Air Pollution Effects on Potato and Bean in Southern Michigan
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Air Pollution Effects on Potato and Bean in Southern Michigan

Cover: Tolerant Katahdin (left) and (right) sensitive Norchip in the non-filtered air of the plastic field houses, Sept. 1, 1971.

SUMMARY

Air pollution injury of potato and bean in southeastern Michigan is described. The speckle leaf disease of potato which caused severe yield losses in 1968 and 1969, and which was present to a lesser extent in 1970 and 1971, is believed related to air pollution injury.

Plants were grown in plastic houses in southeastern Michigan potato fields. Ambient field air was introduced into one house and air was filtered through activated charcoal in another. Tobacco plants in the non-filtered air developed symptoms typical of ozone injury. Bean leaves become bronzed with brown necrotic flecks on the upper surface. Severely affected leaves dropped.

Affected potato plants developed symptoms of early maturity and died prematurely exhibiting chlorosis and early yellowing of the lower leaves. Necrotic spots developed on the upper surface of leaves, upper surfaces became bronzed, leaves rolled upward, and severely affected leaves died and remained attached to the stem. In filtered air, plants grew normally and symptoms of speckle leaf and air pollution were absent.

Symptoms of speckle leaf diseased potato plants in the field were in agreement with those developing in the non-filtered air.

Chemical control of air pollution injury was successful with tobacco and bean. Benomyl (methyl 1-(butylcarbamoyl)-2-benzimidazolecarbamate) 50 ppm in soil was effective in preventing injury in tobacco and bean. Neither soil nor foliage applications to potato have as yet been successful.

Air Pollution Effects on Potato and Bean in Southern Michigan

By

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INTRODUCTION

For approximately 10 years, a disorder of potatoes in Michigan has been of considerable economic importance and the cause has remained undetermined. In 1969, a committee of interested persons was formed within the state to assemble information available at the time. Observations were published (11) in a preliminary account of symptoms, varietal sensitivity or tolerance, nutritional aspects, etc. For lack of a better name, the term speckle leaf was applied.

The disorder, distributed over most of the southern half of Michigan, was especially severe in the southeastern area near Toledo, Ohio. Incidence was not regular from year to year. It was high in 1968 and 1969 with maturity as much as a month early and with greatly reduced tuber yields. The disorder was very mild in 1970 and 1971 with essentially no yield loss even with sensitive varieties.

Symptoms were primarily early maturity associated with a chlorotic yellowing and bronzing. Yield reduction due to early maturity was often considerable and some growers suffered severe losses (Fig. 1).

Fig. 1 Advanced symptoms of speckle leaf, extensive loss of leaves and premature senescence of the Norchip variety Aug. 18, 1969, in southeastern Michigan. Yields will be low following such early season vine death.

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Fig. 2. Leaves of Norchip in the field in southeastern Michigan show bronzing, upward rolling of leaves and necrotic spotting typical of the speckle leaf disease on Aug. 13, 1969. (Photograph courtesy of Dr. E. Doll, Crops and Soils Sciences, Michigan State University.)

Field symptoms included an upward rolling of the leaves (Fig. 2). Necrotic spotting of interveinal leaf tissue was first evident from the upper leaf surface, later necrosis extended to the lower surface, and sometimes affected areas coalesced.

Leaves also became bronzed, somewhat chlorotic and remained attached to the stem. Some stem flecking may or may not have been associated with this disorder. There was no direct injury to underground parts of the plant such as roots, lower stems, stolons or tubers.

Necrotic spots in the leaves were initiated in the palisade mesophyll (the columnar cells under the upper epidermis). Later, the spongy mesophyll cells (loosely arranged cells between the palisade mesophyll and lower epidermis) also became necrotic. These cellular changes within the leaf were consistent in 1967, 1968 and 1969.

Varieties in which speckle leaf develops in severity in Michigan are Haig, Norchip, Norgold, Norgold Russet and Superior. Sebago, Katahdin and Kennebec are more tolerant or resistant.

Air pollution injury to plants, particularly that caused by photochemical oxidants, is becoming an increasingly important problem in the United States. Photochemical oxidants are formed by sunlight acting on hydrocarbons released in relatively large amounts from automobile exhaust. These photochemical oxidants include ozone (O_3), PAN (peroxyacetyl nitrate) and related compounds. Symptoms of injury to plants by air pollutants of this type have been described both in gross aspects (8, 9, 10, 12) and internal leaf disorganization (8, 10, 13). On the basis of these descriptions photochemical oxidants were suspected.

Synergism between sulfur dioxide (SO_2) and the photochemical oxidant ozone (O_3) has been established (14). It is highly probable that both SO_2 and photochemical oxidants were present in air over the plots in southeastern Michigan. Heavy automobile traffic in the vicinity provides hydrocarbons for production of photochemical oxidants and the industrial complex of Toledo provides, among other air pollutants, SO_2. Symptons of sulfur dioxide injury on potato leaves (9) are suggestive of the bronzing and leaf rolling effect of the speckle leaf problem in Michigan.

This paper reports results of studies to determine if the potato problem is related to some type of air pollution. Growth responses of potato varieties sensitive and tolerant to the speckle leaf disorder were determined. Tobacco varieties sensitive and tolerant to ozone air pollution and certain commercial bean varieties were also tested. For this, air filtered through activated charcoal and nonfiltered air were introduced into each of two plastic greenhouses.

MATERIALS AND METHODS

Air filtration units (Fig. 3) were prepared to introduce air into two A frame type houses, 6 x 6 x 16 ft covered with 4 mil polyethylene plastic. One end (facing north) was only partially closed to permit air exhaust and provide entrance to the house. Each unit had a blower fan and adjustable vents to regulate air flow into the houses. One unit had a 2-ft square filtering unit containing 50 lb of activated charcoal. The other unit had no charcoal filter. Each unit contained a furnace filter to prevent large particulate material from entering the houses. Furnace filters were changed at least every 2 weeks.

Within the houses air was changed approximately 8-10 times per minute. Temperatures were similar in both houses and averaged 4-5° F above those outside during the heat of the day. Light intensity was approximately 50% lower than that outside the houses.

Sandy loam soil from the farm on which the problem had been severe was used for potting plants. Precautions were taken to avoid soil to which herbicides and systemic insecticides had been added. To avoid exposure to air pollution **en route**, plants grown in the greenhouses at East Lansing were brought to the field location in plastic bags by covered van.

These field units were serviced once a week and observations recorded. Nurtrient (Plant Marvel [12% N, 31% P_2O_5, and 14% K_2O] 5g/gal) was used to water the pots at weekly intervals. Aphids were controlled satisfactorily with various toxicants applied once a week. Grasshoppers, however, were difficult to control and damaged some potato leaves.

Tobacco varieties included Bel W3 (very sensitive to ozone), Bel C (sensitive to ozone) and Bel B (tolerant) (6). This seed was obtained from the U.S. Department of Agriculture, Beltsville, Md.

Potato varieties were Norchip, Haig, and Superior (very sensitive), and Sebago, Kennebec, and Katahdin (moderately tolerant to tolerant). The above rating was based on previous observations under Michigan conditions.

Benomyl (methyl 1-(butylcarbamoyl)-2-benzimidazolecarbamate) is marketed as Benlate 50% active by the E. I. duPont de Nemours and Co., Wilmington, Delaware. It was used at 50 ppm active benomyl (100 ppm commercial Benlate) in soil and as a foliage spray. This material is an effective systemic fungicide and is cleared for use on some crops. However, it is not approved for potatoes or beans. These results describe experimental work only. **Do not use benomyl** for growing potatoes or beans which will be used for human or livestock food.

RESULTS

The study was made in 1970 and 1971 on the farm of Wayne K. Lennard and Sons at Samaria, Michigan. This is about 15 miles north from Toledo and 1.75, 2.0, and 4.0 miles from 3 major highways to the east and 7.5 miles from an interstate freeway to the west. Potato plants in this field were severely affected in 1968 and 1969.

Results in 1970 were not satisfying due in part to low speckle leaf incidence and because plants were planted directly into the field soil and growth effects from herbicides were encountered. However, evidence was obtained that air pollution was, in part, responsible for injury.

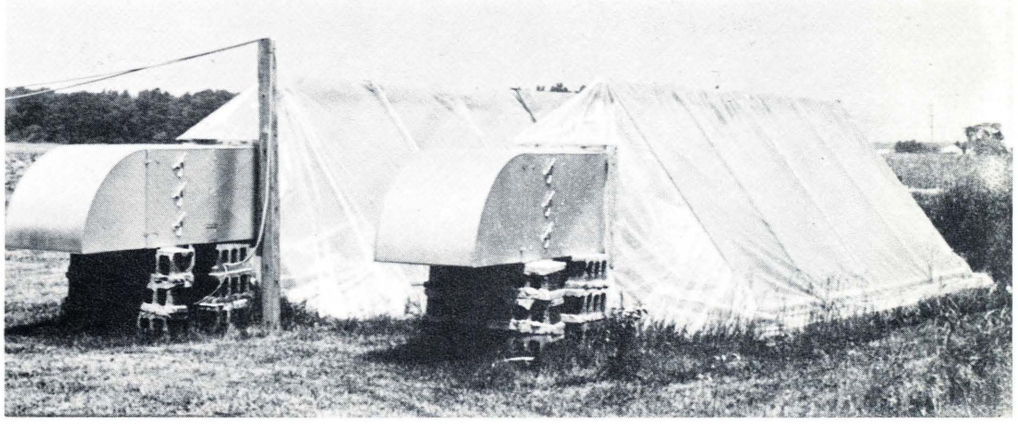

Fig. 3. Plastic houses for studying plant growth in polluted field air. Non-filtered air was blown through the house at the left while air purified by filtration through activated charcoal was blown through the unit on the right. Potatoes and other indicator plants were grown in these houses.

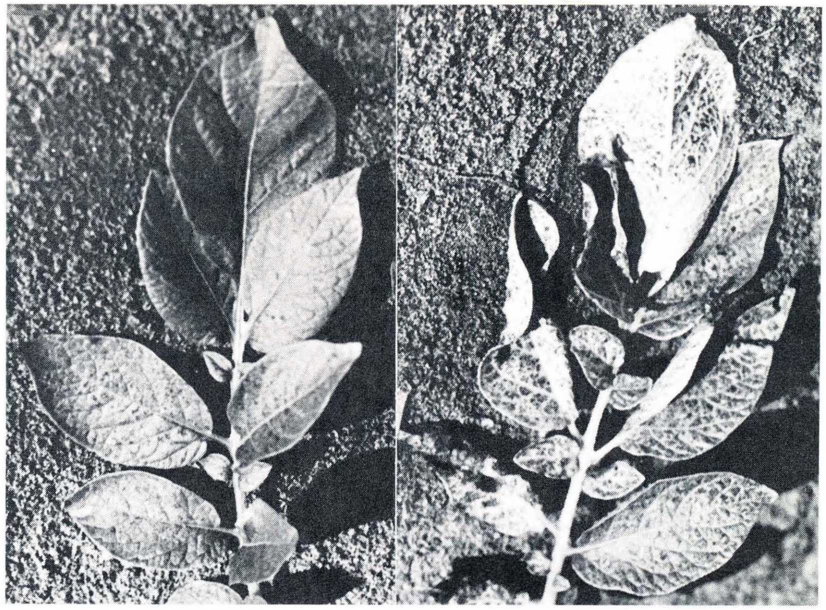

Fig 4. (left) Acute injury with well developed necrotic spotting and marked leaf rolling without bronzing in field grown Norchip leaves, Sept. 1, 1971. Fig. 5. Early symptom (top center) and advanced injury with bronzing and extensive necrosis (top right) of field grown Norchip, Sept. 8, 1971.

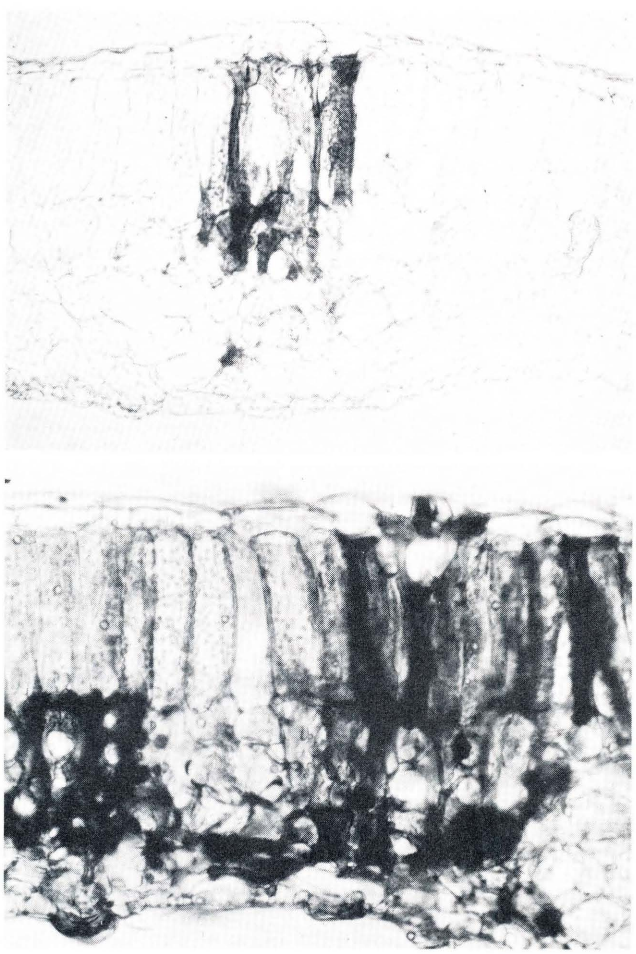

Fig. 6. Norchip potato leaves in cross section showing: (top) early injury — palisade cells under the upper epidermis are first affected, and (bottom) advanced necrosis involving also the spongy mesophyll.

Potato (*Solanum tuberosum* L.)

In the Field

The houses were placed next to a field of the speckle leaf sensitive variety, Norchip, in 1971. In this field, speckle leaf was first observed on July 27. The leaf canopy was well established at this time. Lower leaves were not appreciably affected, but necrotic spotting of the apical leaves had developed.

By August 11, because of additional apical growth, affected leaves were situated approximately ⅔ up the stem from the base. The appearance of affected leaves was essentially unchanged. Below and above this point, leaves were apparently healthy. This suggested that leaves had been affected for only a short time by a toxicant. Later in August or early September, conditions causing the disorder once again developed and more injury followed (Figs. 4, 5).

Affected leaves from field plants were cut in cross section and photographed without fixing or staining. Dead cells turned brown and affected tissue was clearly differentiated from healthy cells. At first injury developed in the palisade cells (Fig. 6, top) under the upper epidermis but lateral spread was rapid in the spongy mesophyll (Fig. 6, bottom). Dead tissue extended completely through the leaf.

In the Air Filtration Houses

In 1971, all potato plants were grown in clay pots using field soil from another part of the farm. Sebago, Norchip, Katahdin, Superior, and Haig were planted June 2 in 8-in. pots. No typical symptoms of speckle leaf developed until August 4.

By early August, vines were approximately 24 in. tall. In the non-filtered air, typical speckle leaf had developed similar to that seen in the field. It was especially severe on the more elevated stem tips. Leaves were rolled and brown spots were present between the veins.

Plants in the filtered air were free from this disorder. Norchip was severely affected, and Haig moderately affected. Katahdin, Sebago, and Superior were essentially free from the disorder in early August.

Later in the month, Norchip (Fig. 7), Haig, and Superior were severely affected. Sebago was moderately affected and Katahdin (Fig. 7) was slightly affected to healthy. No speckle leaf developed on plants in the filtered air.

In the non-filtered air, portions of plants which were out of the mainstream of air movement, either behind pots or protected by foliage masses, exhibited less speckle leaf than those exposed to air movement.

Fig. 7. Tolerant Katahdin (left) and (right) sensitive Norchip in the nonfiltered air of the plastic houses, Sept. 1, 1971.

The above experiment was a split plot design – half of the plants received nutrient once a week; the other half were not fertilized. Speckle leaf incidence in this preliminary trial was not influenced by the nutritional differences.

A second planting of Norchip and Haig was made on July 16 into pots containing greenhouse compost. By August 18, symptoms were first evident on potted plants growing outside the houses, and inside the house with non-filtered air. Disease during the next 4 weeks in the non-filtered air inside or outside the houses became progressively more severe (Fig. 8). Plants growing in the filtered air were not affected.

Fig. 8. Haig potato plants grown in non-filtered (left) and filtered air (right), Sept. 1, 1972.

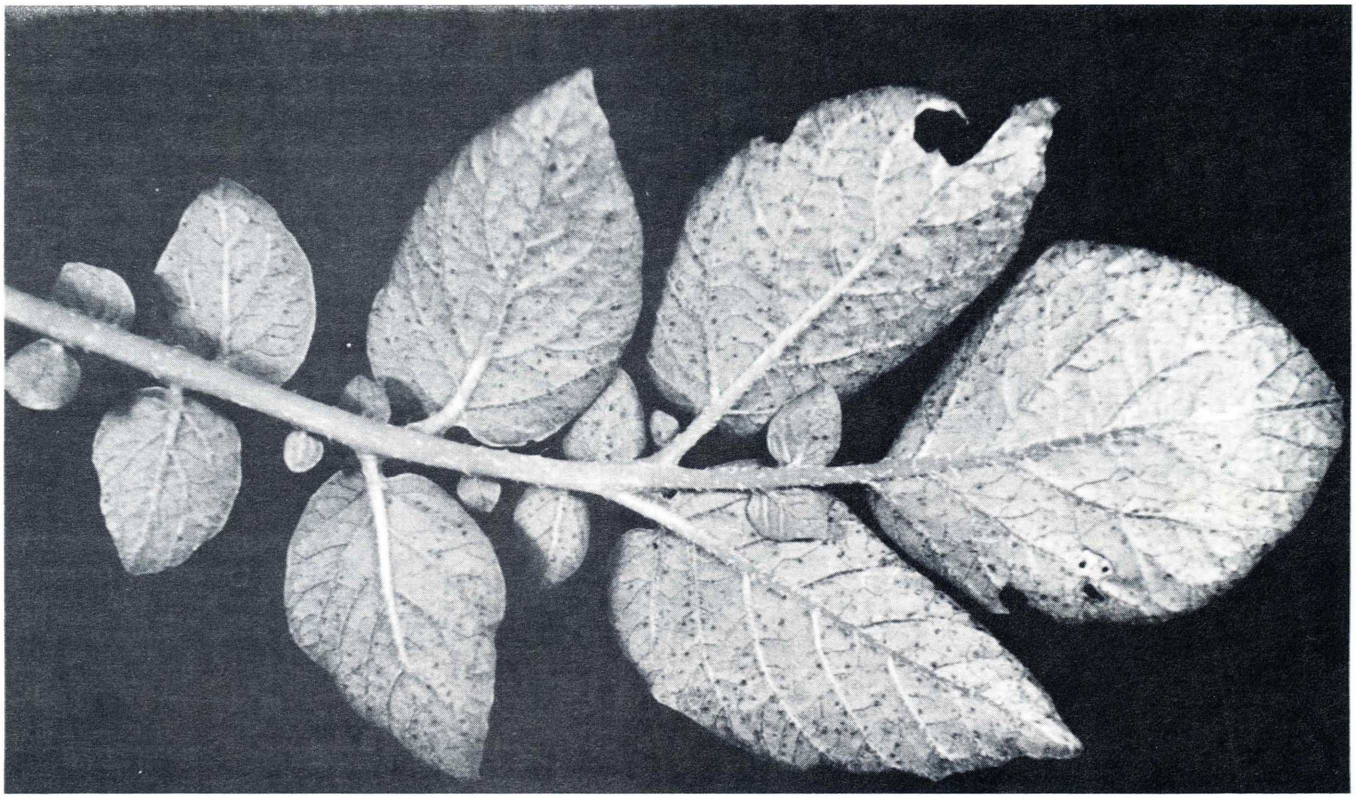

Fig. 9. Another disorder apparently unrelated to air pollution injury on Katahdin leaves. This does not appreciably affect growth of the potato. Small circular spots develop early in the season on all varieties examined in both the field and filtered air.

Symptoms in the second planting consisted of upward rolling of affected leaves, necrotic spotting between the veins, and premature death of affected leaves. Dead leaves did not abscise but remained attached, hanging limply or dried on the stems. Both varieties were severely affected. Haig was somewhat more severely injured than Norchip. By September 7, Haig plants in non-filtered air outside as well as inside the houses were almost dead, but in the filtered air they were healthy.

Necrotic leaves of typically affected plants in both the early and late planting were cut in cross section. Cellular necrosis was similar to that observed in field plants. Necrotic cells were first present in the palisade mesophyll and later involved the spongy mesophyll. Affected leaves were rolled upwards suggesting vascular involvement. On August 18, no vascular discoloration could be found in the petioles of affected Norchip or Haig varieties in either the first or second planting test.

A Symptom on Potato Apparently Unrelated to Speckle Leaf

Another unrelated leaf spotting of minor importance should be differentiated from the speckle leaf symptoms described earlier. The second leaf spotting, the cause of which is not yet understood, is characterized by small circular areas on the lower leaf surface about 1/16 in. in diameter (Fig. 9).

Unlike speckle leaf, they were scattered over the lower leaf surface while speckle leaf injury first appeared on the upper surface. These were water soaked at first and later became bluish to blackish and then brown. Spots first developed on the oldest leaves in practically all potato plants in either field or plastic house plantings.

The spots usually did not enlarge further and seldom became a problem. The spot as it developed inside the leaf was clearly different from typical speckle leaf. In cross sections of leaves (Fig. 10), these spots were present in the spongy mesophyll above the lower epidermis. Necrosis was usually limited to the spongy mesophyll and restricted in lateral spread.

This leaf spot occurred in the house with filtered air and in that with field air. It developed on varieties, such as Katahdin, that did not develop typical speckle leaf and on other varieties – Haig, Norchip and Superior – in which speckle leaf was severe. This disorder was also present in nearby fields of Norchip and Kennebec.

Tobacco (*Nicotiana tabacum* L.)

Tobacco seedlings were transplanted in the greenhouse at East Lansing to peat pots and taken to the field houses on June 10 as described earlier. By July 2, leaves of Bel W3 tobacco (very sensitive) and Bel C (sensitive) had developed white spots on the older leaves; the upper leaves were free from lesions. This condition became progressively more severe through July 16 (Fig. 11). Tolerant Bel B did not develop symptoms.

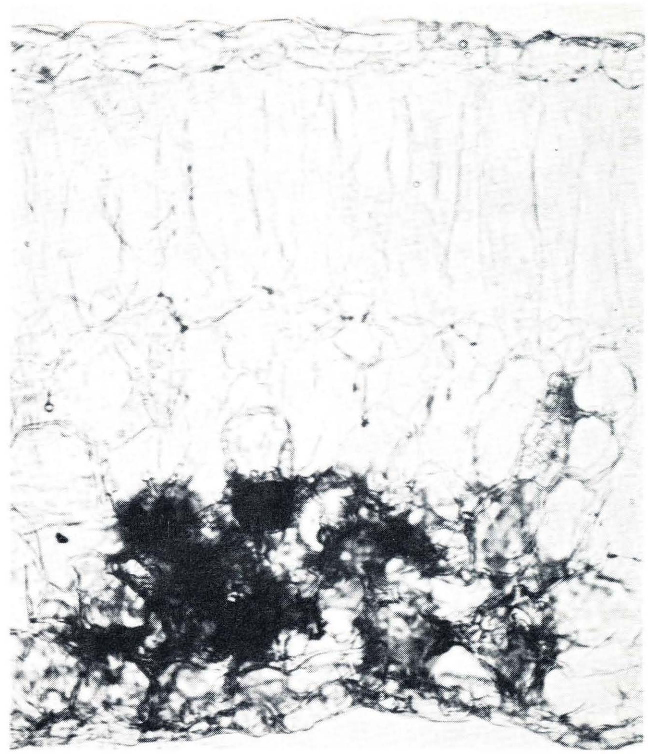

Fig. 10. Cross section of the variety Kennebec with breakdown of cells in the spongy mesophyll. This is not believed to be air pollution injury.

Fig. 11. Air pollution injury in sensitive tobacco, Bel W3. Healthy plants grown in filtered air (left) and injured plants (right) in non-filtered air.

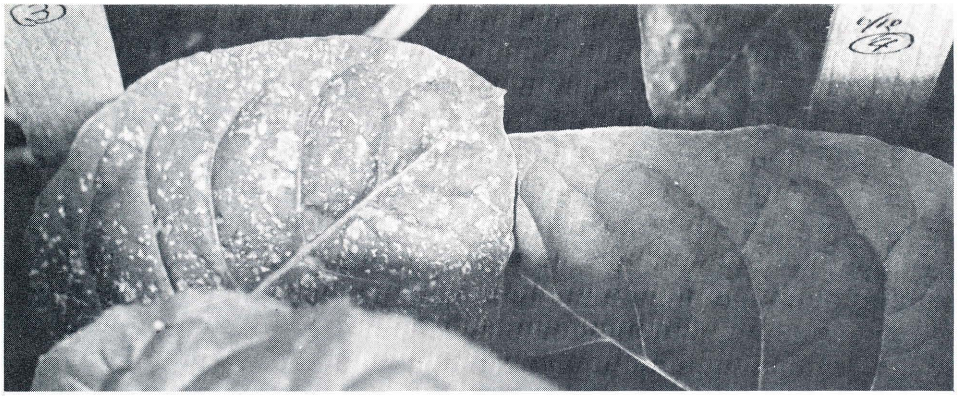

Fig. 12. Chemical protection of Bel W3 (sensitive) tobacco by benomyl soil treatment in non-filtered air. Plant without treatment (left) and (right) plant grown in soil with 50 ppm benomyl.

Benomyl soil treatment (50 ppm) was prepared in the greenhouse. The commercial chemical (Benlate 50% active) was mixed 100 mg/L of soil for a final concentration of 50 ppm active. A few days after transplanting Bel W3 tobacco plants were moved to the field houses. Flecking of leaves was absent on plants grown in benomyl treated soil (Fig. 12).

A second transplanting of Bel W3 on July 19 responded similarly. Plants were also placed outside the houses. Plants in non-filtered air either inside or outside the houses had symptoms within 2 weeks and were severely affected within a month. Again, filtering the air protected plants from injury.

In the second trial, benomyl was mixed into the soil at 50 ppm active, and plants were placed in the field houses at once. One group of plants was left outside in ambient air. Benomyl in the soil effectively protected young tobacco leaves in the non-filtered air inside and outside the houses. However, protection was not immediate and lower leaves were affected by air borne toxicants. Presumably, this was due to time required for root uptake and translocation into the leaves.

In a third trial, Bel W3 was transplanted to field soil at the MSU greenhouses. Plants were placed in the house with non-filtered air and with filtered air. Some plants were also placed outside in ambient air. Leaves of one-half of the plants in each location were sprayed with benomyl 50 ppm active on August 26 after transplanting in the greenhouse and again on August 27 when they were placed in the field houses. Benomyl gave excellent protection as in previous trials.

There was no evidence that benomyl was phytotoxic to tobacco at this concentration (50 ppm active) in any trial.

Bean (*Phaseolus vulgaris* L.)

Field beans (Charlevoix, Sanilac, Michelite and Seafarer varieties) were grown from seed in soil from the W. Lennard Farm. By the time plants were in the monofoliate leaf stage, symptoms were present in non-filtered air on all varieties. Monofoliate leaves dropped prematurely. Later trifoliate leaves developed symptoms and leaflets dropped prematurely. Plants in the filtered air did not develop leaf symptoms and growth was more vigorous.

A second planting of Sanilac and Charlevoix bean reacted similarly in the non-filtered air (Fig. 13). Small, rust colored lesions developed in considerable numbers. Affected leaves became chlorotic, often somewhat bronzed, and abscised early. Lesions became evident from the lower and the upper surfaces at approximately the same time.

Leaves were not appreciably glazed as those described for PAN injury. In the filtered houses, plants in both tests remained healthy (Fig. 13), leaves did not drop prematurely, and plants were vigorous. Leaves with necrotic spots were sectioned (Fig. 14). Necrotic cells first developed in the spongy mesophyll near the lower edge of the palisade mesophyll. In severe responses, necrosis extended within the spongy mesophyll and involved the palisade mesophyll.

Benomyl (50 ppm active) was incorporated in the soil in the second trial. Protection was incomplete soon after emergence, as mild symptoms were present on monofoliate Sanilac leaves in benomyl treated soil. Both Charlevoix and Sanilac were completely protected as plants became older. Benomyl-treated Charlevoix plants grew as well in the filtered air as did the non-treated controls. No toxic effects were apparent. Growth of Sanilac indicated some toxicity. Foliage application of benomyl on beans was not attempted.

Fig. 13. Sanilac bean leaves in the house with non-filtered air (left) and filtered air (right).

Fig. 14. Cross section of Sanilac bean leaf showing early injury.

White Pine (*Pinus strobus* L.)

White pine seedlings were taken to the greenhouse from the nursery of the MSU Forestry department. In the non-filtered air, older needles of certain individual plants were severely affected and dropped. Younger leaves were not affected suggesting insufficient duration or concentration of toxicants. Variation between individual plants was high and populations were not sufficient to assess damage satisfactorily.

Petunia (*Petunia hybrida*)

The Pale Face variety placed in the houses in early June remained free from symptoms until discarded. Growth was similar in both houses.

Annual Blue Grass (*Poa annua* L.)

Pots of grass were placed in the houses in July. Growth in the filtered air was somewhat more vigorous than that in the non-filtered air. Otherwise, there were no differences.

Chemicals for Potatoes

Benomyl as a soil treatment in 1971 was successful with tobacco and bean. However, potatoes did not respond. In the first trial, the Superior variety was grown in the filtration houses. Benomyl was incorporated into the sandy loam soil of the Wayne Lennard farm at 50 ppm active material at the time the seed piece was planted in early June. In these preliminary trials, no evidence of protection was obtained and benomyl was slightly phytotoxic.

In the field of Norchip potatoes adjacent to the filtration houses, benomyl was applied as a soil drench around plant roots late in June. To each plant, 5.0 g of commercial 50% benomyl in 4 pt of water was poured around the roots. The soil was opened with a garden fork and 1 pt of suspension was poured around the fork. The fork was rotated 90° around the plant and the process repeated until 4 pt had been added to each plant. There was no evidence of either injury or protection.

Benomyl foliage spray applied twice, 8 oz (50% active) per 100 gal of water (312 ppm active benomyl), was not effective nor toxic to the vines.

DISCUSSION

Air pollution in southeastern Michigan is responsible for foliage injury to potato and bean. Photochemical oxidants are believed to be involved in these symptoms. Early death of palisade mesophyll cells in potato leaves corresponds closely to descriptions of ozone injury. Only a single pollutant may have been involved. However, it is highly probable that more than one pollutant was present and that their combined effect was toxic. Circumstantial evidence suggests that ozone and PAN may have been present because of the nearness of major freeways within a few miles of the plots. Furthermore, industries along the lake shore from Toledo, Ohio to Detroit, Michigan may provide sulfur dioxide.

Atmospheric ozone from extremely high altitudes might cause plant injury. Speckle leaf was severe in 1968 and 1969, but mild in 1970 and 1971. Late in June 1968, a widespread storm centered on the Gulf of Mexico and intensified as it moved toward Michigan. Air turbulance may have been sufficient to bring ozone down from the troposphere (19). Speckle leaf developed in severity early in the season and the Haig variety was senescing with bronzed and yellowed leaves by July 16.

In 1969, three somewhat milder storms developed. One in late June may have been centered too far to the west. Another vigorous storm on July 27 and 28 was centered over Detroit. Hurricane Camille on August 18 and 19 may have contributed to ozone movement from higher altitudes into Michigan fields (19). Speckle leaf this year was severe in early August. Storms of similar severity were absent in 1970 and 1971.

Air pollution injury (20) may be acute (collapse and necrosis), chronic (chlorosis and leaf abscission), or latent (growth suppression without detectable injury).

Heck (3) lists certain plants as sensitive to ozone injury (tobacco, potato, bean, tomato, spinach, and radish), intermediate (onion, spinach, sweet corn, wheat) and resistant (radish, bean, strawberry, carrot, and beet). Presumably, varietal differences account for plants such as radish, bean, and spinach being listed in more than one group.

Heggestad (4) points out that it is difficult to evaluate sensitivity of a plant species to ozone because of wide varietal differences in response. Sensitivity of Bel W3 tobacco is so great that there is no location at which injury has not been observed somewhere in the season.

Ledbetter *et al* (13) classed bean, tobacco, and potato as extremely sensitive to ozone injury. They described symptoms on potato (variety not named) as necrotic areas extending completely through the leaf either between the veins or at the margins. Necrotic tissue was light tan in color and papery in texture.

Rich and Hawkins (17) observed early season injury to potato varieties in the field in which old leaves turned yellow with necrotic spots. Leaves of one variety were glazed on the under surface. Later new foliage developed on all varieties hiding the injured leaves. The same varieties responded similarly in the greenhouse.

In our potato trials in plastic houses with nonfiltered air, necrotic spots developed on the upper surface of the lower leaves and soon afterward the upper fully expanded leaves became involved. Lower leaves turned yellow and died but remained attached to the stem.

In the field (1968 and 1969) symptoms were essentially similar. In 1971, when symptoms were very mild, injury was limited to the upper leaves presumably because of the heavy leaf canopy. Affected leaves were rolled suggesting that the vascular system may have become impaired. No evidence of vascular necrosis could be found in 1971.

Symptoms of sulfur dioxide injury of potato leaves (9) resemble to some extent symptoms observed in Michigan fields. The upward rolling of leaves and the appearance of necrotic areas are similar, but not identical to sulfur dioxide injury.

Brennan *et al* (2) tested a number of potato varieties and after 4 hr exposure to 0.10 ppm ozone observed slight injury in Chippewa, Cobbler, Plymouth, and Pungo varieties. These varieties were severely injured with 0.23 ppm ozone. Katahdin, Green Mountain, and Kennebec were also slightly injured at 0.35 ppm and severely injured with 0.56 ppm. The variety Avon tolerated exposure to 0.56 ppm and showed no injury. Unfortunately, symptoms on potato were not described.

In contrast, Rich and Hawkins (17) found Katahdin, Kennebec, and other varieties sensitive to ozone after field and greenhouse exposure. Superior and late maturing varieties were more tolerant. Heggestad (5) found Haig, Irish Cobbler, and Norland most sensitive to naturally polluted air near Washington, D.C. Avon, Superior, and Peconic were intermediate and Kennebec and Alamo were most tolerant. Tuber yields of sensitive varieties were reduced by 50% in non-filtered air; Kennebec and Alamo yields were unaffected. In these Michigan trials, Katahdin was more tolerant than Sebago, which was more tolerant than Haig and Norchip.

Ozone injury of bean (8) is characterized by bronzing and necrotic (yellowish green to white) flecking of the upper leaf surface. No lesions extended through to the lower surface of the leaf. Bronzing, necrotic stipple, chlorosis, and abscission also developed in the field in southeastern Ontario (22) and palisade mesophyll first became necrotic.

PAN (15) caused a glazing, bronzing, and tissue collapse of the lower surface. Symptoms of bean leaf injury in the non-filtered air in southeastern Michigan resembled injury by PAN, but the glazing was not distinct. Necrosis consistently started in the cells of the spongy mesophyll in the area bordering the palisade mesophyll. Possibly both ozone and PAN were present and caused some injury. Synergism between ozone and sulfur dioxide may also have been a factor.

The duration of time over which plants are exposed to pollutants influences the extent of injury. Heck (3) points out that plants sensitive to ozone may be injured in 0.1 hr by 0.4 ppm; over an 8 hr exposure, 0.03 ppm ozone may be equally effective.

Sulfur dioxide and ozone when present at the same time can injure tobacco at levels below which neither could cause injury alone (14). Symptoms on tobacco were similar to those of ozone (tiny white flecks scattered over the upper surface of mature leaves). Heck (3) also reports synergism of sulfur dioxide with ozone on radish, tomato, broccoli, and alfalfa.

Furthermore, he (3) observed synergism with sulfur dioxide and nitrogen dioxide. Sulfur dioxide, nitrogen dioxide and ozone in mixtures of 0.05 ppm each were also toxic to sensitive tobacco. Combinations of pollutants may give different symptoms than those obtained by single pollutant exposures. Exposure to one pollutant may predispose a plant to injury by another pollutant (1).

Potato and bean symptoms observed in the Michigan plots do not fit precisely those of ozone, PAN or sulfur dioxide injury. More than one pollutant may have been involved.

Ozone uptake from surrounding atmosphere by bean leaves was demonstrated in 1970 (18). The removal rate was regulated by the same processes regulating stomatal opening and closing. Hill (7) points out that vegetation may be an important sink for removing several pollutants including sulfur dioxide, nitrogen dioxide, ozone, PAN, and carbon monoxide. The pollutant removal rate was influenced by wind velocity above the plants, height of the leaf canopy, and light intensity. Waggoner (21) discusses plant potentials for removing ozone.

Toxicants were apparently removed by foliage masses in the house with non-filtered air. Leaves of susceptible plants sheltered by leaves of the same type plant or leaves of other plants were sometimes completely free from injury. Injury was consistently most severe in the main air stream.

A similar response developed in the field in 1971 in which toxic levels were sufficient to kill Norchip potato leaves. Injury was confined to the exposed leaves near the top of the plant. Had the foliage canopy been less dense so that individual plants were exposed, field injury may have been severe.

Plants at the edge of the field were more severely injured than those some distance inside the field. Furthermore, potted plants outside the houses at the edge of the field were severely affected.

These factors become important when growing plants where air pollution is present. Cultural practices stimulating rapid early plant growth may permit plants to escape serious injury by presenting large foliage masses that can remove some toxicant from the surrounding air.

Ozone injury may be reduced by applying certain chemicals (anti-ozonants or antioxidants) to the under surface of plant leaves. Chelates of 8-quinolinol, certain naphthoquinones, and zineb (zinc ethylene bisdithiocarbamate) protected tomato (16) when applied to shade cloth over the plants.

Several other compounds were tested by different investigators with some success. Recently, effectiveness of benomyl and benzimidizole on tobacco, bean and other plants was reported informally (1).[2] Our results using benomyl on tobacco and bean were very encouraging. However, the materials tested were not effective on potato.

[2] Since this manuscript went to press the following paper was published describing this work: Pellissier, M., N. L. Lacasse, and H. Cole, Jr. (1972). Effectiveness of benzimidazole, benomyl, and thiabendazole in reducing ozone injury to pinto beans. Phytopath 62:580-582.

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(2) Dunbar Forest Experiment Station, Sault Ste. Marie. Established 1925, forest management.

(3) Lake City Experiment Station, Lake City. Established 1928. Breeding, feeding and management of beef cattle; and fish pond production studies.

(4) Graham Horticultural Experiment Station, Grand Rapids. Established 1919. Varieties, orchard soil management, spray methods.

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(6) Muck Experimental Farm, Laingsburg. Plots established 1941, crop production practices on organic soils.

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(8) W. K. Kellogg Farm and Bird Sanctuary, Hickory Corners, and W. K. Kellogg Forest, Augusta. Established 1928. Forest management, wildlife studies, mink and dairy nutrition.

(9) Fred Russ Forest, Cassopolis. Established 1942. Hardwood forest management.

(10) Ferden Farm, Chesaning. Plots established 1928. Soil management, with special emphasis on sugar beets. (Land Leased)

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(13) Trevor Nichols Experimental Farm, Fennville. Established 1967. Studies related to fruit crop production with emphasis on pesticides research.

(14) Saginaw Valley Beet and Bean Research Farm, Saginaw. Established 1971. Studies related to production of sugar beets and dry edible beans in rotation programs.