Bulletin 794

Air Pollution As It Affects Agriculture in New Jersey

NEW JERSEY AGRICULTURAL EXPERIMENT STATION
RUTGERS—THE STATE UNIVERSITY
NEW BRUNSWICK

CONTENTS

Air Pollution As It Affects Agriculture in New Jersey

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Although air pollution damage to vegetation dates back about 100 years, the problem did not become acute in New Jersey until the late years of World War II. Prior to this time air pollution damage in the State was believed to be limited to that produced by sulfur dioxide, illuminating gas, and ethylene. However, industrial expansion and the development of new processes in connection with the war effort introduced hitherto unknown pollutants. In 1944 an unusual pattern of foliage injury was noticed on many cultivated crops, ornamentals, and indigenous vegetation in two areas along the Delaware River. Field surveys in both areas revealed that certain varieties of plants showed similar damage. This injury was often followed by partial or complete defoliation of many deciduous and coniferous plants. Monocots such as gladiolus and tulip showed considerable terminal injury; corn showed a characteristic mottling. Peach growers in the affected areas reported that along with foliage injury and defoliation, early fruit drop caused considerable loss in the peach crop. Although the injury seemed to be developing constantly, it was most pronounced following wet periods of low wind velocity. The youngest expanded leaves were generally more sensitive than older leaves. Since this injury was not due to any known disease, nor to temperature or fertilizer effects, the evidence strongly suggested an air pollutant as the cause. Its similarity to damage described in the literature on corn and peach foliage following the use of cryolite, a fluorine-bearing insecticide, implicated fluorine as the responsible pollutant. As feelings were running high with law suits threatening, the senior author was appointed by the Director of the Experiment Station to investigate the problem and with the aid of the farmers, $13,000.00 was appropriated by the State Legislature for the study. Thus was begun a series of experiments in which plants were fumigated with hydrogen fluoride in especially equipped chambers.

Since the start of the project, the scope of the investigation has been expanded to include chlorine and sulfur, illuminating gas, 2,4-D and other growth regulators, and still more recently ozone and other oxidants.

Acid Gases

Sulfur dioxide, chlorine, and hydrogen fluoride may be considered together under the term acid gases. Acute injury to vegetation by acid gases usually presents a typical pattern of marginal or interveinal collapsed areas in the leaves. However, sulfur dioxide tends to produce more intercostal injury than the fluoride or chlorine. Subsequently, these areas dry to a buff color, though in some plants which have considerable anthocyanin the final color may be brown or red-brown as in clover, apple, or pear leaves. Though areas adjacent to injured portions of a leaf may absorb an appreciable amount of gas, unless the injury threshhold is surpassed, visible symptoms are not exhibited. Necrosis, unless extensive, seldom extends across the veins.

Occasionally, as a result of sulfur dioxide fumigations, injured areas on leaves occur as necrotic streaks especially on monocotyledonous plants. Bobrov, (1) in investigations of the effect of hydrocarbons on oat leaves, observed that the presence of abundant stomata and the loose arrangement of cells favored the entry and rapid diffusion of the toxic gas into the inner leaf. The vascular ridge was seldom injured. Here the conducting elements are surrounded by tightly compacted brick-shaped cells which are frequently lignified. In addition, this area has few or no stomata. Since the highly ventilated area in monocots is bordered by parallel veins, the injured areas frequently run parallel with the leaf.

Although the three gases may produce somewhat similar symptoms on a particular plant, species vary in their susceptibility to each phytotoxic air pollutant. Some plants are susceptible, whereas others are much more tolerant to a given pollutant. For example, corn and peach are quite susceptible to hydrogen fluoride, but they are both resistant to sulfur dioxide. Ragweed on the other hand is susceptible to sulfur dioxide and very tolerant to hydrogen fluoride. Even among plants of the same species, variation in susceptibility may be rather impressive due to differences in heredity, nutritional status, water and light relationship and the general growth conditions of the plant.

Sulfur Dioxide. Katz (10) has found that vegetation may be affected by sulfur dioxide when ground levels exceed 0.3-0.5 ppm. When the stomata are open sulfur dioxide is absorbed into the leaf and injury may occur. Environmental conditions conducive to the opening of the stoma are favorable temperatures, adequate water supply, high relative humidity, and high light intensity. Plants which close their stomata at night are resistant to sulfur dioxide during that period. Katz also found that conifers are more susceptible to sulfur dioxide during the spring and early summer months than during the rest of the year. When sulfur dioxide is absorbed by the leaf cells, it unites with water and forms the phytotoxic sulfite which may be slowly oxidized in the cell to the inocuous sulfate form (10), providing the plant with a mechanism which protects it against low concentrations of the gas. The toxicity of sulfur dioxide is therefore a function of the rate at which it is absorbed. A given dose absorbed rapidly will produce a higher concentration of the toxic sulfite in the cells than the same amount, or even a greater amount of gas absorbed at a slower rate.

Studies on the effect of sulfur dioxide on photosynthesis of alfalfa by Thomas and Hill, (22) showed that high level fumigations of too short a duration to kill tissue reduced the rate of photosynthesis during the exposure, but immediately after the gas was removed the rate of photosynthesis returned to normal. Where tissue killing occurred there resulted a permanent reduction in the rate of photosynthesis proportional to the amount of tissues destroyed. Low level fumigations for long periods which did not produce chlorosis had no effect on photosynthesis. When fumigation was continued for a sufficiently long period to cause chlorosis, photosynthesis was adversely affected. These studies demonstrate that hidden injury is not produced by sulfur dioxide; that injury is not systemic, but is confined to the areas that are visibly affected.

Hydrogen Fluoride. Research has indicated that hydrogen fluoride is an extremely phytotoxic gas; certain species of gladiolus plants for example have been injured by concentrations as low as 0.1 and 0.2 ppb (parts per billion). In New Jersey experiments gladiolus was injured by a 21 day fumigation of 1 ppb, and moist peach foliage was burned by a 3 hour fumigation of 50 ppb. A three hour fumigation of 40 ppb of hydrogen fluoride produced a mottled chlorosis on corn leaves, consisting of small green and faded green areas interspersed irregularly over the leaf which persisted through the life of the leaf. Apparently fluoride at this low level damaged the chlorophyll of the corn leaf before killing the cells.

Although fluoride injury symptoms may resemble those produced by sulfur dioxide, methods of absorption and perhaps the mode of action seem to be quite different for the two gases. Injury occurring from fluoride is not as dependent upon open stomata at the time of the fumigation as injury from sulfur dioxide. In fact, no significant differences have been observed in New Jersey between night and daytime fumigation. It therefore appears that absorption may occur through the cuticle. Unlike sulfur dioxide, hydrogen fluoride injures wet more severely than dry leaves. Wilting does not seem to protect against this gas (2).

As is the case with sulfur dioxide, plants vary in their capacity to absorb fluoride and in their tolerance to this gas. Usually the plants that accumulate fluoride most readily are the most tolerant to it. For example, where corn and tomatoes were fumigated together, pronounced injury occurred on the corn foliage while no injury developed on the tomato leaves. A composite analysis of foliage showed that corn absorbed 70-76 ppm of fluoride by weight of dry leaf tissue, whereas the tomato leaf accumulated nearly 200 ppm. (12) Plants are most susceptible to injury during seasons of the year and under cultural and nutritional treatments providing the most rapid growth.

Whereas the toxic sulfite ion is disposed of in the plant by its conversion to the non-toxic sulfate or by death of tissue or loss of leaves, the toxic fluoride ion may be lost to the plant through volatilization and washing (rain), in addition to tissue killing, defoliation, and possibly translocation and conversion to less toxic compounds.

Studies in New Jersey have shown that plants may absorb fluoride from the soil, especially under acid conditions. This fluoride tends to accumulate in the roots but some is translocated into the leaves. Experiments in which fluorine compounds were added to the soil resulted in reduced growth of tomato plants, and mottling of corn foliage (19).

Studies on the effect of fluoride on plants by Hill et al (9) and Thomas (33) have shown that sublethal concentrations could be tolerated for long periods of time without a reduction in the rate of photosynthesis. High gas concentrations caused a reduction in the rate of photosynthesis in excess of that expected from the apparent leaf injury. After the fluoride gas was removed recovery was rapid at first, then slowed down requiring 2-3 weeks for complete recovery.

Chlorine. Chlorine damage to vegetation has been observed in New Jersey only on two occasions and is not considered to be of much importance in the state.

2,4-D Herbicides

Since the herbicidal action of 2,4-D and 2,4,5 trichlorophenoxyacetic acid was reported in 1944 by Hammer and Tukey, selective weed killers have been widely used for the control of undesirable plants. Although these materials do an excellent job in the destruction of many plants, damage has occasionally resulted from the drift of sprays, dusts, or fumes from areas under treatment or industries manufacturing these compounds. The observed cases in New Jersey of plant damage resulting from airborne-herbicides have been restricted in each instance to localized areas extending to a maximum of 1 or 2 miles from the industrial plants engaged in the production of herbicides.

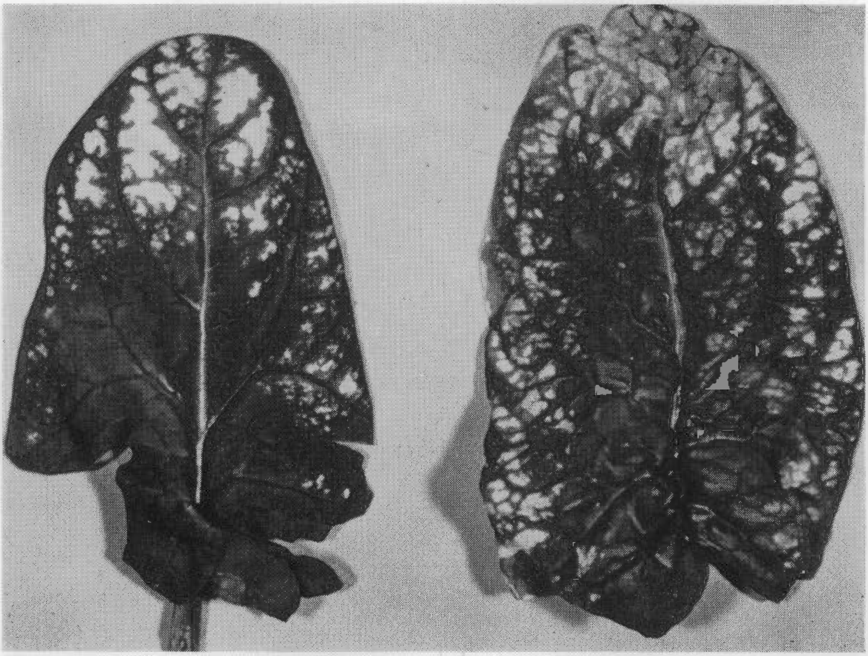
The symptom commonly observed from 2,4-D like herbicides is distortion of the leaves and petioles. Dwarfing, curling, twisting and uneven serration of the leaves are often symptoms of injury. In severe cases the leaves are filiform in shape. Injured leaves exhibit a yellow-green mottling or stippling and prominent clearing of the veins.

Plant susceptibility to sublethal exposures of 2,4-D is markedly influenced by the growth condition of the plant and also by environmental factors. Since the symptoms are characteristically growth responses, the plant must be developing new leaves to show the injury. Plants in shaded areas respond more slowly than those exposed to the direct rays of the sun. Because of these and other factors, variations in susceptibility should be expected. Of the plants observed in the field, grape was the most sensitive to 2,4-D injury. On several occasions it was injured when no other plants near it revealed any evidence of the chemical. Severe distortion and vein clearing have also been observed on box elder, sumac, tree of heaven, sweet gum, red oak, pin oak, black oak, Norway maple, mulberry, linden, hickory, London plane, birch, apple, yellow wood, sorrel, dogwood, wisteria, elderberry, choke cherry, forsythia, tomato, zinnia, and lamb's quarter. Some of the less severely affected plants are cherry, peach, Colorado blue spruce, hemlock, cedar, rhododendron, yew, privet, wild aster, corn, potato, gladiolus, giant ragweed, and some varieties of rose.

In fumigations conducted by Daines (3) it was found that ethyl, n-butyl, n-propyl, and iso-propyl esters produced pronounced injury to tomato plants. N-hexyl, sec-amyl, methyl cellosolve, butyl-cellosolve and methyl carbitol produced only slight response in the tomato, whereas oleyl, ethyl cellosolve, n-octyl, butyl carbitol, n-decyl, n-dodecyl, and n-octyl esters produced even less plant response. Thus, it was apparent that the likelihood of injury from vapors decreased as the size of the molecule and the molecular weight increased. In recent years crop damage from herbicide air pollution has become very much reduced with the introduction of less volatile heavy esters, amines, and emulsifiable formulations of 2,4-D, 2,4,5-T and M.C.P.

Oxidants

Ozone. During the late fall of 1958, a Bordentown farmer who experienced damage to his spinach crop requested that various members of the Experiment Station staff inspect his fields to diagnose the cause of the injury and recommend corrective measures. At the time of the first inspection, chlorosis and leaf spotting were conspicuous. These symptoms were variously diagnosed as being due to nutritional deficiencies, hardpan, root rot, and air pollution. The etiology of only one type of spot, a disease called anthracnose, was really known. An inspection of spinach fields throughout the state revealed that these injury symptoms were widespread. Spinach and certain other plants were observed frequently during the 1959 growing season. During the spring and fall various spinach production problems were encountered including injury from 2 types of air pollution. The most prevalent type of foliage injury first appeared as dark oily areas on the upper leaf surface. On close inspection these dark areas appeared to be water soaked and on further development imparted a glazed appearance to the leaf surface. Milky white necrotic spots varying in number from few to



Spinach leaves showing injury from a 2½ hour fumigation with 0.3 ppm ozone. This injury appears identical to that occurring in the field.

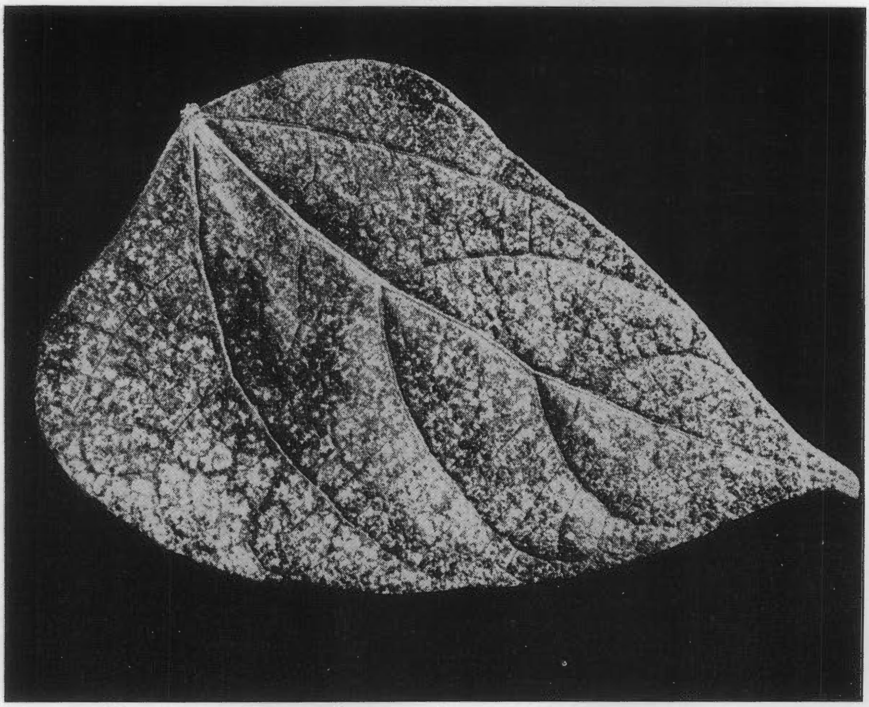
several on a single leaf could be seen in the glazed area. Some of these spots involved only the palisade and a few mesophyll cells, while others extended through to the under leaf surface. In the field this glazing of the upper leaf surface was occasionally exhibited for only a few days; however at times it persisted for a much longer period. The least severe injury consisted of a loss of chlorophyll in the upper palisade cells of the leaf causing a grey-green to yellow mottling of the upper leaf-surface. The injury regularly appeared on the oldest leaves of a plant. The new leaves produced by rapidly growing plants soon obscured the symptoms observed earlier. The conclusion reached after extensive survey and fumigation experiments was that the observed symptoms were identical with those resulting from ozone fumigations. To date ozone injury has been observed in New Jersey not only on spinach, but also on alfalfa, rye, barley, orchard grass, tobacco, petunia, radish, red clover, bean, parsley, grape and perhaps chicory, endive, broccoli, carnation, and pine. On alfalfa foliage destruction of the chlorophyll in the palisade cells occurred in certain areas, tending to be basal. In clover and radish these areas of chlorophyll destruction were irregular in shape and location. They regularly appeared first on the upper surface but in the case of the radish lower surface bleaching often occurred. Chlorophyll destruction in the cereals appeared as longitudinal streaks between the veins, tending to be located at the bend of the leaf. In the cereals the injury manifested itself as readily on the lower as the upper surface. This variation in symptom may result from

Ozone injury to alfalfa occurring as necrotic areas between veins and tending to be basal in position.

the fact that these leaves do not possess palisade cells. When injury is severe enough necrosis also occurs.

The fact that ozone at certain concentrations in the atmosphere could be injurious to plants was first recognized by those experimenting with mixtures of ozone and unburned hydrocarbons (7). However, it was believed that ozone as such was of no economic concern (15, 17) until Richards, Middleton and Hewitt (20) reported in 1958 that small brown to black lesions observed in the field on the upper surface of grape leaves could be reproduced by a 3-hour fumigation with 0.5 ppm ozone and Heggestad and Middleton (8) reported that a flecking of tobacco leaves in the eastern part of the country was caused by ozone. This present report is the first to emphasize that ozone is our most important single phytotoxic air pollutant, affecting as it does many plant species within our state. Fumigations conducted in Utah by Hill and associates and Daines have reproduced the upper surface silvering, yellowing, and necrosis observed on spinach, and the injury pattern occurring on alfalfa, oats, barley and petunias in New Jersey. Experiments by Todd and others (5, 26, 27) indicate that ozone reduces photosynthesis and increases respiration. Whether ozone per se affects growth has not yet been well demonstrated.

Oxidants Other Than Ozone. Injury to vegetation produced by acid gases or herbicides is usually restricted to a small area with the source of the emission located within the area of plant dam-



Characteristic "flecking" of the upper surface of tobacco caused by ozone.

age. Since 1944 a new type of injury to vegetation has been recognized in Los Angeles county in California and in many other metropolitan areas around the world. It was at first termed "smog" injury, and more recently "oxidant" injury. The geographical area involved is usually very large, encompassing for example, the entire Los Angeles county extending as far south as the Mexican border (13). It has been estimated by Middleton and others that the visible damage to 11 crops has amounted to over three million dollars annually in Los Angeles county alone (15).

This oxidant injury which is occasionally observed on certain plants in New Jersey is often named by its most conspicuous symptom, "silver leaf." Although the symptom complex varies among plant species, a silvering of the under surface of the youngest fully expanded leaves is the most characteristic injury expression. This silvering results from the destruction of cells just under the lower epidermis and their consequent separation from the remainder of the leaf by an air layer. The silver appearance of the under leaf surface is usually accompanied by necrotic spots, some of which may extend through to the upper surface. The lower surface injury from oxidants begins in the well aerated spongy parenchyma mesophyll cells, whereas the upper surface injury from ozone first appears in the more compact palisade layers of mesophyll which are so rich in chyorophyll. Oxi-

Stipple of bean caused by exposure to ozone.

dant injury has been observed in New Jersey on spinach, celery, red beets, swiss chard, cultivated dandelions, Romaine lettuce, sour grass, petunia, snapdragon and chickweed.

Experiments have demonstrated that plant species vary considerably in their suceptibility to lower leaf-surface oxidant injury (11). There is some evidence to indicate that succulent plants receiving ample supplies of water and nitrogen are more easily injured than those receiving deficient supplies of these nutrients. It is also reported that plants grown at 75°F. are more susceptible to injury than those at 55°.

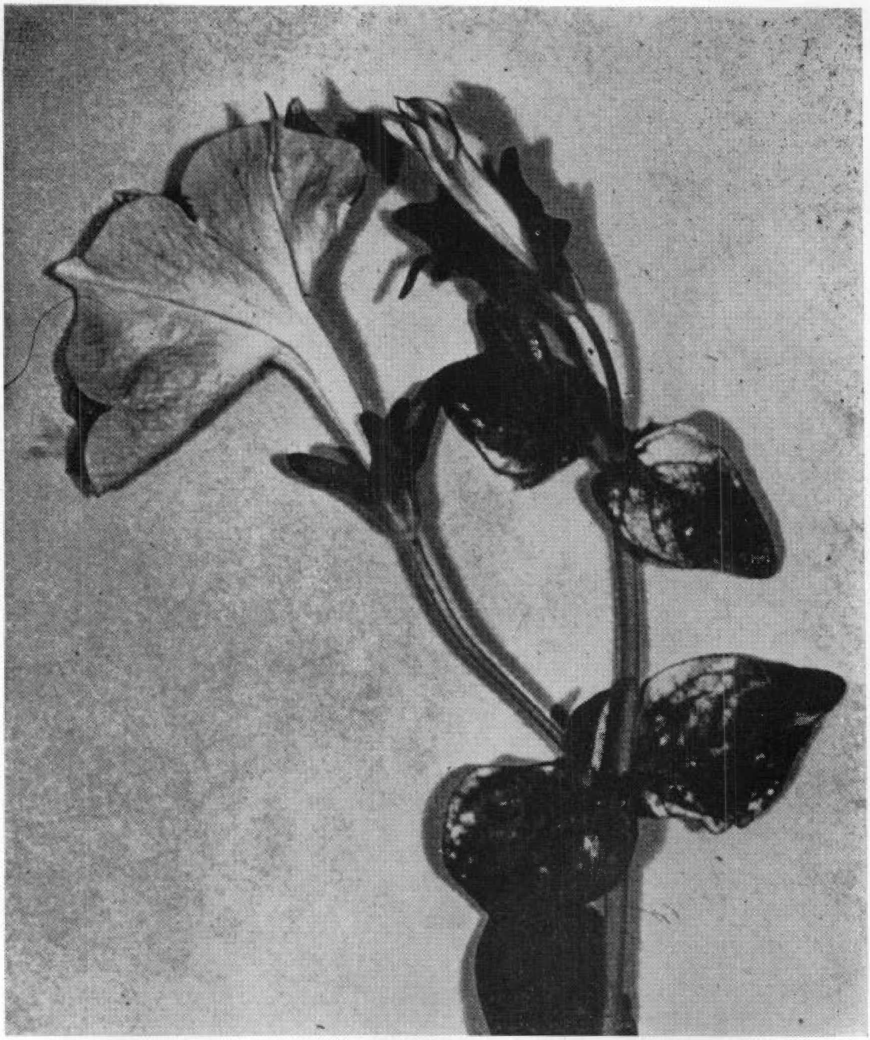
In addition to the visible injury produced by hydrocarbons and ozone mixtures, Todd and others (5, 25, 26) have shown a reduction in photosynthesis and an increase in the respiration rate, i.e. the rate at which stored foods are utilized in plants. It is also reported that plants exposed to these pollutants produce less growth and drop their leaves earlier than unexposed plants (16, 18, 24, 27).

The magnitude of the problem in the Los Angeles basin, where it has been intensively studied and publicized, is undoubtedly associated with the meteorological conditions of the area. The semi-permanent Pacific high pressure cell together with the mountain range which nearly surrounds the basin, are partly responsible for the occurrence in that area of rather frequent and prolonged periods of low air movement at the ground level. In addition, this atmospheric stagnation is enhanced by rapid nocturnal radiational cooling resulting from clear skies and low humidity. The air at the ground level tends to remain cooler during the day than the air above it since the temperature of the air moving into the area is influenced by the cold waters of the Pacific Ocean. This helps maintain an inversion layer i.e. a layer of warm air above cooler air which prevents the upward dispersion of atmospheric pollutants. On the West Coast such periods of inversion and low air movement may last for a week or two at a time. Although a semi-permanent Bermuda high exists along the Atlantic Coast the topography and meteorological conditions here are such that periods of low air movement at ground level accompanied by inversions are relatively short-lived, existing for only a few hours to a day or two at a time. A report by Wanta of the U. S. Weather Bureau and Heggestad of the USDA (28) indicates that ozone occasionally reaches concentrations .3-.5 ppm between 10:00 a.m. and 5:00 p.m. in the air at Beltsville, Maryland that are well within the range of vegetation damage. During this study on the 5 days of highest ozone concentration a high pressure ridge occurred to the southeast not far from Washington, D. C., with a trough of low pressure to the northwest. On all days the wind for the 2 hours preceding the ozone high came from the direction of Washington, with the velocity varying from 3 to 9 miles per hour, and the convection layer was bounded by an inversion layer or by a layer of considerable stability. Such conditions accompanied by high solar radiation could be expected to result in ozone accumulations.

Source of Oxidants. Identification of the air pollutants present in smog that are responsible for plant damage has presented a most difficult problem. The early work of Haagen-Smit and associates (6) demonstrated that gasoline as such was not phytotoxic even in concentrations of several hundred parts per million of air nor was nitrogen oxide in reasonable concentrations. However, when vapors of gasoline were mixed with ozone or NO_2 in the presence of sunlight, a phytotoxic oxidant was formed which caused injury to the lower leaf surface. Studies of these mixtures revealed that the fraction boiling between 39°-69°C., was the most damaging. It has since been learned that all gasoline vapors, whether olefins or not, can in the presence of ozone or NO_2 and sunlight produce plant damage if given sufficient exposure time. In later work (14) ozone (O_3) concentrations as low as 0.1 ppm were demonstrated to be phytotoxic producing chlorosis, silvering, and spotting of upper leaf surfaces.

The sources of the hydrocarbon vapors, NO_2, and ozone responsible for the plant damage is of particular interest. Hydrocarbons that are not completely burned reach the free air from all types of combustion. An article in the Oil and Gas Journal of February 16, 1959 states that of the 1,411 tons of hydrocarbons lost daily to the air in Los Angeles county, automobiles contribute 1,000 tons. Refineries add another 103 tons, and without controls they would add 800 tons daily. Crude oil-producing activities add 60 more tons daily while marketing adds 43 tons. Other industrial and commercial sources contribute another 205 tons. NO_2 is produced from oxygen and nitrogen in the air by any hot combustion source such as open fires, home furnaces, and in automobile combustion chambers. Motor cars contribute 430 tons daily, refineries 56 tons and industrial and commercial sources 215 tons.

Haagen-Smit (6,7) and Middleton (16) reported that ozone is produced in the air by the action on NO_2 of the ultra violet light in sunshine. This reversible reaction might be illustrated as follows: $NO_2 + O_2 + \text{Sunlight} = NO$



Bleaching of the upper surface of petunia leaves caused by ozone.

$+ O_3$. The ozone (O_3) formed may react with the nitric oxide (NO) to produce nitrogen oxide (NO_2). If a hydrocarbon radical is present to remove the nitric oxide from the air, a build up of ozone occurs. According to Scott, Stephens, Hanst and Doer (21) peroxyacyl nitrite is formed in the atmosphere from a reaction involving an oxidized hydrocarbon radical and nitric oxide while Darley and associates (4) suggest the formation of a zwitter ion from reactions involving ozone and certain hydrocarbons. Although the exact compounds responsible for plant damage have not been definitely ascertained, these compounds are thought to be likely offenders. Such reaction products are responsible for the under-surface oxidant injury to the youngest fully expanded leaves, while ozone per se is responsible for the upper-surface injury to the older leaves. Peroxyacyl nitrite on decomposing produces nitrogen oxide which in turn is acted upon by the rays of the sun to produce additional ozone and nitric oxide. In this way the ozone concentration builds up in urban and industrial areas under appropriate environmental conditions. Middleton reports that during smoggy periods in Los Angeles, the ozone concentration becomes 10 to 20 times as great as that naturally occurring in clean air (0.03 ppm). This puts it well within the plant damaging range.

Discussion

While injury to vegetation from acid gases appears to be decreasing in New Jersey and 2,4-D herbicides no longer pose a problem, injury from ozone and other oxidants is increasing in frequency by virtue of greater population concentration. Ozone injury has now reached the point of seriously threatening the continued commercial production of spinach and possibly endive, chicory, and some varieties of petunias in many areas. Although photochemically produced compounds other than ozone which are responsible for oxidant injury do not at present represent as great a threat to as many crops in New Jersey as ozone, damage has been observed on celery, spinach and a few greenhouse crops from these compounds. As our population grows further increase in sources of emission of the constituents responsible for the production of ozone and other oxidants can be expected in urban areas, especially during this age of automobile travel, rendering the air pollution problem especially serious near large cities. Since the solution of the problem by the use of controls seems most discouraging, emphasis must be placed on breeding new plant varieties that will tolerate the air in our increasingly urbanized state. In addition the use of protective chemical sprays for sensitive plants should be investigated.

In a letter dated November 20, 1959 from Ellis Darley, chairman of the air pollution research group at Riverside, California, the following statement is made. "In general, from irradiated mixtures of auto exhausts, ozone formation can be expected in less than an hour after the required ingredients viz., oxides of nitrogen and hydrocarbons reach bright sunlight. Also from our experiments, oxidants (mixture that is toxic to under leaf surface) from the same type of reaction seem to be produced in adequate amounts after a 30 minute irradiation. Since the principal sources of the raw materials are themselves rather diffuse, I would expect that the damage resulting from the final products would also be widely distributed rather than confined to a local area."

With the sources of contamination, cars, home, and industrial fires, refineries, etc. being so numerous both in and bordering New Jersey, it is not surprising that test tobacco plants, placed in 14 different locations in New Jersey during the growing season just past, showed injury from ozone in every location. It appears therefore that this is a problem, which, while being most serious near such cities as Philadelphia and New York, can be expected to affect sensitive plants in all areas of the state.

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