THE IMPACT OF SO_2 ON POTATOES CHRONICALLY STRESSED WITH OZONE

Final Report
California Air Resources Board
Agreement No. A7-141-30

K. W. Foster
Department of Botany and Plant Sciences
University of California
Riverside, CA 92521

Present Address
Department of Agronomy and Range Science
University of California
Davis, CA 95616

November, 1980

THE IMPACT OF SO_2 ON POTATOES CHRONICALLY STRESSED WITH OZONE

Final Report
to the
California Air Resources Board
Research Division

Agreement No. A7-141-30

K. W. Foster

Department of Botany and Plant Sciences
University of California
Riverside, CA 92521

November 1, 1980

ABSTRACT

Potato crops in the San Joaquin Valley of California may be damaged by air pollution, specifically ozone and/or sulfur dioxide. Experiments at the University of California, Riverside, were conducted to examine the effects of four levels of ambient oxidant treatment in factorial combination with two level of sulfur dioxide treatment on yield and quality of 'Centennial', a russet-skinned cultivar. Root and shoot dry weights and tuber yield were linearly reduced by oxidant treatments. Sulfur dioxide effects were less marked but of possible importance. No treatment effects on dry matter or sugar contents of tubers were observed.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

List of Tables (Continued)

ACKNOWLEDGMENTS

The able assistance and diligence of Scott Simpson and Benny Navas in maintaining the fumigation facility and Richard Flagler for generating PAN are greatly appreciated. Minn Poe, Dave Lick, and Pat Braegelmann were indispensable in data processing and statistical analyses. Much of the interpretation of symptom development is attributable to R. J. Oshima and O. C. Taylor.

This report is submitted in fulfillment of Agreement A7-141-30 by the University of California, Riverside, under the sponsorship of the California Air Resources Board. Work was completed as of July 1, 1979.

DISCLAIMER

The statements and conclusions in this report are those of the contractor and not necessarily those of the California Air Resources Board. The mention of commercial products, their source or their use in connection with material reported herein is not to be construed as either an actual or implied endorsement of such products.

SUMMARY AND CONCLUSIONS

Substantial varietal differences in susceptibility to ozone damage have been documented in potato (Solanum tuberosum L.). Research at the University of California, Riverside, and in at least three additional states (Michigan, Ohio, and Maryland), has shown that the potential exists for substantial economic losses in potato production due to moderate air pollution. An affliction of potatoes in the southern San Joaquin Valley, specifically Kern County, known as "speckle leaf" has been present and increasing in severity in that important production area for ten or more years on certain varieties. The speculation arose that air pollution, specifically ozone, might be involved. This conjecture, now confirmed to the extent that ozone is certainly a major antagonist in causing speckle leaf, became more pointed and demanding with the introduction into California of the 'Centennial' cultivar in 1974. Centennial presented Kern County producers with a new market class of potatoes, the long russet type, which was previously unavailable or unprofitable for them due to unsuitable cultivars. However, Centennial proved to be extremely susceptible to speckle leaf. Expressed grower interest led directly to Department of Botany and Plant Science and Statewide Air Pollution Research Center (SAPRC) involvement in the project.

The research described herein was conducted at the University of California, Riverside, in conjunction with personnel and facilities of SAPRC. The 20-chamber closed-top ambient fumigation facility developed under ARB contract A6-162-30 in 1977 was used to conduct the bulk of the research.

A replicated experiment was conducted to investigate the effects of added sulfur dioxide (SO_2) at each of four levels of ambient oxidant (unfiltered Riverside air). The experiment was conducted on the oxidant sensitive Centennial cultivar from mid-September through December of 1978. Primary objectives were to determine the effects of treatments on plant growth, tuber yield, and tuber quality. An important secondary objective was to further study speckle leaf symptomatology to more clearly understand the factors causing symptoms relatively atypical of oxidant damage, especially as related to interactions with SO_2.

High hourly average oxidant concentrations for each chamber are given in Appendix Table B9. Despite a relatively light total ambient ozone dose (5043 pphm-hr), dramatic reductions in leaf and root weight, and in tuber number and yield were obtained in oxidant treated chambers. Tuber yield was reduced by 45% at a total seasonal oxidant dose of 3850 pphm-hr, averaged over both SO_2 treatments, while a seasonal SO_2 dose of 2555 pphm-hr reduced yield on average of 6% (statistically non-significant). However, the SO_2 effect may have been underestimated in this experiment due to anomalous behavior of both 67% filtered, 0 pphm SO_2 chambers. In addition, the overwhelming response to oxidant made it difficult to detect SO_2 effects, especially when only two levels of SO_2 (0 and 10 pphm) were included.

Tuber dry matter and sugar concentrations were unaffected by any treatment. Protein percentage increased with decreasing tuber yield, but not sufficiently to increase protein production on a per plant basis.

Consistent and severe foliar symptoms were observed in treatments receiving 67 or 100% ambient air and substantial additional injury occurred if SO_2 was added as well. No visible SO_2 symptoms were observed in treatments receiving predominantly filtered air.

Detailed observation of symptom development, utilizing ambient air treatments and controlled fumigations with PAN and ozone, led to the conclusion that ozone is the primary antagonist in producing speckle leaf in sensitive potato cultivars. Precise duplication of field symptoms has not yet been achieved, however.

RECOMMENDATIONS

1. Further elucidation of SO_2 effects is needed. The SO_2 fumigation concentrations (substantially below federal standards) used in this study caused apparent but statistically non-significant yield decreases. Treatment designs encompassing a greater range of SO_2 levels would address this problem. With the oxidant response well characterized, perhaps only two oxidant levels need be considered, allowing more latitude in SO_2 treatments. The marked acceleration of necrosis affected by SO_2 in the presence of oxidant, but the lack of symptoms in filtered air suggests the necessity of further characterizing the oxidant x SO_2 interaction. Also, since the Centennial cultivar utilized was suspected to be oxidant sensitive and appears to be representative of those cultivars which are, but was totally uncharacterized for SO_2 response, some preliminary varietal screening for SO_2 sensitivity may be in order.

2. A field-scale exclusion facility in the southern San Joaquin Valley should be developed to study a number of crops. With proper management such a facility could realistically accommodate two crops per year. This region represents the most intensive agricultural production area in the world; potentially significant production constraints demand reasonably complete characterization.

3. Consistently effective and convenient pollutant protectant (e.g. antioxidant) compounds should be developed as research tools. Such materials could serve three purposes: a) provide relatively economical estimates of crop loss, b) provide a selective tool for plant geneticists and breeders in developing cultivars resistant to pollutants by allowing

evaluation of genotypes for other characters in polluted environments, e.g. it is presently difficult to evaluate potato or common bean genotypes at UCR for yield and quality characteristics because of the devastating effects of oxidant, and c) at a more basic level, effective protectants may be useful in elucidating damage mechanisms.

INTRODUCTION

Crop injury from air pollution is a significant constraint in some agricultural production areas. Injury to crop plants may be manifest by either a reduction in total productivity (yield), or by a decrease in quality which may be expressed in a visual or cosmetic sense or in nutritional aspects. Potatoes (*Solanum tuberosum* L.) are documented to be sensitive to oxidant air pollutants, with this sensitivity modulated by genetic and environmental differences (2,5,6,8).

California growers annually produce potatoes on about 60,000 acres with a gross farm value of roughly $100 million. Approximately 50% of this acreage is located in the southern San Joaquin Valley, specifically Kern County (3). The major Kern County cultivar has long been 'White Rose' or California Long White, a long, white-skinned type. Market pressures in recent years have accelerated the search for adapted, profitable russet-skinned cultivars. Such a cultivar would provide Kern County growers a badly needed market option. The cultivar, 'Centennial', released in 1977 (11) but grown commercially in Kern County since 1975, rapidly assumed importance in the district by filling this russet niche. However, the variety was soon characterized as being susceptible to "speckle leaf".

Speckle leaf is a foliar affliction of potato which has been noted in the San Joaquin Valley for at least 10 years. The disease is generally believed to be slowly but gradually increasing in severity. Prior to the initiation of research (which this report pertains to) on this problem, the etiology had not been identified. Speckle leaf is a frequently debilitating disease characterized by initially small, glazed abaxial lesions which may or may not be accompanied by adaxial stippling. Advanced stages include progressive coalescence of lesions, necrosis, defoliation, and premature plant death. Numerous growers have expressed the opinion that extremely poor yields of Centennial frequently observed are attributable to speckle leaf. Centennial has recently been characterized as being susceptible to oxidant injury (8) but the likelihood of similar problems in the San Joaquin Valley has not been widely recognized. The historical basis of the disease in California rests on red-skinned cultivars, chiefly 'Red La Soda', which are also susceptible. This market class is of relatively minor importance, and since the cultivars grown have extrememly high overall yield potential and are early maturing, the speckle leaf problem was not critical until Centennial was introduced.

Attempts to isolate pathogens from speckle-leaf lesions have been fruitless (Appendix D). Also, since the symptoms are unlike any known disease, pathogens as a causal agent are unlikely. Cultural practices, including irrigation and fertilizer, insecticide, herbicide, and fungicide applications likewise cannot explain the observed varietal differences for two reasons: 1) virtually all fields of Centennial and Red La Soda in Kern County are consistently affected to some degree, while the resistant varieties are not. Resistant and susceptible varieties may even be grown together in the same field, and the predicted contrast remains, and 2) replicated variety yield trials also consistently show the same varietal differences.

General observations indicate that nitrogen status of the plant may influence the severity of symptoms. Susceptible varieties show increased symptoms in waterlogged areas of fields where nitrate leaching is likely. Differences noted, however, are small compared to varietal differences.

Speckle-leaf is of definite significance in Kern County. Grower concerns about the problem have been expressed on numerous occasions. Preliminary field investigations into the problem were funded by the California Potato Research Advisory Board for the 1979 crop year. Information on these trials may be obtained from that organization.

The objectives of the research outlined under this contract were to: 1) evaluate the potential for economic yield losses of susceptible potato cultivars in response to sulfur dioxide (SO_2) and ambient oxidant (ozone) fumigations and 2) attempt to describe conditions, including different pollutants, leading to expression of the somewhat anomalous speckle leaf symptoms.

MATERIALS AND METHODS

I. Fumigation Facility

The fumigation facility utilized for these experiments consisted of the 20-chamber facility located at the Statewide Air Pollution Research Center (SAPRC) on the Riverside campus of the University of California. Salient features of the facility include: 1) individual chambers having infrared-transparent envelopes to reduce internal heat load, 2) individual flow controls to enable the use of variable mixtures of ambient and carbon filtered air, 3) ability to introduce additional gases into individual chambers in a precise manner, and 4) environmental monitoring system. A complete description of the facility is given in Appendix A. Facility performance during the course of plant growth is discussed in Appendix B.

II. Treatment Design

To pursue both objectives, two simultaneous experiments were conducted. Sixteen chambers were utilized to obtain quantitative estimates of the effects of ambient oxidant and introduced SO_2 on tuber yield. Oxidant was applied at four nominal levels by treating plants continuously with 0, 33, 67, and 100% carbon-filtered air. Actual ozone concentrations were attennuated by approximately 14% in 100% ambient treatments in transit through the air distribution system. Actual doses are given in Table 1. At each oxidant level, two SO_2 levels were compared to investigate possible SO_2 and SO_2 x oxidant effects. SO_2 was injected at 10 pphm for six hours per exposure. Exposures were usually five per week; 45 exposures totaling 255 hours were actually achieved (Table 2). Thus, a total of eight treatments in a 2 x 4 factorial design resulted.

The remaining four chambers were utilized in efforts to mimic observed field symptoms of speckle leaf. Controlled fumigations with PAN and later with generated ozone were used for this phase. Treatment details and results are presented in RESULTS - Sections VIC, VID.

III. Experimental Design

The eight treatments were arranged in a randomized block with two replications; all chambers within a replication were serviced by one air distribution and sampling system. Each treatment replicate consisted of eight plants within a single chamber.

IV. Plant Selection and Handling

A. Cultivars - Centennial Russet seed potatoes were maintained at 5 - 10 C for approximately 10 months.

B. Seed Selection and Plant Establishment - After warming at 20 C for 1 week 35 kg of tubers were dipped in 0.14% thiobendazole fungicide solution, and air dried for 24 hours. On 9/3/78 approximately 350 uniform 45 g apical seed pieces were cut and allowed to suberize for 48 hours. After placing in moistened vermiculite, the seedpieces were maintained at 20 C for 13 days for sprout initiation. On 9/18 all sprouted seedpieces were removed from the vermiculite and graded. To maximize uniformity, both extremely vigorous (5%) and non-vigorous (45%) sprouted seedpieces were eliminated. One hundred seventy-six sprouted seedpieces were then planted in the chambers and ambient plots, with the eye of the main shoot placed 5 cm below the soil surface. Rate of plate emergence is given in Table 3. Non-emerged plants were replaced on 9/29, and emergence was complete by 10/2. (Note: emergence is given as appearance of first green shoot. Since each seedpiece produces numerous main stems, several days may elapse from recorded date of emergence to complete plant establishment).

Conditions for potato plant establishment were extremely unfavorable during the two-week period following planting. Beginning 9/21, the daily maximum ambient temperature exceeded 38 C (100 F) for 10 consecutive days, with maxima of 43 C (110 F) recorded on 5 days. The presprouting step is probably responsible for the successful establishment of the crop.

Two plants having seedborne virus diseases were recognized during the course of the experiment. As these diseases are known to deleteriously affect potato yield and quality, these plants were excluded from the analysis.

V. Evaluation Criteria and Data Collection

The experiment was harvested after 120 days from initial seedpiece planting had elapsed. Plant parts and tubers from each plant were harvested and maintained individually. Yield related and growth analysis data were recorded on individual plants while parameters requiring chemical analyses were estimated from chamber composite samples. Three types of information were recorded: 1) measures of overall plant growth, including leaf, stem, and root dry weights at harvest, 2) the important yield traits, number and total weight of tubers distributed into size classes, and 3) internal quality factors such as dry matter, content of total and reducing sugars (important factors in potato processing and frying industries), and protein content. Because of extensive foliar injury in several treatments no attempt was made to differentiate between healthy and damaged leaf tissue in the leaf dry weight determinations.

Analyses of the various sugars were conducted by standard methods (4,9,12), total nitrogen was obtained by the Kjeldahl method and actual protein contents were determined by methods described by Labanauskas and Handy (7) utiizing a Beckman 120C Amino Acid Analyzer.

VI. Sample Preparation

Longitudinal center slabs 5mm thick were cut from all tubers harvested from each plant. The slabs were diced into 5mm cubes, composited and sampled (approximately 15g). The diced subsamples were frozen at -190 C, dried under vacuum and ground to pass a 0.5mm screen. Powder subsamples from individual plants within a chamber were composited and again subsampled to form the composite samples for sugar, total nitrogen, and protein analyses.

VII. Statistical Analyses

Standard analysis of variance and regression procedures were utilized to describe the observed treatment effects. Use of unweighted chamber means, as described by Snedecor and Cochran (10), was necessitated as two diseased plants were excluded from the analysis. One missing plant per chamber mean should have negligible effects on interpretation.

RESULTS

I. General Observations

Initial plant growth following emergence was rapid and vigorous. Severe ozone exposure was realized in ambient and higher level ambient chambers creating a situation somewhat different from the usual conditions confronting a spring-planted field-grown crop. In fact, ambient ozone dosage (pphm-hr) declined rapidly after October 1 (Figure 1). However, symptom development, while more severe early in the growing season, appeared to follow the sequence observed under Kern County field conditions in either spring or fall planted crops. In fact, badly injured field-grown leaves taken from the Arvin area in mid-October were visually indistinguishable from analogous leaves grown on site.

Plants in chambers 3 and 19 (both received 67% filtered air but no SO_2) appeared less vigorous from the outset. The effect was apparent early enough that treatment was not likely responsible. No explanation for this reduced growth was satisfactory; environmental variables, nutrient, pH, and salinity values were all near average. The resultant low yields create some difficulty in interpretation, but in the absence of suitable explanation, the more conservative approach was adopted, i.e. the data points were retained. Estimation of SO_2 effects is complicated to the greatest extent, but spurious oxidant x SO_2 interactions of small magnitude were also introduced.

Tuber yields of control treatments were excellent, routinely exceeding 1250g/plant. Thus, overall conditions were conducive to plant growth and tuber yield, and conclusions can be drawn with some assurance.

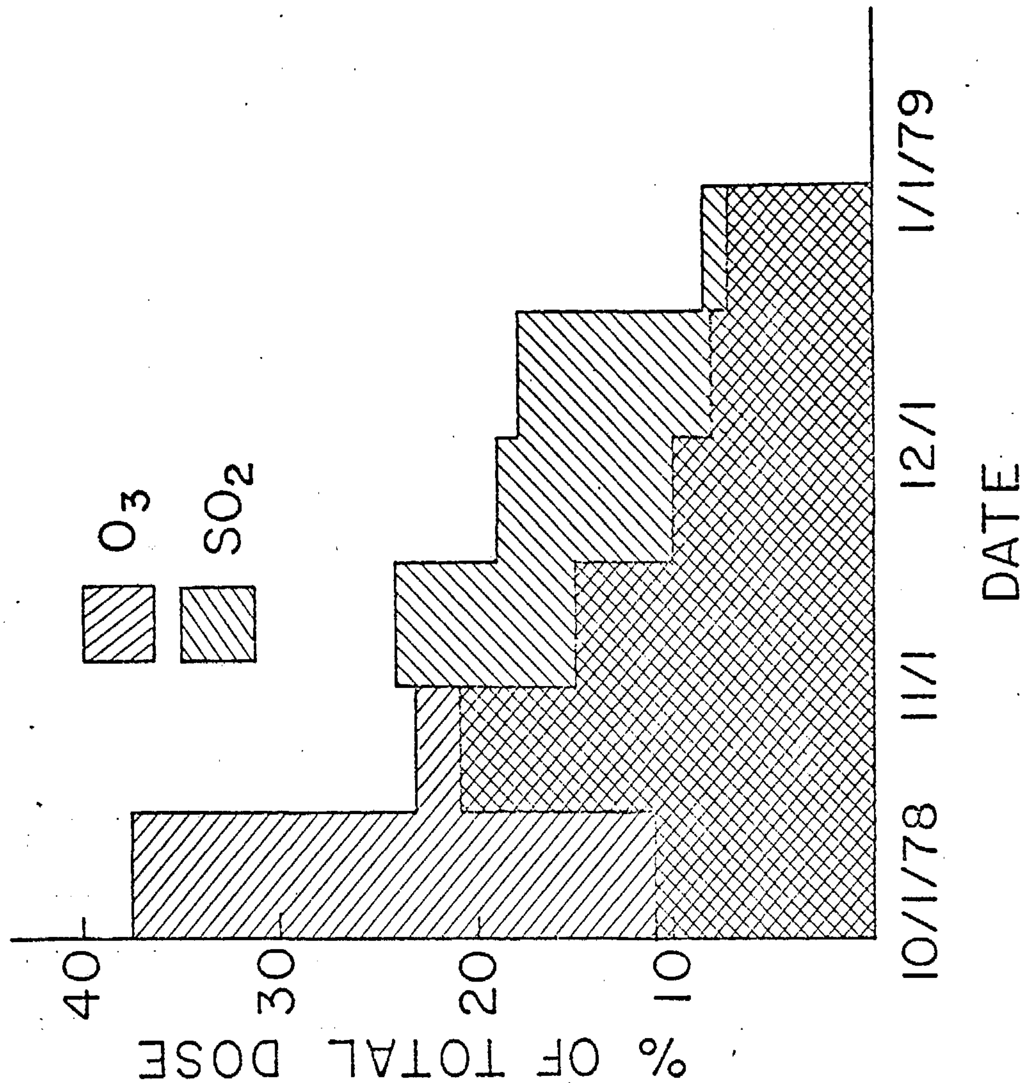


Figure 1. Distribution of SO_2 and oxidant dose by semi-monthly interval

II. Growth Analysis

(Table 4, Appendix Table C1)

Stem number is an important determinant of yield in potato because the number of potential sites for tuber formation on any one stem is limited. Presprouted and aged seed potatoes produce increased stem numbers. Both factors were involved in the present research, thus stem number, and hence, tuber number, are high. Since stem number is determined very early in a potato plant's ontogeny, little effect of air pollutants was expected. This prediction was realized in that no significant treatment effects for stem number were found. Stem length was slightly but significantly affected by oxidant treatment, increasing linearly with increasing oxidant dose. There was no appreciable SO_2 effect on this parameter. Despite the stem length response, total stem dry weight was not significantly affected by any of the treatments. Similar elongation responses, with decreased dry matter per unit length, have been previously reported in common pepper by Bennett et al. (1), and may represent a response to defoliation. The greater stem lengths of oxidant treated plants were not reflected in increased stem dry weights, thus treated plants were less robust.

In contrast to the observed minimal effects of treatments on stem parameters were the effects on leaf and root dry weights, both of which are of more direct functional significance. Both leaf and root dry weights were decreased drastically by increasing oxidant levels with little overall effect of SO_2. The similar trend in total shoot dry weight (stem weight + leaf weight) reflects the large effects on leaf weight. Again the oxidant response was a linear one, with no evidence that an injury threshold existed. Examination of SO_2 effects at individual oxidant levels shows the SO_2 effect to be highly significant for leaf weight in the 100% filtered treatment although the overall oxidant x SO_2 interaction was not significant. The oxidant (linear) x SO_2 term approaches significance, possibly being thwarted by the aberrant 67% filtered treatment. This possible oxidant x SO_2 interaction is consistent with visual observations of foliar damage (discussed below).

III. <u>Tuber Production</u>

(Table 5, Appendix Table C2)

Treatments, particularly oxidant, were consistently devastating to total tuber number and tuber yield. An essentially linear decrease in tuber number and weight was observed with increasing oxidant dose. Oxidant effects (averaged over SO_2 treatments) were of such magnitude that the treatments receiving only ambient air were reduced in tuber number and yield by 38 and 45%, respectively, compared to filtered controls. Such responses were even greater in the largest size class (>112g), with reductions of 64 and 63%, respectively. Surprisingly, average tuber weight, over all size classes, was not significantly reduced by oxidant (not shown). The yield response observed, therefore, was closely associated with tuber number.

Overall response of tuber number and total tuber yield to SO_2 was not significant, but of interest was an apparent increase in tuber number and yield (in the <56g class only) in plants treated with SO_2. This trend is reversed in the largest size class (>112g) so that overall SO_2 effects on yield tend to cancel. However, there is a slight trend toward reduced productivity in the presence of SO_2.

Reference to Appendix Table C2 shows several instances of statistically significant interactions between SO_2 and oxidant. However, there is little consistency to the trends, and examination of the means (Table 5) suggests that the 67% filtered air, 0 pphm SO_2 treatment produced somewhat anomalous results. These chambers were loweer yielding than expected based on yields of remaining treatments and could account for much of the oxidant x SO_2 treatment interaction variation, especially since the observed interactions are found in higher-order, non-linear terms. The fact that both chambers exhibiting poor growth had the same treatment combination is attributed to an unlikely but chance event. Linear responses were inferred from regression of values on nominal treatment levels expressed as percent filtration. Since actual doses for a given treatment varied somewhat around the nominal expected level, it is also useful to examine the regressions on actual realized dose. Figure 2 represents the regression of total tuber number on oxidant dose, by individual chamber, including both SO_2 treatments. Approximately 62% of the variation in tuber number was linearly associated with oxidant dose. The observed ambient plot values were also consistent with the trend, although they were excluded from regression calculations.

The regression clearly illustrates the anomalous behavior of the 67% filtered treatments (the four points appearing between 10 and 20 ppm.hr oxidant dose), but it appears that while the 0 pphm SO_2 chambers with both quite low relative to the regression, both of the SO_2-treated chambers were unusually high. These two factors combined could easily lead to statistical significance of complex (non-linear oxidant x SO_2 interactions. There is little justification to attribute biological significance however.

The regression of total tuber yield on realized chamber doses also confirms the previous analysis (Figure 3). Approximately 77% of the

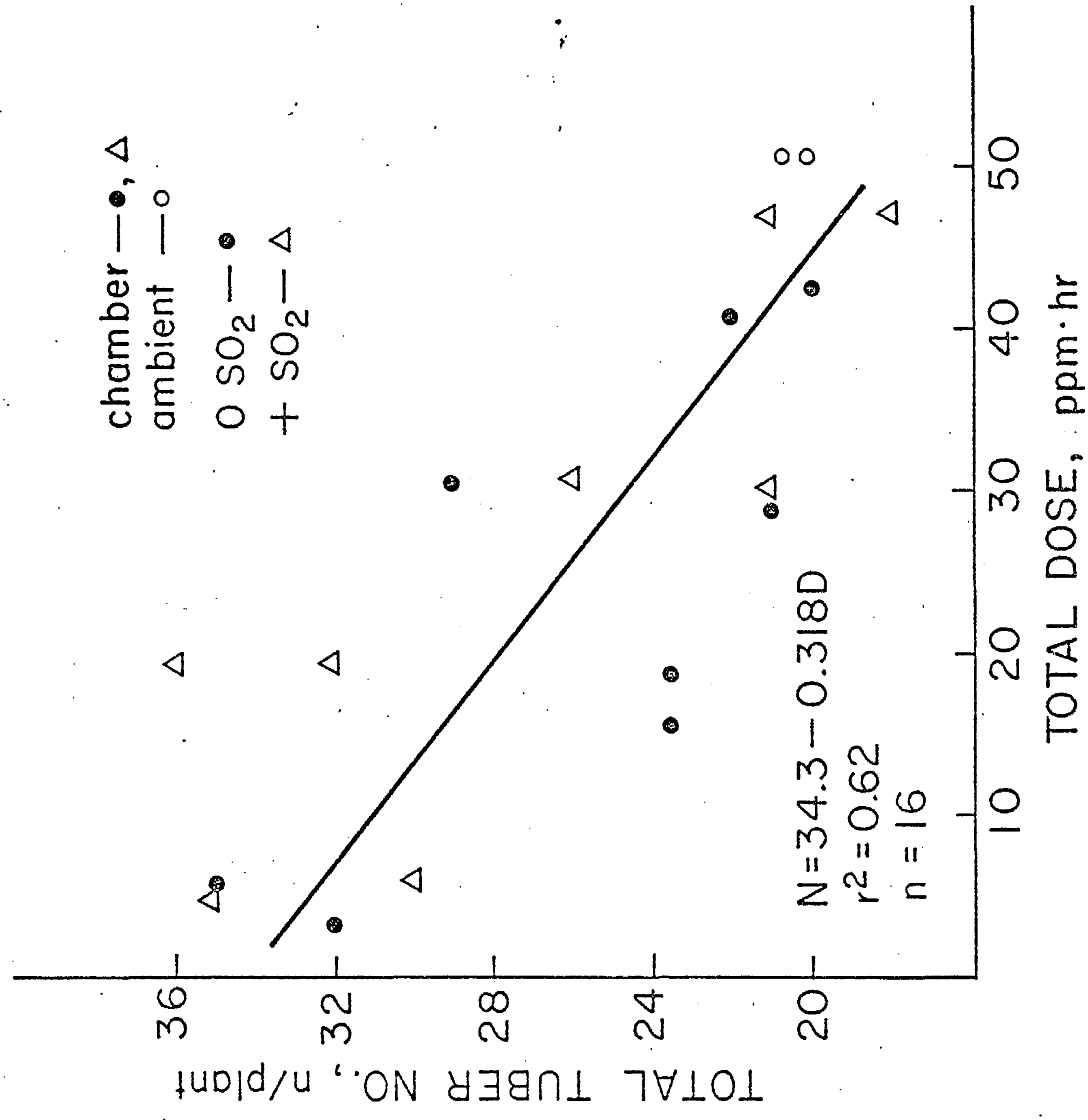


Figure 2. Regression of total tuber number on seasonal oxidant dose

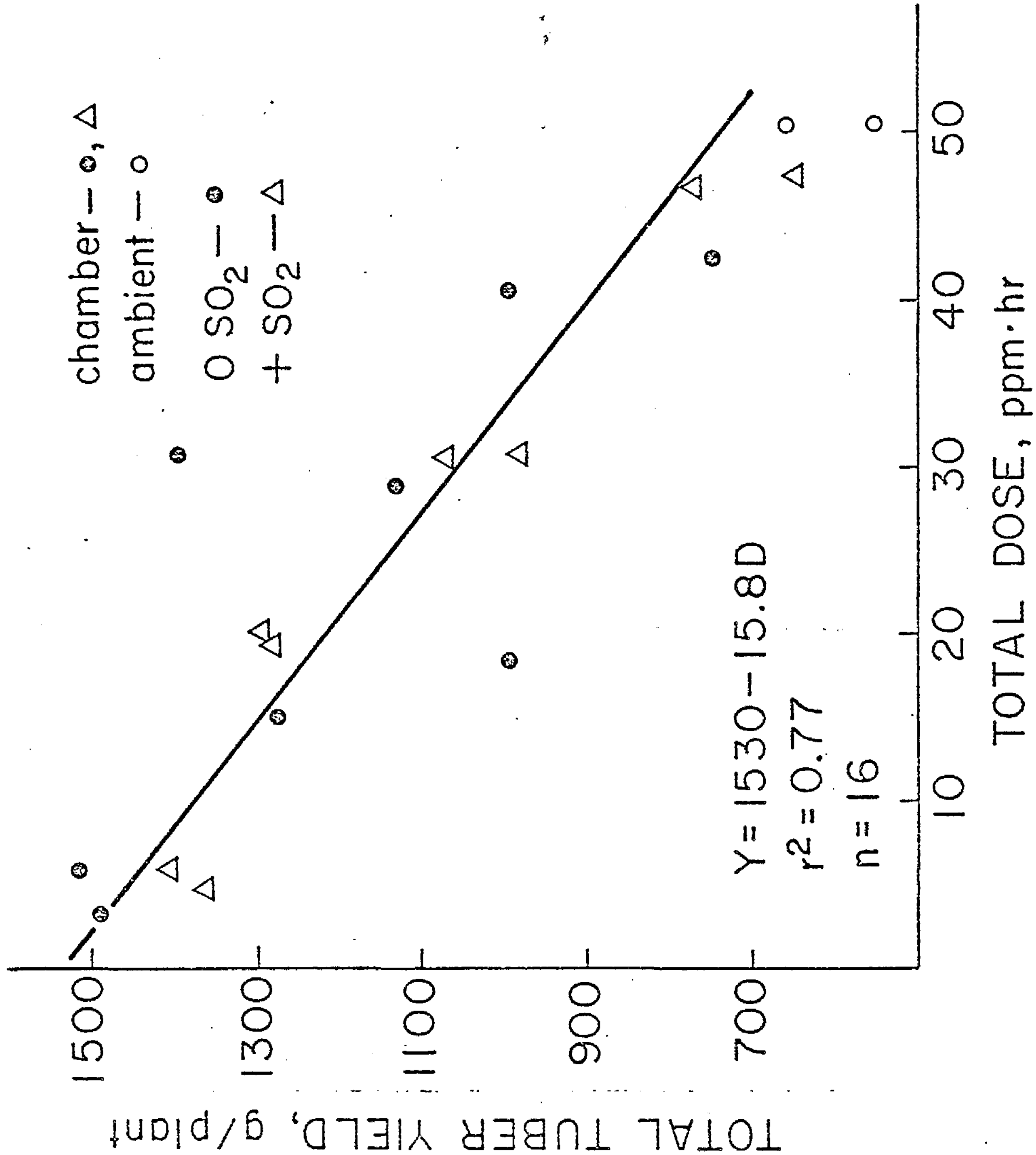


Figure 3. Regression of total tuber yield on seasonal oxidant dose

variation in yield was accounted for by the linear relationship. Again the ambient plot values are consistent with the overall regression. Consistency of the ambient plot values suggests that growing conditions within the chambers were reasonably representative.

It is useful to consider a slightly different approach in analyzing treatment effects. If total plant dry matter (leaves + stems + roots + tubers) is plotted against total oxidant dose, a linear decrease is noted completely consistent with previous observations (Figure 4). In this case approximately 73% of the variation in dry matter is associated with oxidant dose, regardless of SO_2 treatmentm and again there is no indication of a threshold effect. Previous studies in other species have shown marked effects of oxidant on partitioning of dry matter to economic organs (Bennett et al., 1), i.e. proportionately less dry matter is found in the harvested portion of treated plants compared to controls. However, the present results are qualitatively quite distinct. Percentages of total dry matter in each of four fractions (tubers, leaves, stems, and roots) is illustrated in Figure 5. There is remarkably little variation in any aspect of partitioning. It should be noted that some bias may be possible in that the high oxidant treatments had a much greater proportion of abscised and senescent leaves at harvest than predominately filtered treatments. However, all plant material was collected and included in dry matter determinations, and this source of error is believed insignificant. Considering the very large observed oxidant effects on tuber yield, and leaf and root weights, it was interesting to note that there were virtually no effects on partitioning.

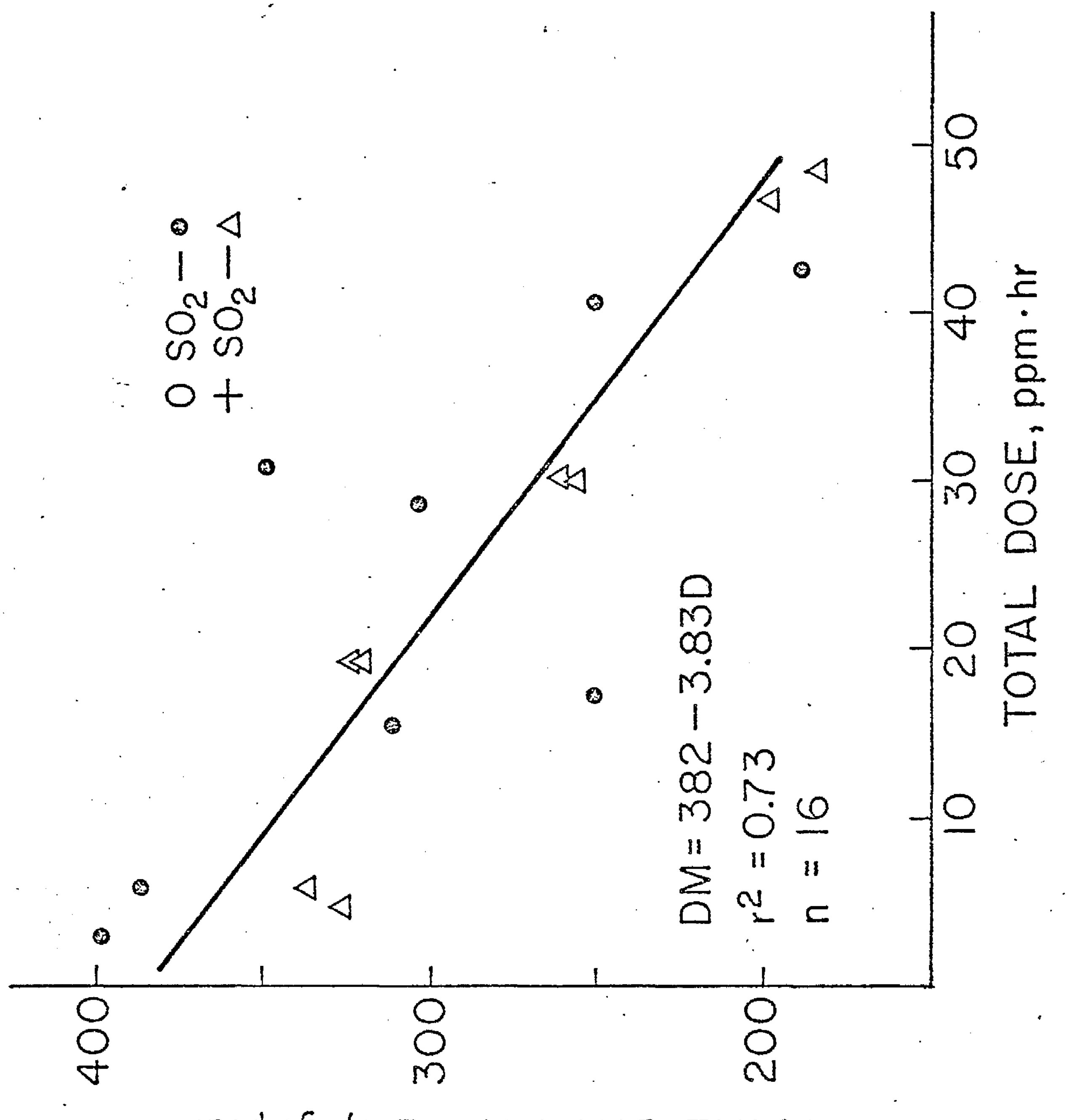


Figure 4. Regression of total dry matter on seasonal oxidant dose

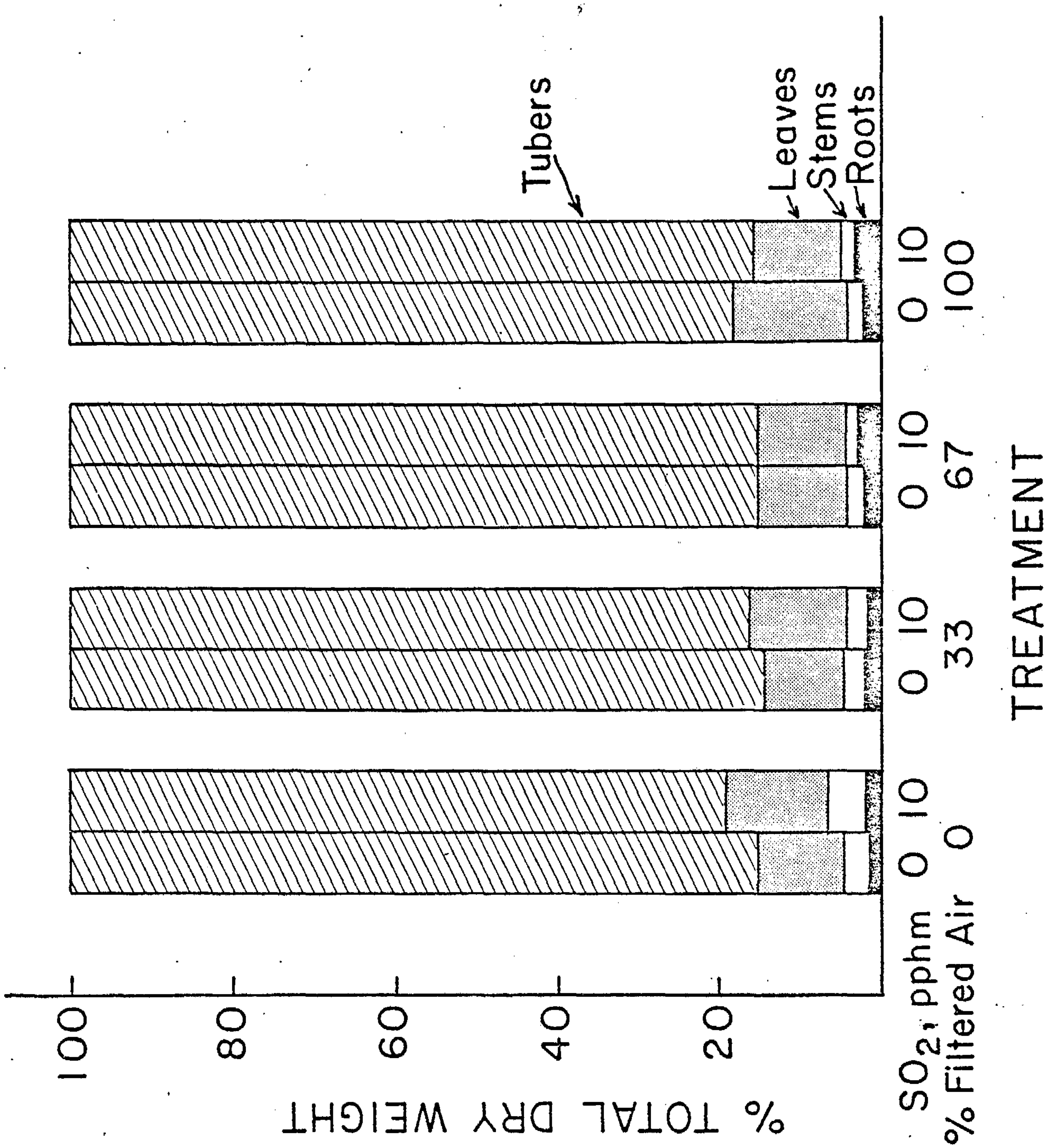


Figure 5. Partitioning of total dry matter into 4 fractions for 8 oxidant - SO_2 treatment combinations

IV. Internal Quality

A. Dry matter content (Table 6, Appendix Table C3) - Both specific gravity determination on tuber bulk samples and actual dry matter determinations on subsamples were used to measure tuber dry matter content. No significant treatment effects on actual dry matter were observed. Slight treatment effects for specific gravity were detected, but were of small magnitude. Oxidant and SO_2 exposures both appeared to slightly increase specific gravity. A possible explanation is that premature death of heavily affected plots allowed some tuber desiccation to occur prior to harvest, this increasing their apparent dry matter content.

B. Tuber sugars contents (Table 7, Appendix Table C4) - There were no significant treatment effects on contents of glucose, fructose, sucrose, or various combinations of these (Table 7, Appendix Table C4). Sugar levels in general were high and variable; this may have been attributable to cool soil temperatures during latter stages of crop growth. Such low temperatures encourage the conversion of starch to sugars.

C. Tuber protein content - Total tuber nitrogen (Kjeldahl) was determined on all samples. Because substantial portions of tuber nitrogen may be present in non-protein forms, the four extreme treatments were also subjected to amino acid analysis for direct measurements of protein content. The analytical method used also converted some protein fraction amino acids to ammonia. Thus, calculated protein values were underestimates of true protein contents. Table 8 shows the comparison of total nitrogen content and the distribution of nitrogen among protein, free amino acids, and ammonia fractions as determined through amino acid analysis. Reconciliation between the amounts of nitrogen recovered by the two methods is excellent. The nitrogen recovered in the protein fraction was a consistent 59-61% of that observed in total nitrogen. This indicates that total nitrogen is a useful indicator of relative protein contents in the present case.

Basing further consideration on total nitrogen shows that both oxidant and SO_2 treatments significantly increased protein contents (Table 9, Appendix Table C5). There is also an indication that the oxidant effect may be greater in the presence of SO_2, as evidenced by the significant oxidant x SO_2 interaction (Appendix Table C5). However, the linear oxidant response certainly predominates. Although protein percentage increased with more severe treatment, total protein on a per plant or per unit area basis was reduced. In this respect, a response typical of many types of stress was observed.

From the amino acid analyses, it was also possible to examine differences in protein composition, i.e. the relative proportions of the various amino acids. Only very minor differences were found, and they are not reported.

V. External Appearance

Several common types of surface or external abnormalities occurred on tubers harvested from the experiment. The most prevalent was common scab caused by Streptomyces scabies. The disease was probably seedborne, was of light but consistent frequency, and affected 10-15% of tubers. The disease rarely affects yield unless it is extremely severe or subjects tubers to secondary rotting organisms. It is primarily objectionable from a cosmetic standpoint, and many of the afflicted tubers were still of a marketable class. Other abnormalities such as misshapen or cracked tubers were very infrequent, and all such blemished tubers were included in the analyses. One of the factors contributing to the success of the Centennial cultivar has been a consistently low percentage of cull potatoes.

VI. Symptomatology

A. Main Experiment General Observations - Marked and severe treatment effects were consistently noted in the experiment. No symptoms attributable to SO_2 alone, i.e. in either 67 or 100% filtered treatments, were seen. Extremely severe oxidant symptoms were seen in ambient plots, and in 0 and 33% filtered treatments in the absence of SO_2. Oxidant symptoms included upper-surface stipple, lower surface pocking (speckling), chlorosis, progressive necrosis, defoliation, and death. In the two higher ambient treatments, the progression of necrosis and plant death was markedly accelerated by the addition of SO_2. Symptoms on more severely affected plants closely resemble field observations made repeatedly in Kern County fields.

B. Main Experiment Symptom Chronology - Development of symptoms on plants subjected to the various treatments is summarized in Table 10. Symptom development is divided into five progressive stages, applicable to the particular circumstances of this study only. Four and possibly five treatments were judged to have escaped serious injury. These include the 100 and 67% filtered treatments regardless of SO_2 level and possibly the 33% filtered treatment without SO_2.

C. Auxiliary Experiment - Attempts to mimic more closely the symptoms of speckle-leaf were conducted in reduced flow chambers 2, 6, 14, and 15. PAN fumigations in chambers 6 and 15 were conducted 10/23, 10/31, and

11/8. Plants were large and vigorous, with an ample number of leaves of different ages. Each fumigation was of 4 h duration and was carried out during midday of bright, sunny days. Mean PAN concentrations for the three fumigations were 17.5, 27.5, and 46.5 ppb, respectively. Essentially no effects were observed. One or two leaves on one plant in chamber 15 at 46.5 ppb PAN showed typical PAN-type symptoms. From the high levels of PAN used, the paucity of symptoms produced, and the dissimilarity of the observed symptoms to those of speckle leaf, we concluded that PAN is likely not responsible for the occurrence of speckle leaf in this potato variety.

Ozone fumigation (by generation) was next carried out with the same objective. Since the severe damage noted in the main experiment was reasonably typical of ozone but also was representative of speckle-leaf, this was a logical step. Generator malfunction caused an ozone spike (50 pphm) in the treated chamber (Chamber 2, previously maintained as a control for the PAN study) for a duration of less than 1 hr. An additional 3 hours at 25 pphm was subsequently given. Within 24 hours, massive tissue collapse and necrosis had occurred, and plant condition subsequently continued to decline. A subsequent fumigation at 10 pphm for 4 hours was carried out in chamber 15 on 12/4. Observation on 12/11 showed marked tissue damage and necrosis. The symptoms were suggestive of speckle leaf although of a more gross nature. This rather extreme susceptibility is surprising and suggests why earlier greenhouse ozone fumigations had failed to produce speckle leaf symptoms.

D. Additional Greenhouse Fumigations - These ozone fumigations were carried out to determine whether low, chronic ozone doses may be responsible for (oxidant) atypical speckle leaf symptoms. At higher levels (9 and 12 pphm 4 hours daily for 5 days) typical ozone stipple was seen on both Centennial and White Rose. At lower levels (3 and 6 pphm for the same duration) Centennial appeared to react differently. A few leaves showed only lower surface lesions, at least superficially similar to speckle leaf. Interestingly these symptoms developed only after several days had elapsed following the cessation of treatments.

DISCUSSION

I. Symptom Development

Visible injury symptoms in ambient plots and in chambers receiving ambient air consisted of predominantly adaxial (upper surface) stipple and bifacial necrotic lesions, but abaxial (lower surface) glazed pocks or speckles were also frequently observed. The abaxial lesions, at least superficially, were similar regardless of whether they were in association with adaxial stipple and necrosis or not. Subsequent field observations suggested that a similar array of responses occurs under production conditions, but often a higher proportion of the lesions are abaxial under field conditions. However, the precise type of foliar response varies from one situation to the next (within the same cultivar). Additional observations of several hundred breeding lines at Shafter in 1979 strongly suggest there may be genetic differences in the way symptoms are expressed; injury types ranged from classical ozone stipple, through the "Centennial type", to some genotypes showing symptoms totally restricted to lower leaf surfaces. However, it is impossible to ascertain at this time whether these symptom differences represent differential expression of response to a single factor, or differential sensitivity to an array of factors, each of which has distinct effects.

On individual leaves, discrete lesions generally increased in number until coalesced lesions developed, at which point leaf collapse became imminent (Table 10). Chlorosis was also a frequent response.

The progression of injury on a whole plant basis strongly suggests ozone involvement. Early symptoms were confined to older leaves with progression to upper leaves as plant growth slowed and leaves near the apex aged. Eventually all leaves were involved. SO_2 appeared to act by accelerating and exacerbating the progressive debilitation observed.

Results of controlled fumigations also suggest the role of ozone in producing speckle leaf. At this time, it appears that it is necessary to fumigate (with O_3) at very low levels on greenhouse plants to approach speckle leaf symptoms, while higher concentrations produce immediate massive injury. However, it seems likely at this time that other factors are also involved.

II. Growth and Yield

The overwhelming response to oxidant treatments observed in the present experiment overshadows possible SO_2 effects. However, there is a consistent trend suggesting the significance of SO_2. If the aberrant 67% filtered chambers are momentarily ignored, several SO_2 related effects become significant: 1) total tuber yield was reduced 14% by added SO_2 (Table 5), and 2) leaf dry weight was drastically reduced by SO_2 at the lowest oxidant dose. It is not likely that plants could normally sustain the loss of photosynthetic area stimulated by SO_2 without yield reduction. It should also be pointed out that SO_2 fumigations began October 9, after a substantial amount of oxidant dose (1224 pphm-hr) had already been received (Figure 1) reducing the likelihood of significant oxidant x SO_2 interaction.

A possible discrepancy (involving tuber yield) between the results of the present study and field observations should be discussed. The common complaint regarding speckle leaf from the grower standpoint is that affected crops fail to "size" properly, but instead produce tubers in undesirably small size classes. The present experiment suggested that tuber number, not mean tuber weight, accounted for the yield reduction in treated chambers. Different growth conditions in the two situations could explain the difference. As the experiment was grown quite late in the year (mid-September to late December) even for a fall crop, daylengths were quite short and mean temperatures were low during most of the growth period. Both of these conditions are conducive to tuber initiation. Thus, tuber initiation may have continued throughout the experiment at the expense of growth of individual tubers. Under this assumption, changes in tuber number would be a logical effect of treatment response. Normal cropping seasons in Kern County are January-June and August-December.

Also, ozone and SO_2 doses were distributed quite differently over the growing season. Ozone was high early and fell rapidly during later growth (Figure 1). Since major activity in tuber initiation probably occurred within 45 days from planting, tuber number would logically be affected early. Conversely, the major portion of total SO_2 dose occurred during a period of declining oxidant concentration (Figure 1). During this period of active tuber bulking, it may be expected that tuber size would suffer. The present results are consistent with this hypothesis in that the major oxidant effect was to reduce tuber number, while SO_2 appeared to slightly affect size distribution. It is possible that the net effect of both pollutants is on dry matter production and that with constant partitioning, manifestation of yield loss as either reduced size or number of tubers depends on the growth stage-dose relationship.

Potatoes are remarkably flexible in growth requirements. With reasonable light and temperature levels, tuber yields can be high regardless of many other factors, including season. The high tuber yields observed in control plots of the present experiment suggest that these basic growth requirements were met and that plant growth was normal. The results should be generally, at least qualitatively, applicable.

The calculation of oxidant dose as a linear function of concentration (Dose = Concentration x Time) is a somewhat arbitrary one considering the wide fluctuation in ozone concentrations throughout the growing season. Peak concentrations could possibly have a disproportionate, or acute, effect (either increased or decreased) on yield. The dose calculation used does not include this possibility. The observed linear relationship of yield vs dose, while not a sensitive indicator, suggests that acute response was not of major importance in this experiment. Visual observation of symptom development supports a similar interpretation.

Controlled environment ozone fumigations previously carried out at UCR on Centennial and White Rose are fully compatible with results of the present study. Ozone treatment significantly decreased tuber yields of Centennial but not of White Rose. Both studies support field observations in important production areas that Centennial is injured but White Rose maintains high yields.

The experiment has proven to be very useful in developing a breeding selection tool for developing resistant cultivars. This utility has evolved through graphic, explicit demonstration of effects on pollution sensitive potato genotypes and through the intensive study of symptom development on a sensitive genotype treated several different ways.

The results have also been useful in providing information to potato growers, especially through the California Potato Research Advisory Board.

REFERENCES

1. Bennett, J. P., R. J. Oshima, and L. F. Lippert. 1979. Effects of ozone on injury and dry matter partitioning in pepper plants. Env. and Exp. Bot. 19:33-39.

2. Brasher, E. P., D. J. Fieldhouse, and M. Sasser. 1973. Ozone injury in potato variety trials. Plant Disease Reporter 57:542-544.

3. California Potato Research Advisory Board. 1978. Potato research program annual report. pp. 154-163.

4. DuBois, M., K. A. Gilles, J. K. Hamilton, P. A. Rebers, and F. Smith. 1956. Colorimetric method for determination of sugars and related substances. Anal. Chem. 28:350-356.

5. Heggestad, H. E. 1973. Photochemical air pollution injury to potatoes in the Atlantic Coastal States. Amer. Pot. J. 50:315-328.

6. Hooker, W. J., T. C. Yang, and H. S. Potter. 1973. Air pollution injury of potato in Michigan. Amer. Pot. J. 50:151-161.

7. Labanauskas, C. K., and M. F. Handy. 1970. The effects of iron and manganese deficiencies on accumulation of non-protein and protein amino acids in macadamia leaves. J. Amer. Hort. Sci. 95(2):218-223.

8. Mosley, A. R., R. C. Rowe, and T. C. Weidensaul. 1978. Relationship of foliar ozone injury to maturity classification and yield of potatoes. Amer. Pot. J. 55:147-153.

9. Nelson, N. 1944. A photometric adaptation of the Somogyi method for the determination of glucose. J. Biol. Chem. 153:375-380.

10. Snedecor, G. W. and W. G. Cochran. 1967. Statistical Methods. pp. 472-503.

11. Twomey, J. A., W. G. Hoyman, and J. J. Shaughnessy. 1977. Centennial Russet: an oblong russetted variety adapted to certain irrigated potato growing areas of the west. Amer. Pot. J. 54:603-605.

12. Von Handel, E. 1968. Direct microdetermination of sucrose. Anal. Biochem. 22:280-283.

Table 1. Realized oxidant and SO_2 total dosages, by replication, for each nominal treatment level.

Treatment		SO_2			Oxidant			Realized Percent of Ambient
Filtered Air pct	SO_2 pphm	I	II	Mean	I	II	Mean	
		pphm-hr						
0	0				4230	4049	4140	82
33	0				3041	2868	2954	58
67	0				1513	1862	1688	33
100	0				587	308	498	10
0	10	2608	2542	2575	4646	4736	4691	93
33	10	2617	2609	2613	3009	3069	3039	60
67	10	2630	2524	2577	1930	1945	1938	38
100	10	2414	2493	2454	593	456	524	10
Ambient							5043	

Table 2. Realized SO_2 fumigation schedule.

Date	Start (Time)†	End	Duration (Hours)	Date	Start (Time)	End	Duration (Hours)
10-9	9	15	6	11-13	9	15	6
10-10	9	14	5	11-14	9	15	6
10-11	9	15	6	11-15	9	15	6
10-12	9	15	6	11-16	9	15	6
10-13	11	17	6	11-17	9	15	6
10-16	9	15	6	11-20	9	15	6
10-17	9	14	5	11-21	9	15	6
10-18	12	17	5	11-22	9	15	6
10-19	9	15	6	11-27	9	15	6
10-20	7	13	6	11-28	9	15	6
10-23	10	13	3	11-29	18	24	6
10-26	9	15	6	12-1	10	16	6
10-27	18	24	6	12-5	9	15	6
10-30	10	16	6	12-7	9	15	6
10-31	11	16	5	12-8	7	13	6
11-1	9	15	6	12-11	9	15	6
11-2	9	15	6	12-12	9	15	6
11-6	10	16	6	12-13	9	15	6
11-7	9	15	6	12-14	9	14	5
11-8	9	15	6	12-18	9	15	6
11-9	9	15	6	12-19	9	14	5
11-10	7	13	6	12-20	9	15	6
						Total	255

†All times are Pacific Standard Time.

Table 3. Number of plants emerged by day.

Date[†]	Number emerged
9-21	15
9-22	35
9-23	68
9-24	139
9-25	160
9-29	171

[†]Sprouted seedpieces (176) were planted 9/18.

Table 4. Effects of ambient oxidant and SO_2 on selected measures of plant growth.

Treatment		Stem			Leaf	Root	Shoot
Filtered air pct	SO_2 pphm	Number	Length	Weight	weight	weight	weight
			--cm--	---------------	----------g/plant	----------	----------
0	0	8.2	58.2	7.6	23.1	2.22	30.7
33	0	8.6	60.8	11.0	31.3	4.30	42.2
67	0	8.0	55.4	8.2	30.4	4.04	38.6
100	0	8.8	54.2	11.3	54.4	5.62	65.7
0	10	9.1	61.8	9.2	23.5	2.40	32.6
33	10	8.2	57.4	8.5	29.5	2.88	38.0
67	10	9.4	52.0	9.8	34.7	4.88	44.4
100	10	8.4	56.1	9.8	36.1	5.26	45.9
S.E.		0.8	1.8	1.1	2.0	0.56	4.3

Table 5. Effects of ambient oxidant and SO_2 on mean tuber number, n, and yield, by size class.

Treatment		<56g		56-112g		>112g		Total	
Filtered air pct	SO_2 pphm	n	Weight g/plant	n	Weight g/plant	n	Weight g/plant	n	Weight g/plant
0	0	15.0	325	4.5	341	1.5	208	21.0	876
33	0	14.5	286	8.5	672	2.0	307	25.0	1265
67	0	14.0	280	5.3	395	2.5	381	21.8	1056
100	0	21.0	416	10.0	752	2.5	337	33.5	1504
0	10	15.5	301	4.0	285	0.3	44	19.8	710
33	10	16.5	370	5.0	382	2.0	276	23.5	1028
67	10	24.5	523	8.5	635	1.0	134	34.0	1293
100	10	22.0	417	8.0	625	2.5	342	32.5	1384
Ambient Plots		17.8	393	2.4	184	0.2	26	20.4	603
S.E.		2.1	34	0.8	54	0.4	65	2.3	74

Table 6. Effects of ambient oxidant and SO_2 on specific gravity and dry matter percentage of tubers.

Treatment: Filtered air pct	Treatment: SO_2 pphm	Specific gravity	Dry matter pct
0	0	1.080	21.49
33	0	1.073	20.94
67	0	1.079	22.23
100	0	1.078	21.34
0	10	1.083	20.21
33	10	1.079	21.20
67	10	1.081	21.20
100	10	1.080	21.33
S.E.		0.001	0.36

Table 7. Effects of ambient oxidant and SO_2 on tuber sugar concentrations.

Treatment: Filtered air pct	Treatment: SO_2 pphm	Total Sugars	Reducing Sugars	Sucrose	Glucose	Fructose
		mg/g				
0	0	58.8	25.8	33.0	13.6	12.1
33	0	65.0	31.0	34.0	21.7	9.3
67	0	77.5	33.5	44.0	20.4	13.0
100	0	62.5	32.5	30.0	20.4	12.2
0	10	50.0	25.5	24.5	12.6	8.4
33	10	46.2	19.2	27.0	14.2	5.1
67	10	60.0	33.5	26.5	14.8	18.6
100	10	71.2	34.8	36.5	15.8	19.0
S.E.		7.3	6.8	4.6	2.9	4.5

Table 8. Comparisons of tuber nitrogen fractions among four extreme treatments.

Nitrogen fraction	Filtered air, pct	0		100	
	SO_2, pphm	0	10	0	10
Total nitrogen†		1.25	1.52	1.17	1.11
Total‡		1.19	1.46	1.17	1.19
Protein‡		0.74	0.90	0.69	0.68
Free amino acids‡		0.18	0.39	0.26	0.27
NH_3‡		0.27	0.18	0.22	0.24

†Determined by Kjeldahl method.

‡Determined by amino acid analysis.

Table 9. Effects of ambient oxidant and SO_2 on total tuber nitrogen concentration as a measure of protein.

Treatment		
Filtered air pct	SO_2 pphm	Nitrogen pct[†]
0	0	1.25
33	0	1.21
67	0	1.00
100	0	1.17
0	10	1.52
33	10	1.26
67	10	1.22
100	10	1.11
S.E.		0.05

[†]Dry weight basis.

Table 10. Date of first occurrence of five symptoms in nine treatments.

Treatment		Stipple and/or Speckling	Chlorosis	Defoliation	Coalescing necrosis	50% Mortality
Filtered air pct	SO_2 pphm					
0	0	10/18	10/18	10/18	-	-
33	0	11/8	11/15	11/29	-	-
67	0	12/11	-	-	-	-
100	0	12/18†	-	-	-	-
0	10	<10/18	10/18	10/18	10/26	11/28
33	10	<10/18	10/18	10/26	11/1	12/13
67	10	11/8	-	-	-	-
100	10	12/18†	10/20	-	-	-
Ambient		10/5	10/18	10/18	11/22	‡

†Very slight speckling on several leaves.

‡Killed by frost.

APPENDIX A

Description of Fumigation Facility

APPENDIX A

(Excerpted from: Oshima, R. J. 1978. The impact of sulfur dioxide on vegetation: A sulfur dioxide-ozone response model. Final Report, ARB A6-162-30. pp. 11-18.)

Fumigation Facility

1. General Schematic (Figure 1)

The facility consists of 20 Teflon exposure chambers divided into 2 replicate 10-chamber sets. Each set of chambers is connected to a common air handling system, consisting of ambient and filtered ducts. An instrument shack is centrally located between chamber sets to minimize sampling line lengths.

2. Air Handling system (Figure 2)

This system consists of 2 sets of 2 backward-curved blowers powered by 2 H.P. 220 V motors. Each set consists of a filtered (three-2′ x 2′ x 8" activated carbon filters) and an unfiltered blower, central underground plenums of 12" PVS (polyvinyl-coated steel spirallok pipe), and 6" PVS pipes with butterfly valves leading to each of 10 chambers. All PVS pipe, electrical, and water lines, and butterfly valves are underground. The proportion of filtered to ambient air going to each chamber is controlled by the 6" butterfly valves. A comparison of replicate 0% filtered chambers with ambient ozone indicated that 17 to 21% of the ozone was lost in the air handling system.

3. Exposure Chambers (Figure 3)

The exposure chambers are a modification of the constant-stirred

Figure 1. General Schematic of Fumigation Facility

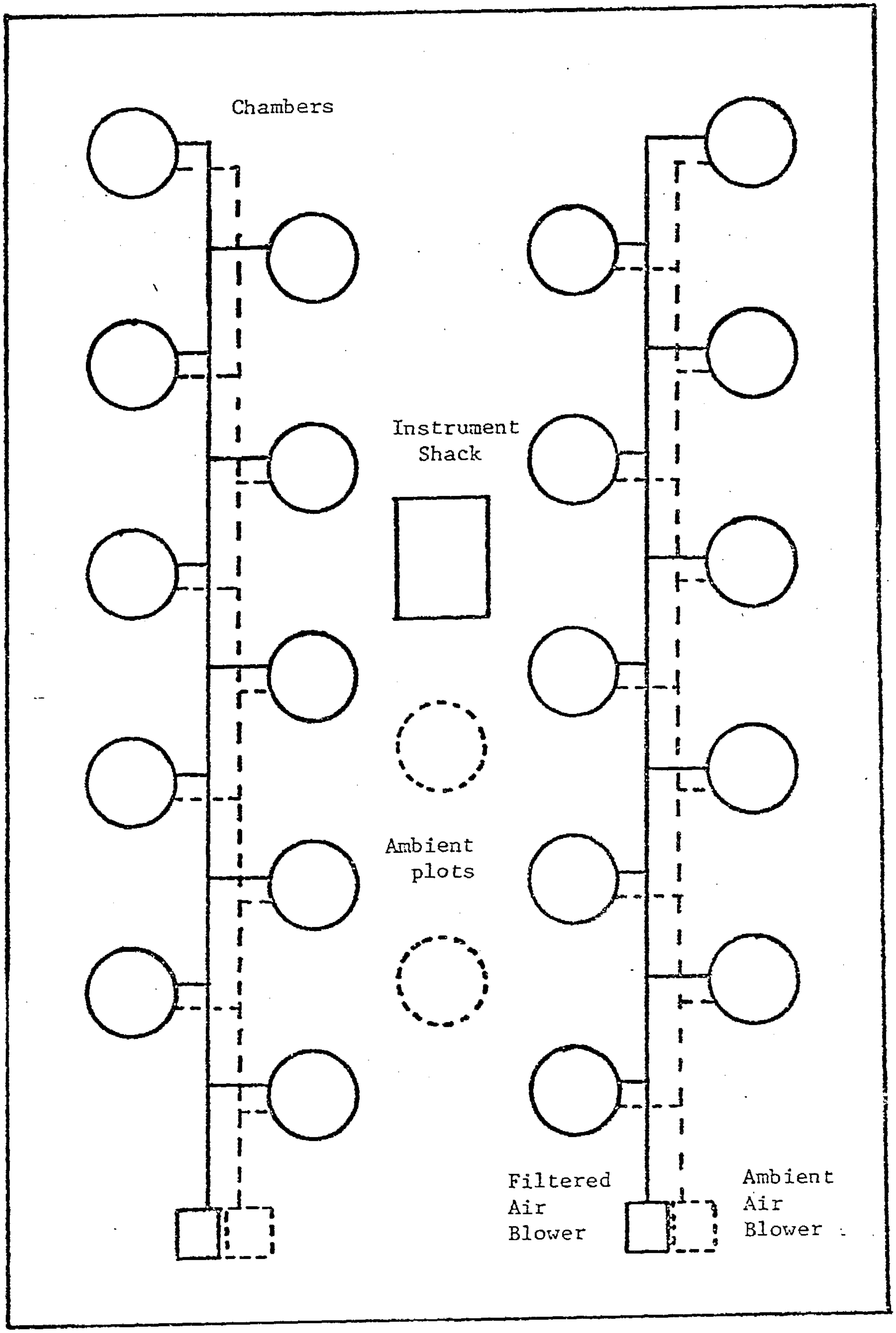


Figure 2. Detail of Air Handling System for Fumigation Chambers

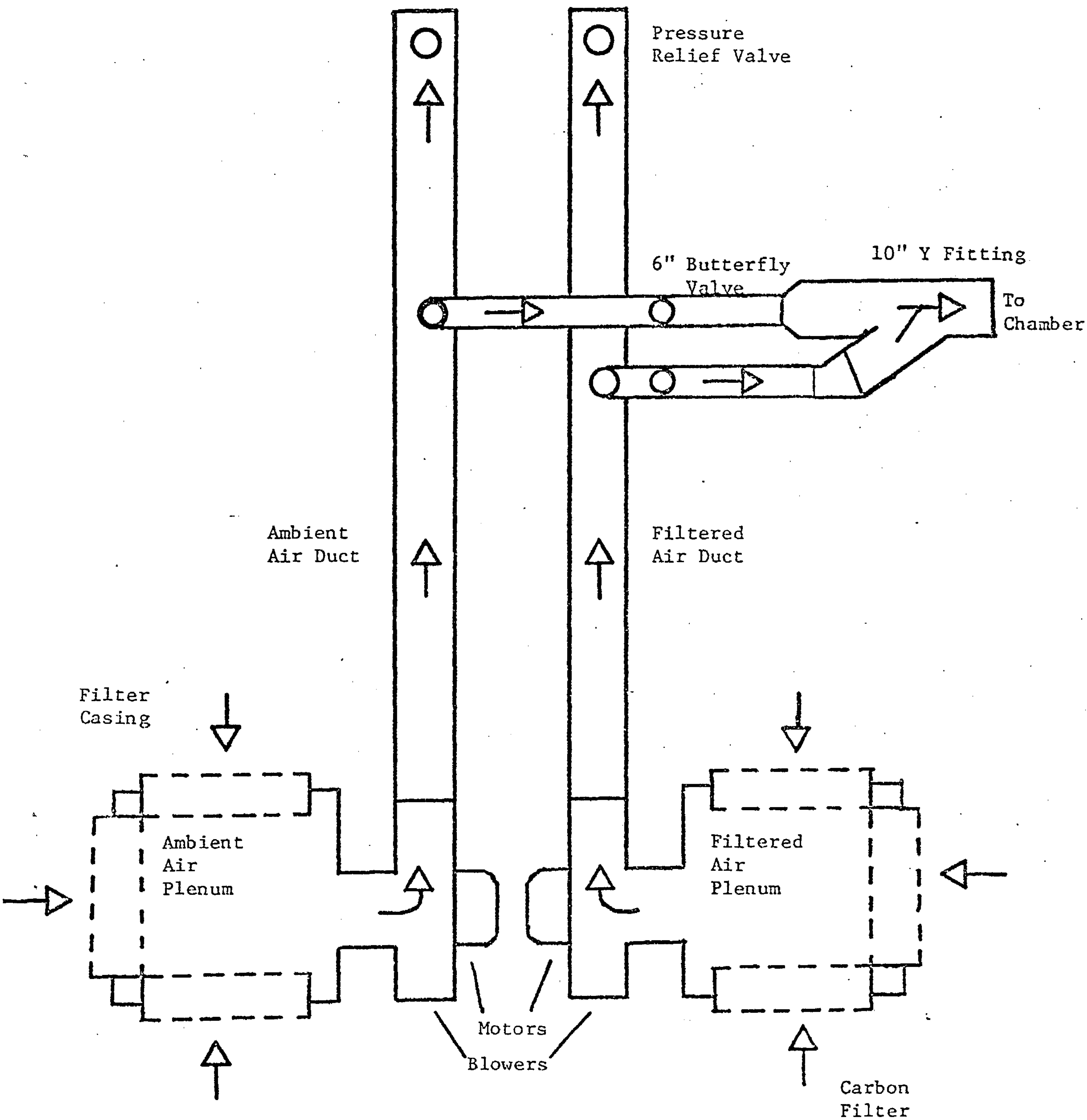
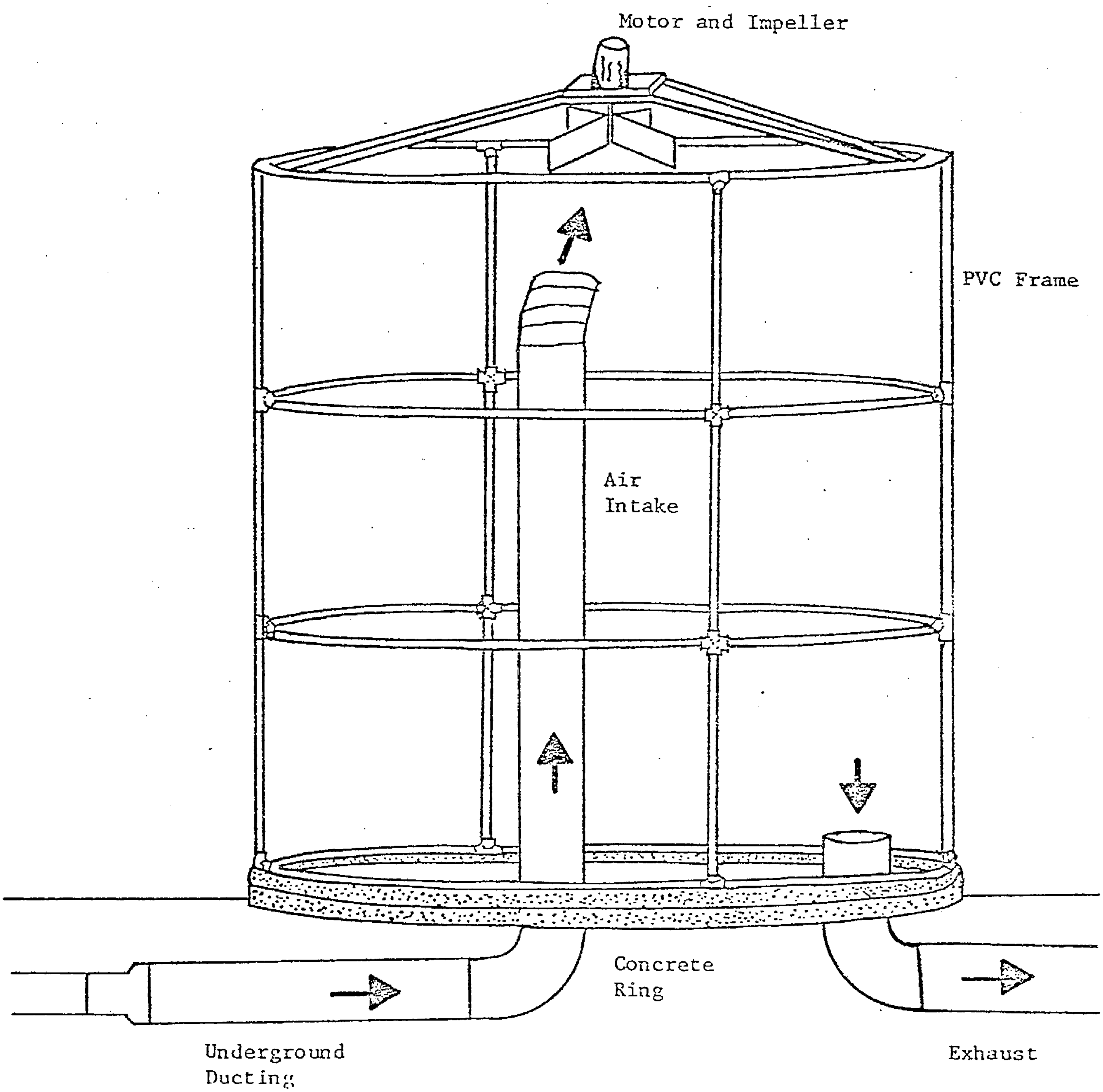


Figure 3. Diagram of Chamber Showing Structural Components
Chamber dimensions are 7' x 7'.



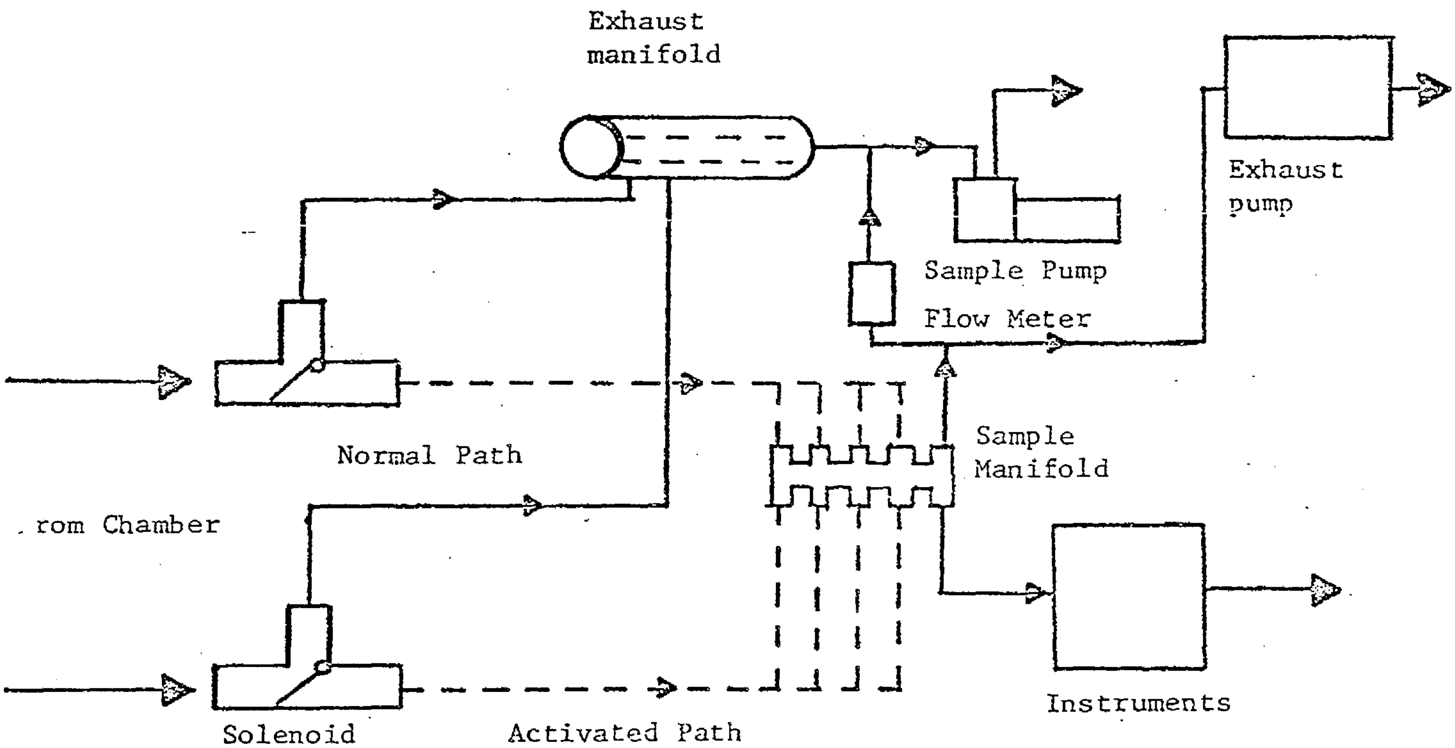
reactor designed by Rogers, USDA, North Carolina State University, Raleigh North Carolina. Each chamber consists of a 7′ x 7′ PVC schedule 80 frame bolted to a concrete ring. A 5 mil FEP Teflon envelope is suspended from the uppermost ring and anchored to the concrete with a 1/2" PVC ring. A small 1/120 H.P. shade pole 110 V motor is mounted at the apex of the PVC frame and anchors the uppermost portion of the Teflon envelope. An extension shaft from the motor protrudes through the Teflon envelope and supports a 6-blade impeller which rotates at 60 rpm. The mixture of filtered and nonfiltered air enters the chamber via a 10" PVS underground duct which then extends 5 ft. vertically and directs the air stream directly at the impeller. Chamber exhaust is vented through a 10" PVS "U" tube directly into the atmosphere.

4. Fumigant Monitoring System (Figure 4)

Seventy-ft. 1/4" FTE Teflon lines run from each chamber. The air sample is pulled through a 3-way Teflon solenoid valve to an exhaust manifold. An electrical control box regulates solenoid activation. Once activated, the solenoid valve diverts the flow to a sampling manifold from which the ozone and SO_2 instruments sample. This system continually pulls about 30 liters/min. through sampling lines. Different chambers can therefore be monitored with a minimal lag time for purging the sampling manifold. All gas lines, solenoids and sampling manifolds are Teflon. All other valves, connectors and fittings are stainless steel. The entire sampling system, exclusive of the sampling lines, electronic control box and pumps, is contained in an insulated, thermally regulated box kept at 100 F.

Ozone was monitored by 2 Dasibi Model 1003-AH ozone monitors which use an ultraviolet absorption method for detection. Sulfur dioxide was monitored

Figure 4. Flow Diagram of Gas Sampling System



by 2 Thermoelectron Model 43 SO_2 analyzers which use a pulsed fluorescence method of detection.

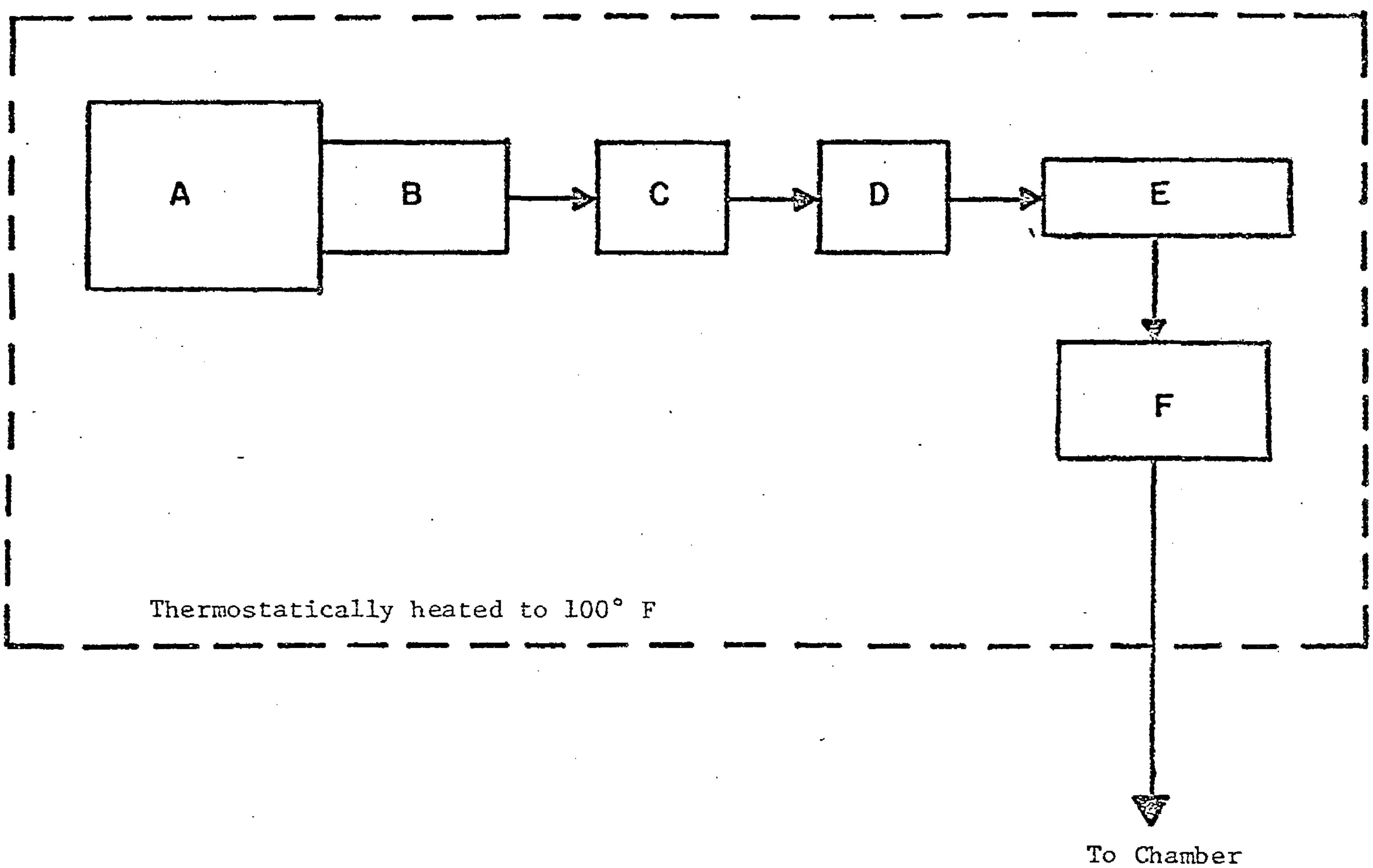
Ozone calibrations were conducted using an additional Dasibi ozone monitor as a transfer standard. This claibration instrument was vertified at the ARB facility in El Monte, California by ultraviolet photometry and kept solely as a calibration standard for the Statewide Air Pollution Research Center.

The Thermoelectron Model 43 SO_2 analyzers were calibrated using a Monitor Laboratories calibrator with a permeation tube. The calibrations were then verified using a known gas standard of SO_2 in nitrogen.

5. SO_2 Dispensing System (Figure 5)

The SO_2 dispensing system consists of 10 independent SO_2 generators housed in insulated, heated 40 gal. transh cans. Each generator contains a 6.7 liter tank of liquid SO_2 (99.8%), a pressure regulator, a 7 μ in-line filter, a Teflon solenoid valve, a 29 inch length of .005 in I.D. stainless steel capillary tubing, and a manual shut-off valve. All fittings and tubing are stainless steel. The SO_2 flow is diverted into the exposure chamber inlet duct to be diluted before entering the exposure chamber. Flow adjustments can be accomplished by changing the setting on the pressure regulator.

Figure 5. Flow Diagram for Sulfur Dioxide Dispensers
The flow of SO_2 starts at the tank (A) and continues through the regulator (B), a solenoid (C), and 7 μ filter (D), a capillary tube (E), and through a shut-off valve (F) to the chamber.



APPENDIX B

Fumigation Facility Performance

APPENDIX B

I. Nutrient Analyses

Available sulfur as sulfate was measured on an individual chamber basis (upper and lower strata combined) and on a stratified basis (combined over chambers) (Appendix Table B1). Mean post-harvest sulfate concentration in chambers receiving or not receiving SO_2 fumigation was 74 and 83 ppm, respectively. All sulfate levels were within acceptable limits.

Salinity was measured as electrical conductivity (ECe, mmhos/cm) on a stratified individual can basis. Chamber means and ranges for ECe values are given in Appendix Table B2. All values are below those levels injurious to potatoes, but some values were surprisingly high. Care was continually exercised to avoid excess leaching; this may contribute to the relatively high values. A similar sampling pattern was followed for pH measurements, the summary of which is also in Appendix Table B2. Again, the values all fell within normal expectations.

Soil nutrient analyses were conducted on the soil mix prior to planting and on a stratified basis following harvest (Appendix Table B3). Most nutrients were only slightly depleted; calcium and magnesium were substantially depleted but remained above deficiency levels.

Thus, effect of sulfur availability, soil salinity and pH, and soil nutrients were minimal and should not affect the interpretation of experimental results.

II. Environmental Control

Appendix Tables B4, B5, and B6 concern photon flux density of photosynthetically active radiation (PAR) [in μEinsteins per $m^2 \cdot s$ ($\mu E/m^2 \cdot s$)]. Light transmissability of the chamber envelopes was high during most of the experiment, ranging from 80-100% of incident sunlight, except for the late sampling date, 12/15 (Appendix Table B4). The reduction in light transmission at this date was attributed to storm damage sustained prior to 12/10. Dirt accumulation, excessive crinkling, and patching tape all contributed to this problem. Growth was greatly reduced by December 1, so the impact was probably minimal.

Appendix Table B5 demonstrates both the effect of clouds and of reduced light intensity and shortened days. The effects were especially marked early and late in the day. Appendix Table B6 also demonstrates declining photon flux density with advancing season, but inside a chamber.

Temperature and humidity control were adequate throughout the experiment. Temperatures averaged slightly higher (0.2 C) inside chambers during daylight and about 1 C higher at night (Appendix Table B7). Such differences should be insignificant. Humidity was consistently increased within chambers as a result of transpiration (Appendix Table B8).

III. High Hourly Oxidant and Ambient SO_2 Readings

The three highest hourly oxidant concentrations for each chamber are given in Appendix Table B9. Highest readings usually occurred very early in the growing season with three days (277, 279, 286) being especially severe.

The maximum observed concentrations of SO_2 in 0 SO_2 chambers was 2 pphm recorded on numerous occasions. Rounding errors lead to consistent recording of small fractional concentrations as 1.0 pphm, so that a summation of these values is misleading.

Appendix Table B1. Chamber composite concentrations (top and bottom soil combined) of water soluble sulfur as sulfate.†

Chamber	Treatment % Filtered	SO_2 - pphm	Sulfate Concentration ppm
A1	Ambient	-	80
A2	Ambient	-	60
1	33	10	45
2	100	0	85
3	67	0	70
4	0	0	65
5	67	0	105
6	100	0	60
7	100	10	70
8	33	0	110
9	0	10	100
10	100	0	70
11	33	10	40
12	100	0	80
13	0	0	85
14	100	0	80
15	100	0	80
16	33	0	110
17	100	0	65
18	67	10	85
19	0	10	75
20	67	0	110

†Sulfate concentraton in bulk planting mix (prior to experiment) was 70 ppm. Post-experiment sulfate concentrations averaged 73 and 45 ppm for upper and lower portions of all cans, respectively.

Appendix Table B2. Salinity and pH values from individual cans following harvest.

Chamber	ECe, mmhos/cm				pH			
	Upper Soil		Lower Soil		Upper Soil		Lower Soil	
	Mean	Range	Mean	Range	Mean	Range	Mean	Range
A1	0.81	0.40-1.11	0.51	0.16-0.87	6.9	6.7-7.2	6.8	6.5-7.0
A2	0.75	0.28-1.60	0.61	0.35-1.51	6.8	6.5-7.3	6.9	6.3-7.1
1	1.08	0.50-1.75	0.23	0.20-0.32	6.8	6.4-7.2	7.2	6.4-7.4
2	1.03	0.89-1.20	0.51	0.28-0.85	7.0	6.8-7.2	6.9	6.6-7.5
3	1.86	0.83-3.00	0.25	0.16-0.36	6.7	6.1-7.2	7.2	6.8-7.4
4	1.00	0.65-1.57	0.37	0.15-0.74	7.0	6.8-7.4	7.2	6.7-7.5
5	1.19	0.71-1.79	0.38	0.19-0.55	7.0	6.6-7.3	7.0	6.9-7.2
6	0.72	0.55-1.00	0.36	0.22-0.56	7.0	6.8-7.2	7.0	6.7-7.4
7	0.45	0.24-0.64	0.52	0.23-1.25	6.9	6.5-7.3	7.1	6.4-7.1
8	1.01	0.26-2.00	0.44	0.27-0.84	7.1	6.7-7.6	7.1	6.8-7.3
9	1.71	1.10-2.60	0.34	0.14-0.61	6.7	6.3-7.0	7.1	6.3-7.4
10	0.89	0.55-1.40	0.23	0.16-0.36	7.0	6.6-7.2	7.3	6.8-7.4
11	0.79	0.38-1.35	0.36	0.27-0.53	7.1	6.7-7.3	7.2	7.0-7.5
12	1.08	0.46-1.70	0.56	0.22-1.08	7.1	6.8-7.3	7.2	6.6-7.6
13	0.86	0.46-1.20	0.94	0.33-1.35	6.8	6.6-7.1	6.6	6.5-7.3
14	1.43	0.66-2.00	0.35	0.22-0.51	7.0	6.6-7.4	7.2	6.9-7.6
15	1.14	0.54-2.00	0.33	0.21-0.50	7.2	6.8-7.4	7.4	7.0-7.6
16	1.02	0.50-2.20	0.36	0.16-0.65	7.2	6.7-7.6	7.4	6.9-7.7
17	1.13	0.60-1.70	0.51	0.19-0.70	6.9	6.8-7.1	7.1	6.6-7.3
18	1.32	0.72-2.00	0.43	0.14-0.80	7.2	7.1-7.4	7.0	6.7-7.5
19	0.62	0.28-1.15	0.52	0.25-0.75	7.1	6.7-7.3	7.0	6.8-7.1
20	1.51	1.15-2.00	0.44	0.15-1.10	7.1	7.0-7.2	7.1	6.5-7.7
Mean:								
Ch. 1-20	1.09	0.24-3.00	0.42	0.14-1.35	7.0	6.1-7.6	7.1	6.3-7.7
Ambient	0.78	0.28-1.60	0.56	0.16-1.51	6.8	6.5-7.3	6.8	6.3-7.1

Appendix Table B3. Nutrient analyses on bulk soil prior to planting and on composite samples following harvest.

Sample	SP %	pH	ECe mmhos cm-1	K† ppm	K‡ ppm	B ppm	P ppm	Zn ppm	Mn ppm	Fe ppm	Cu ppm	Ca me/l	Mg me/l	N ppm	Ca+Mg me/l	SO_4-S ppm
Pre-plant soil mix	36	5.8	1.9	96	720	0.50	74	7.8	19.	12.	8.6	12.6	4.1	383	16.7	70.0
Top soil after harvest	42	6.5	1.4	46	700	0.32	52	11.	6.4	16.	9.8	8.9	2.8	411	11.7	73.0
Bottom soil after harvest	39	6.7	0.76	32	628	0.19	50	7.1	3.5	15.	9.4	3.8	0.8	368	4.6	45.0

† = 1 N ammonium acetate (pH 7.0) extractable potassium.

‡ = 1 N Nitric acid extractable potassium.

Appendix Table B4. Chamber no. 1 envelope light transmission on three dates.

Hour, PST	10/13 In	10/13 Out	10/13 Pct.	11/15 In	11/15 Out	11/15 Pct.	12/15 In	12/15 Out	12/15 Pct.
750	675	800	84	-	-	-	-	-	-
800	875	925	94	-	-	-	150	225	67
850	650	700	93	750	750	100	150	225	67
900	1175	1300	90	900	900	100	350	425	82
950	1475	1375	107	1025	1075	95	425	525	81
1000	1025	1275	80	1100	1150	96	525	650	81
1050	1300	1650	97	1100	1250	88	650	800	81
1100	1550	1825	85	1200	1275	94	675	825	82
1150	1450	1725	84	1250	1325	94	700	850	82
1200	1500	1650	91	1250	1300	96	650	800	81
1250	1400	1675	84	-	-	-	-	-	-
1300	1350	1525	88	1050	1150	91	500	650	77
1350	1250	1350	92	1000	1100	91	300	425	70
1400	1150	1225	94	825	950	87	300	425	70
1450	875	1050	83	750	800	94	200	275	73
1500	750	850	88	450	475	95	150	200	75
1550	600	700	86	350	375	93	-	-	-
1600	250	300	83	100	150	67	-	-	-

Appendix Table B5. Daily PAR reading outside chambers as an average integrated over 8 hr (800-1600).

Date	PAR $\mu E/m^2 \cdot s$	Comments	Date	PAR $\mu E/m^2 \cdot s$	Comments
9/21	1442		11/8	1010	
22	1411		9	830	
25	1390		10	203	Rain
26	1316		13	294[†]	Rain
27	1294		14	951	
28	1308		15	937	
29	1248		16	928	
10/2	1152		17	898	
3	1133		20	635	Cloudy
4	1122		21	247	Rain
5	992		22	555	
6	1127		27	873	
9	1211		28	937	
10	1242		29	769	
11	1180		30	765	
12	1170		12/1	356	
13	1218		4	834	
16	1062		5	458	
17	998		6	710	
18	1013		7	816	
19	722		8	795	
20	933	Rain	11	830	
23	1137		12	655	
24	1026		13	819	
25	832	Cloudy	14	739	
26	1059		15	552	
27	1076		18	139	
30	330	Cloudy	19	613	
11/1	830	Cloudy	20	806	
2	949		21	756	
3	1037		22	650[‡]	
6	1014		27	710	
7	984		28	280	Cloudy
			29	563	

[†]900-1600.

[‡]

Appendix Table B6. PAR values at plant canopy height in chamber no. 1.

Date	PAR $\mu E/m^2.s$				
	900†	1100	1300	1600	
10/12	-	-	1250	-	
17	-	1350	-	-	
19	600	800	-	-	
26	600	1300	-	350	
11/1	800	1200	1100	200	
3	700	1300	-	-	
7	950	1150	850	200	
9	500	750	300	150	
13	850	1200	1100	25	
15	-	1125	1000	100	
20	300	150	150	25	Rain
28	875	1200	1000	100	
30	450	950	875	100	
12/5	550	850	200	25	
7	-	1050	50	-	
12	400	475	400	75	Cloudy
14	600	950	800	50	
19	750	250	350	50	Cloudy
21	500	1050	650	75	

†Times are PST.

Appendix Table B7. Mean daily maximum and minimum chamber temperatures over 108 days.

Chamber	Maximum, °C	Minimum, °C
Ambient	27.0	7.7
1	25.9	8.7
3	26.5	8.7
4	30.1	8.6
5	26.8	8.7
7	27.3	8.7
8	27.2	8.7
9	28.2	8.6
10	27.8	8.6
11	26.2	8.7
12	25.4	8.7
13	26.8	8.7
16	27.1	8.7
17	27.1	8.7
18	27.5	8.7
19	28.2	8.4
20	27.5	8.7

Appendix Table B8. Mean daily relative humidities at four facility locations averaged over 108 days.

Location	Relative humidity
Rep I exhaust	43.2
Rep II exhaust	46.1
Chamber 4 exhaust	51.4
Chamber 13 exhaust	53.8

Appendix Table B9. Season high hourly average oxidant concentrations (3 highest) for each chamber.

Filtered air pct	Chamber number	Hourly average pphm	Hour	Day†
	4	26,18,18	17,16,15	286,279,277
0	9	24,24,19	16,17,16	286(2),279
	13	27,18,18	17,16,15	286,279,277
	19	27,26,21	16,17,16	286(2),279
	1	16,11,11	17,16,15	286,279,285
33	8	17,13,13	17,16,15	286,279,277
	11	15,11,11	17,16,15	286,279,277
	16	18,13,12	17,16,15	286,279,277
	3	7,6,6	17,16,15	286,279,277
67	5	8,6,6	17,16,15	286,279,277
	18	8,7,7	17,16,15	286,279,277
	20	7,7,7	17,16,15	286,279,277
	7	2,2,2	17,16,15	286,279,277
100	10	3,3,2	17,16,15	286,279,277
	12	2,2,2	14,15,15	289(2),285
	17	Numerous observations at 2 pphm		

†October 1 is day 274.

APPENDIX C

Analysis of Variance Tables

Appendix Table C1. Mean squares for effects of ambient oxidant and SO_2 on selected measures of plant growth.

Effect	Stem number (X 10)	Stem length	Stem weight	Leaf weight	Root weight	Shoot weight (X 10^{-1})
Replications	1.314	8.02	0.40	8.0	0.020	0.48
SO_2	5.513	4.73	0.17	60.2	0.150	6.68
Oxidant	0.807	36.66*	3.61	334.2**	7.087**	40.12**
Linear	0.038	79.02*	6.94	923.1**	21.125**	109.02**
Quadratic	0.333	5.94	0.07	31.3	0.088	3.42
Residual	2.050	25.01	3.82	48.1	0.048	7.91
Oxidant x SO_2	8.341	12.99	4.33	99.1	0.902	12.68
Linear	2.820	1.30	1.24	125.9	0.023	15.21
Quadratic	0.588	37.55*	0.27	104.1	0.037	9.37
Residual	21.615	0.11	11.47	67.4	2.646	13.45
Experimental Error	11.93	6.66	2.30	28.2	0.020	3.66

*,**Significant at 5 and 1 percent levels, respectively.

Appendix Table C2. Mean squares for effects of ambient oxidant and SO2 on mean tuber number and yield, by size class.

Effect	Tuber number				Tuber yield, g			
	<56g	56-112g (X 10)	>112g (X 10)	Total	<56g (X 10^{-3})	56-112g (X 10^{-3})	>112g (X 10^{-3})	Total (X 10^{-4})
Replications	8.71	30.62	40.00**	1.56	2.02	19.71	100.84*	1.02
SO_2	56.25*	15.62	22.50*	22.56	40.48**	10.65	44.12	2.05
Oxidant	35.17	150.62**	21.67*	115.40**	6.24	94.56**	33.43	28.58**
Linear	96.80*	406.12**	50.00**	337.80**	12.82	242.31**	71.38*	78.59**
Quadratic	6.25	0.62	2.50	2.89	2.44	0.72	5.72	0.71
Residual	2.45	45.12	12.50	13.69	3.46	40.66*	23.19	6.42*
Oxidant x SO_2	27.08	90.62*	7.50	55.06*	12.73*	54.62**	12.33	4.44*
Linear	6.05	3.12	4.50	54.40	0.01	5.97	4.85	1.86
Quadratic	36.00	15.62	0.00	105.12**	20.82*	6.37	2.55	2.03
Residual	39.20	253.12**	18.00*	5.67	17.36*	151.52	29.59	9.44*
Experimental Error	8.71	12.05	2.86	10.70	2.32	5.93	8.44	1.10

*,**Significant at 5 and 1 percent levels, respectively.

Appendix Table C3. Mean squares for effects of ambient oxidant and SO_2 on specific gravity and dry matter percentage of tubers.

Effect	Specific gravity (X 10^6)	Dry Matter (X 10)
Replications	13.81	14.04
SO_2	42.52*	10.61
Oxidant	17.15	5.50
Linear	42.20*	8.78
Quadratic	6.84	3.60
Residual	2.42	4.12
Oxidant x SO_2	6.52	5.73
Linear	7.76	3.15
Quadratic	1.61	0.68
Residual	10.16	13.36
Experimental Error	4.22	2.63

*Significant at 5 percent levels, respectively.

Appendix Table C4. Mean squares for effects of ambient oxidant and SO_2 on tuber sugar concentrations.

Effect	Total sugars ($X\ 10^{-2}$)	Reducing sugars	Sucrose ($X\ 10^{-1}$)	Glucose	Fructose ($X\ 10^{-1}$)
Replications	4.75	19.58	54.06	7.70	5.22
SO_2	3.26	3.33	17.56	87.89	5.74
Oxidant	2.21	67.60	3.32	22.44	7.22
Linear	5.08	107.88	6.66	41.62	1.52
Quadratic	0.09	13.50	1.41	19.14	6.68
Residual	1.45	81.41	1.90	6.56	13.44
Oxidant x SO_2	4.82	58.00	9.81	7.54	2.87
Linear	1.42	0.04	5.95	3.92	0.41
Quadratic	3.31	98.50	12.66	14.25	3.81
Residual	0.09	75.47	10.81	4.46	4.40
Experimental Error	1.08	97.86	4.60	17.03	4.07

Appendix Table C5. Mean squares for effects of ambient oxidant and SO_2 on total nitrogen concentration in tubers.

Effect	Nitrogen content ($X\ 10^3$)
Replications	0.02
SO^2	62.08**
Oxidant	149.64**
Linear	32.40*
Quadratic	4.20
Residual	60.02**
Oxidant x SO_2	23.38*
Linear	33.62*
Quadratic	1.22
Residual	35.28*
Experimental Error	4.38

*,**Significant at 5 and 1 percent levels, respectively.

APPENDIX D

Pathogens as Speckle Leaf Causal Agents

92

COOPERATIVE EXTENSION
UNIVERSITY OF CALIFORNIA

DAVIS, CALIFORNIA 95616 REPLY TO: Dept. of Plant Pathology

Date: July 24, 1978

To: Ken Foster

Dennis

From: Dennis Hall
Ext. Plant Pathologist

Dear Ken:

In answer to your letter on possible cause of speckle leaf or speckle-belly of potatoes, I am convinced that the necrosis associated with the disease is not induced by a pathogen. For several years I have attempted to isolate for possible organisms without finding any evidence that fungi or bacteria are involved in the tissue necrosis. The problem has been seen on many potato varieties but certain varieties appear to be more prone to damage than others. For example, Kennebec, Red LaSoda, Chieftain and Cenntenial seem to show more severe symptoms than do such cultivars as White Rose or Russet Burbank although the latter are affected.

Drs. Weinhold and Schroth, Department of Plant Pathology, Berkeley, have reached the same conclusion that it is highly unlikely that either fungi or bacteria are involved in the disease. We concur that it is most likely the disease is due to environmental factors with air pollution a prime suspect.

DHH:emj

cc: A. R. Weinhold