Air Pollution in Denver — A Brief Review

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Plant damage resulting from some of the light hydrocarbons that may be present in air has been known for a number of years (3, 14, 24, 28). During the second decade of this century, Crocker and others (3, 14, 28) investigated toxicity effects of smoke and illuminating gas. In particular, it was found that ethylene could cause epinasty in the sweet pea at concentrations of 200 ppb (parts per billion), acetylene at 250 ppm (parts per million), propene at 1000 ppm, and carbon monoxide at 5000 ppm. Methane, ethane, propane, and butane (called "saturated" hydrocarbons as contrasted to "unsaturated" ethylene, propene, butene, and acetylene) could cause severe burning. But, a typical "growth regulatory" response was not evident with the latter. Ethylene could inhibit growth at 100 ppb. Zimmerman et al. (28) found that carbon monoxide could stimulate root growth at 500 ppm. In terms of economic loss, ethylene and the photooxidation products of the other light hydrocarbons, particularly the unsaturated olefins, are most important.

As analytical techniques improved, it was found that ethylene has a considerable effect on maturation and senescence of cut flowers (18, 19, 27). Concentrations as low as 30 ppb may significantly reduce longevity of the carnation cut flower, depending upon temperature and exposure time (27). The initial analysis of hydrocarbons by Hanan (10) in the Denver region showed ethylene concentrations as high as 200 ppb, along with significant concentrations of photoreactive, smog producing hydrocarbons. The seriousness of these levels is emphasized by the conclusion of Hardenburg et al. (11), who stated that California flowers often kept as well as Colorado carnations in shipments to Maryland. The problem is compounded by the fact that ethylene is considered to be a growth regulator which may be produced by the plant itself (1, 7, 12, 13). However, there appears to be some opportunity of control since it has been found that CO_2 at suitable concentrations apparently suppresses the effect of ethylene (19, 27).

Significant quantities of organic materials in the air imply that additional damage from smog, as well as directly from ethylene, occurs. In general, methane, ethane, and propane, in studies on photochemical reactions, (8, 9, 20-22), have been found to be inactive at the levels studied. As the length of the straight chain, saturated paraffin increases, however, photooxidation rates also increase. The introduction of a double bond (e.g. ethylene, propene, butene, etc.) increases the reaction rate still further. Ethylene with 2 carbon atoms, although capable of being oxidized, is not as reactive as those olefins with 4 to 6 carbon atoms (e.g. 1-butene, isobutene, 1-pentene, etc.). If a second double bond (e.g. 1, 3-butadiene) is introduced, the reaction rate may be doubled. The smog producing reactions are not limited to hydrocarbons, but may also include aromatic hydrocarbons, aldehydes, acids, ketones, and alcohols (8, 9, 26). The details of the reactions have not been worked out. But, in the presence of solar radiation--particularly ultraviolet--and the oxides of nitrogen (automobile emission), ozone is produced which then oxidizes the organic materials in the air, leading to smog and consequent health and plant damage (26). This is the general photooxidation reaction. As a rule, 150 ppb ozone will result in plant damage, and all plants are injured over the range of 150 to 900 ppb (4, 5).

The effects of air pollutants on plants and animals are well known qualitatively (2, 15, 17, 24, 25). It is sufficient to point out that response may be directly mediated by concentration and exposure time and also by 1) plant species, 2) previous history of the plant, 3) temperature, 4) presence or absence of other gases in varying concentrations, 5) level of light intensity, and, 6) physiological status of the plant--i.e. nutrition, rate of growth, stress, etc. In regard to item 6) Koritz and Went (15), using a synthetic smog produced with vapors of 1-hexene and 100 ppb ozone, found that plants grown under a limited irrigation regime were more resistant to damage than plants where water was freely supplied. On the basis of their work (15), we may surmize that our cultural procedures in Colorado tend to make effects of air pollution more critical.

The sources of ethylene and related hydrocarbons are many. In terms of air pollution, the major polluter is the automobile, although evaporation from gasoline storage, leakage from natural and liquid gas storage, incomplete combustion in burners, and activities of the petrochemical industry may also significantly contribute (4, 5, 16, 20-22, 26). By comparing the ratios for example of methane to ethane plus propane, or acetylene to ethylene plus propene, the pollutant source may be tentatively assigned (20-22). Especially important in greenhouses is the production of ethylene and carbon monoxide from incomplete combustion. Since, depending upon the species, damage from ethylene can occur at levels as low as 2 ppb (5), any factor which may result in improper ventilation and combustion may aggravate damage from pollution brought in from outside the greenhouse. The photochemical activity of hydrocarbons within greenhouses has never been adequately examined, nor has adequacy of open-flame burners for CO_2 production been suitably studied.

Complicating the entire problem is the fact that meteorological and topographical conditions peculiar to the site are often most important in determining concentrations and exposure durations (16, 17). The effect may result in a type of pollution different from the so called "London" or "Los Angeles" smogs. Djordjevic (6) examined air trajectories in Denver. The Colorado Department of Public Health has also made various meteorological measurements. Generally, Denver is characterized by a semi-arid, high solar radiation climate, which probably increases photo-oxidation rates. The location of Denver along the eastern slopes and in the Platte River Valley tends to concentrate pollutants that move up and down the valley in accordance with south-southwest and north-northeast winds (6), and may be further increased by occurrence of numerous and strong temperature inversions. As urbanization continues along the eastern Rocky Mountain slopes, the interactions between climate and pollution will become more important. We are, in fact, seeing a development similar to California's, where air pollution has resulted in economic loss and relocation of the industry.