EXECUTIVE SUMMARY

EFFECTS OF SO_2 AND OZONE ON CROP PHYSIOLOGY AND PRODUCTIVITY

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Investigations conducted from 1982 through 1984 were directed to determine the effects of low level exposures of the gaseous air pollutants O_3 and SO_2 on some major crops grown in California. Plant growth and productivity were related to a number of physiological and biochemical parameters that could be used as markers in screening new crop introductions and established crop cultivars for improved air pollution resistance. The plant water status, behavior of cell membranes, and production of the gas ethylene from leaves were investigated. Intact plants, as well as specific plant tissues, were tested under both laboratory conditions with controlled environment and under field conditions in open-top fumigation chambers. The fate of SO_2 in soils was also studied.

In assessing the effects of the gaseous air pollutants O_3 and SO_2 on plants it is necessary to distinguish between two principally different situations, acute and chronic episodes. Acute exposure of plants to high level pollution causes visual plant injury after a short period of time, and plants frequently release the gas ethane from leaves into the atmosphere, a condition indicative of severe tissue injury. Our investigations were not directed to acute exposure of air pollutants but were concerned with the effects of chronic exposure of plants to low level air pollution which usually do not cause immediate visible tissue injury.

1. Behavior of SO_2 in Soil

The soil surface acts as a barrier to SO_2 and O_3 penetration. Seed germination and root growth were unharmed in soil and potting media since SO_2 penetration was less than 1 centimeter into the soil surface and SO_2 was converted to SO_4^{2+} in less than 24 hours. Absorption and conversion of SO_2 to SO_4^{2+} was faster on moist soil than on dry soil. These data were obtained with soils considered not acidic in reaction (pH 7.0 or higher) and included soil textures from sandy loam, to silt and clay loam with low concentrations of organic matter (less than 1%). It should be noted that our studies were very short-termed. Over a long time span light texture soil (sand) can

more readily become acidic than heavier texture soil (clay) as a result of continuous exposure to SO_2. Prolonged usage of acid forming fertilizer, such as ammonium sulphate, $(NH_4)_2SO_4$, has effected a lowering of the pH-reaction of many sandy soils in the San Joaquin Valley of California. The reaction of soils under cultivation for crop production can be reasonably and economically controlled by applications of limestone (crushed $CaCO_3$). However, some soils, deficient in sulphur, would show an improvement in general fertility as a result of SO_2 deposition.

2. Tissue Development and Plant Yield Response

a. Laboratory studies

Seed and/or pollen of several species of plants (alfalfa, corn, cucumber, pumpkin, squash, and tomato) reported to display varying sensitivity to either SO_2 or O_3 were exposed to levels of gases alone and in combination under controlled temperature conditions of 25°C to determine tissue growth responses.

Seed germination was unaffected by exposure to levels of SO_2 ranging up to 1.5 $\mu\ell\ \ell^{-1}$ and O_3 at 0.14 $\mu\ell\ \ell^{-1}$ ($\mu\ell\ \ell^{-1}$ is equivalent to ppm). However, marked differences in seedling root growth occurred. Tomato root growth was the most sensitive to SO_2, with the greatest response occurring when exposed at the third and fourth day after germination. Cucurbits (cucumber, squash, and pumpkin) were less sensitive to SO_2. They displayed greater variability in response than tomato. Of the three corn cultivars studied root elongation of NK 51036 was less sensitive to SO_2 than were Bonanza and NC+59. Greater root growth retardation occurred with SO_2 alone than where O_3 was included.

Variability in seedling root growth was in part due to the germination media. Root growth apparently was adversely affected by the absorption of SO_2 in the unbuffered distilled water that resulted in an increase in H^+ (lower pH), whereas in the MES-buffered (2N-morpholino ethane sulfonic acid) media the formation of HSO_3^- was likely. In general, as the dose rate increased root growth declined.

Pollen germination was apparently unaffected directly by SO_2. However, a change in media pH did effect lower germination of tomato pollen in unbuffered media. In both unbuffered and buffered media pollen tube growth of alfalfa, cucumber, and tomato decreased with addition of SO_2. The introduction of O_3 had little or no direct effect on pollen viability. These responses of pollen to fumigation were found (in vitro) in an artificial environment. Whether the environment at the interface between pollen and stigma of the flower would be significantly altered by fumigation with pollutants and cause abnormal behavior of pollen germination and/or tube growth (in vivo) is not known.

The impact of SO_2 on seedling root growth and pollen tube growth in unbuffered media is due to an increase in H^+ (lower pH) whereas in buffered media the formation of HSO_3^- is implicated. The magnitude of tissue response is dependent upon exposure time and level of SO_2, and plant species sensitivity. These findings may be useful in screening quickly plant cultivar sensitivity to pollutants.

b. Field study

In the summer of 1984 snap bean cultivar Blue Lake Stringless 290, reported sensitive to O_3, was grown (at two soil moisture conditions) in field chambers and outdoor in the field to ascertain the influence of daily 5-hour chamber fumigation with a low level of O_3 between 0.07 and 0.10 $\mu\ell\ \ell^{-1}$ upon plant productivity. Plant development was measured at three stages of growth, pre-bloom, bloom, and at mature green bean pod harvest.

A marked decline in plant growth with time and lower total fresh green pod yield was due primarily to daily exposure of plants to O_3. Some decline in plant productivity was due to chamber environment and to soil moisture status. At harvest plants that had been treated with O_3 had developed 25% less leaf area and yielded about 41% lower fresh green pod weight compared with nontreated chamber and outdoor grown plants.

A gradual change in foliar color from a dark to yellowish green of plants exposed to O_3 was indicative of chlorophyll degradation that most likely led to a lowering in photosynthetic efficiency and carbohydrate production.

Fresh green pod yield was lower at a mean soil moisture tension of -0.10 MPa than at -0.05 MPa whether grown in chambers or in the field. Megapascals are equivalent to 0.5 and 1.0 atmospheres tension respectively. The decline in fresh green pod yield of O_3 treated plants was about half at -0.05 MPa and about one-third at -0.10 MPa mean soil moisture tension compared with the pod yield of plants not exposed to O_3. The lowest fresh green pod yield was found with plants exposed to O_3 yet the pod yield was the same at both mean soil moisture tensions. This response suggests that plants at the more optimal soil moisture condition maintained a longer period of stomatal conductance for O_3 penetration. The gradual decline in foliar color was a symptom of O_3 damage. It was not clearly shown that leaf water potential and/or stomatal function was different among plants between the two soil moisture tensions. A gradual loss in chlorophyll could account for the decline in plant productivity.

Despite the limited number of plants available for plant growth and pod yield measurement it has been shown that plant productivity is adversely affected by low level O_3 fumigation for 54 days. It is likely that had plant exposure to O_3 continued the yield of beans would also have been lower with present cultural inputs. There was no indication that plant nutrition or lack of adequate soil moisture limited plant growth. Further studies could ascertain the specific interactions of plant responses between low level O_3 exposure and plant water potential on plant productivity.

3. Physiological and Biochemical Processes

a. Laboratory studies

Experiments using controlled-environment air pollutant exposure chambers were done with several varieties of corn and bean that have been previously described by other investigators to differ in their O_3 sensitivity. The varieties used were NC+59 and Bonanza (O_3-resistant) and NK 51036 (O_3-sensitive) for corn, and Black Turtle Soup and French's Horticultural (O_3-resistant) and Blue Lake Stringless and Spurt (O_3-sensitive) for bean.

We studied the physiological responses of plant tissue to SO_2 of the three corn cultivars known to differ in O_3 sensitivity, at two distinct stages of growth, in young seedlings with small leaves without functional leaf pores (stomata), and in established plants with green leaves and leaf pores. Cultivar sensitivity to SO_2 is different from that to O_3. The O_3-sensitive NK was the most SO_2 resistant cultivar among the three studied. NK showed resistance to SO_2 at both the young and seedling stage (measured as root growth) and with established plants (determined as root and shoot growth and visible leaf injury). The differential effect of SO_2 on the leaf pores of the three cultivars could not be correlated with their differential sensitivity expressed as growth or injury. However, after long-term, low-level exposure, only the sensitive cultivars NC and B showed a change in plant water status.

The studies on corn demonstrate that in this crop species cultivar differences in SO_2 sensitivity are not due to difference in gas absorbed through the leaf pores. The plant's ability to neutralize (detoxify) this gas may be an important factor in determining this plant's sensitivity or resistance to SO_2.

A plant under stress produces the gas ethylene. Ethylene production in the three corn varieties was correlated with differential SO_2 sensitivity. Sulfur dioxide at a low level did not stimulate ethylene production. At a somewhat higher level of SO_2 ethylene production was stimulated in NC, which tended to be the most SO_2 sensitive cultivar in terms of growth without signs of visual injury. Thus, ethylene production appears to be an indicator of SO_2 stress at SO_2 levels below those that cause visible injury; moreover, ethylene production was only stimulated by SO_2 in the cultivar that is most sensitive to SO_2.

The experiments on the four bean cultivars known to differ in O_3 sensitivity aimed at determining whether effects of O_3 and SO_2 on the leaf pores and on the function of leaf membranes were correlated with differential sensitivity of the cultivars to both pollutants. It was found that O_3 sensitivity in these bean cultivars was related to the length of time the leaf pores remained open and therefore related to high rates of leaf absorbed O_3. Sulfur dioxide at low levels did not cause visible injury in bean leaves. The observed pollutant effects on the leaf pores were not correlated with differential pollutant sensitivity. Relative to leaf membrane responses, the cultivars showed differential responses to O_3 and SO_2, applied singly, that were not related to differential air pollutant sensitivity. Damage of leaf membranes by SO_2 has not previously been demonstrated. Combining O_3 with SO_2 damaged leaf membranes in all four cultivars. Application of calcium to the leaves protected the leaf membranes somewhat from the pollutant-induced damage. It would be interesting to test whether fertilization of soils with lime or gypsum could protect the foliage of crops from air pollutant-induced injury under field conditions.

Sulfur dioxide can cause injury to the chloroplasts of leaf tissue - the sites of photosynthesis - which can be experimentally determined by the formation of the gas ethane. Spinach chloroplasts when exposed to SO_2 showed that ethane formation occurred in the light and with concomitant detoxification of SO_2.

b. Field study

In the summer 1984 the O_3-sensitive bean variety BBL was grown in the field at two soil-moisture regimes and exposed to long-term, low-level O_3 for 5 hours daily in field chambers. At pre-bloom, bloom, and at maturity of the crop the effects of O_3 on the leaf pores, leaf water status and functioning of leaf membranes were assessed. The field data were quite variable. Long-term exposure to O_3 had no effect on the leaf pores. Plants at the pre-bloom stage showed a response of the leaf water status caused by O_3 and this was the case with plants at both soil water regimes. However, this effect could not be observed in older plants. Ozone caused some damage to leaf membranes in plants at bloom, particularly in plants that were grown on soil with lower available moisture.

The field experiment showed variable results relative to the measured physiological parameters. The gas exposure characteristics of these field chambers may have had effects on water loss of both plants and soil, and thus made it difficult to interpret possible interactions between O_3 and the soil water regime. Furthermore, the study was conducted with four chambers which limited the number of plants for measuring plant growth and physiological responses. An additional field-chamber study is needed before the effects of O_3 on leaf chlorophyll content, sugar production, leaf water status, and leaf membrane function in bean plants can be fully evaluated and their implications assessed. The study should include nine or more chambers to provide a plant population to adequately support the volume of plant tissue necessary for both plant growth measurement and physiological testing.

4. Proposed Applications

Ethylene production may serve as a physiological indicator in screening crop varieties for differential air pollutant sensitivity. Our results indicated such a possibility for corn varieties that differ in sensitivity to SO_2. An additional focused investigation needs to be made before one can make a general recommendation on the use of ethylene as an indicator for air pollutant sensitivity. Sensitivity of natural vegetation to air pollutants may also be tested in the field by detecting the release of ethylene from plants.

In our study we found that application of calcium to the leaf may protect leaf membranes from damage caused by gaseous air pollutants. We propose to test in the field whether fertilization of soils with lime or gypsum may protect crop foliage (or foliage of natural vegetation) from air pollution injury.