweed, dahlia, dandelion, dill, Douglas fir, endive, escarole, fennel, lettuce (Romaine), lilac, muskmelon, mustard, nettle (little-leaf), oat, certain orchids, pepper, petunia, pine (Coulter, Jeffrey, Monterey, ponderosa), poinsettia, potato, primrose, rose, salvia, snapdragon, spinach, sunflower, Swiss chard, tobacco, and tomato.

Somewhat Resistant Plants

Azalea, bean (lima), begonia, broccoli, cabbage, chrysanthemum, corn, cotton, cucumber, onion, pansy, periwinkle, radish, redwood, sequoia, sorghum, touch-me-not, and wheat.

Ethylene

Damage caused by ethylene (H₂C-CH₂) is often associated with PAN and ozone in urban areas. Ethylene modifies the activities of plant hormones and growth regulators, which affect developing tissues and normal organ development, without causing leaf-tissue collapse and necrosis. Injury to broad-leaved plants occurs as a downward curling of the leaves and shoots (epinasty), followed by a stunting of growth. Ethylene also causes dry sepal in *Cattleya*, *Phalaenopsis*, and other orchids; "sleepiness" (an inward petal-curling and failure of buds to open) in carnation, narcissus, and rose; color-breaking and blasted buds in roses; and the shelling (early drop) of azalea, snapdragon, stock, larkspur, and calceolaria blooms. More-resistant, broad-leaved plants and grasses may only be stunted. Conifers drop their needles and young cones. New needle growth is stunted, and cone development is poor. Similar symptoms are produced by other unsaturated hydrocarbons such as acetylene and propylene.

Ethylene is one of the many products of auto, truck, and bus exhaust. Ethylene also results from the incomplete combustion of coal, gas, and oil for heating and is a by-product of polyethylene manufacture. Ethylene is a problem in fruit, vegetable, and cut-flower storage rooms and greenhouses where manufactured gas is still used.

Concentration

Air concentrations of 0.001 ppm for 24 hours will cause the sepals of orchid flowers to turn brown or

wither and die. An exposure of 0.1 ppm for 6 hours will cause epinasty in tomato or pepper and sleepiness in carnation. The extent of injury depends on the air temperature, plant species, and age of the organ, as well as on the ethylene concentration.

Very Sensitive Plants

Azalea, bean (Black Valentine), blackberry, buckwheat, calceolaria, carnation, cotton, cowpea, cucumber, larkspur, lilac, lily (Regal), marigold (African), narcissus, orchid, pea, peach, pepper, philodendron, potato, privet, roses, snapdragon, stock, sunflower, sweet pea, sweet potato, tomato, and tulip.

Somewhat Resistant Plants

Beet, cabbage, clover, endive, lettuce, oat, onion, radish, ryegrass, and sorghum.

Conclusion

Plant responses to air pollution are helpful in:

- Establishing the early presence of air-borne contaminants.
 - Determining the geographical distribution of the pollutants.
 - Estimating the concentration of pollutants.
 - Providing a passive system for collecting pollutants for chemical analyses later.
 - Obtaining direct identification of different air pollutants on the basis of plant species and variety affected.
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Source for figures 1-5 and 8: Shelley, John M., et al., eds. 1987. *Diagnosing Injury To Eastern Forest Trees*. USDA--Forest Service, Atlanta, GA and The Pennsylvania State University, University Park, PA.

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