Soybean Yield in New Jersey Relative to Ozone Pollution and Antioxidant Application

G. SMITH, Former Graduate Student, B. GREENHALGH, Technician, E. BRENNAN, Professor of Plant Pathology, Department of Plant Pathology, and J. JUSTIN, Extension Specialist in Department of Soils and Crops, Cook College-NJAES, Rutgers University, New Brunswick, NJ 08903

ABSTRACT

Smith, G., Greenhalgh, B., Brennan, E., and Justin, J. 1987. Soybean yield in New Jersey relative to ozone pollution and antioxidant application. Plant Disease 71:121-125.

The yield of two commercial soybean cultivars, Williams and Cutler 71, was compared in ethylenediurea-treated and untreated test plots in New Brunswick, NJ, over a 3-yr period. No statistically significant ($P = 0.05$) difference between treatments was found for the cultivars although the National Ambient Air Quality Standard (NAAQS) of 0.12 ppm ozone was exceeded for as many as 72 hr per growing season and the 7-hr daily mean equaled 0.062 ppm. On this basis, it was concluded that Williams and Cutler 71 do not sustain a yield loss attributable to ozone pollution in New Jersey. This is contrary to predictions based on the National Crop Loss Assessment Network (NCLAN) models relating yield loss to the 7-hr ozone mean during the growing season. The open-top chamber method on which the models are based do not reflect the episodic nature of ozone pollution or some of the more important environmental conditions that influence plant growth in the field.

Additional key words: abiotic stress

In 1978, Carnahan et al (3) described a new chemical that increased the ozone resistance of several plant species when applied as an aqueous solution to the foliage or roots. The chemical was *N*-[2-(2-oxo-1-imidazolidinyl)ethyl]-N′-phenylurea (abbreviated EDU for ethylenediurea). The du Pont chemists predicted that the antioxidant would be "useful as a survey tool to determine the location and magnitude of crop losses due to ozone" (3). Their prophecy was quickly fulfilled by scientists who compared the yield of EDU-treated and untreated crops in ozone-polluted areas of eastern Canada. EDU applied to field plantings increased yields of onion by as much as 37% (25), navy bean by 36% (11), white bean by 24% (19), tomato by 30% (14), potato by 35% (1), and tobacco by 20% (2). In the United States, EDU treatment increased potato yield by 31% in New Jersey (4) and 19% in California (7). The investigators generally reported that EDU had reduced or delayed the occurrence of ozone injury symptoms on the foliage of the developing crops and had also delayed defoliation or plant senescence. Two groups of researchers (7,14) stated that yield loss correlated better with the early decline of the plants than with leaf symptoms. In these field experiments, EDU did not increase the yield of ozone-resistant cultivars, e.g., New Yorker tomato (14) had similar yields in EDU-treated and untreated plots, as did Green Mountain potato (4) and White Rose potato (7). The EDU treatment did not increase the yield of ozone-sensitive cultivars when ozone had been deliberately removed from the environment (7) or when ozone episodes had not occurred frequently in ambient air (4). The use of EDU therefore appears generally reliable for assessing yield loss attributable to ozone.

Preliminary investigations by Heck et al (9,10) in 1982 concluded that soybean yield in the United States was reduced 17.5% by ozone pollution. Their results, like others obtained by the National Crop Loss Assessment Network (NCLAN), were based on yield comparisons of soybeans grown in open-top chambers supplied with either charcoal-filtered air or air containing artificially generated ozone (13). Open-top chambers have been found to create environmental conditions that differ from those in the field in respect to air temperature, light intensity, relative humidity, and airflow (7,18,24). These changes in environmental conditions can affect yield, as demonstrated by Howell et al (12); soybeans grown in chambers with unfiltered air had lower yields than those grown in unfiltered air outside a chamber.

During the past 5 yr, we have used the EDU technique to investigate the impact of ambient ozone pollution on soybean yield, because this field crop is among the most economically important in New Jersey (17). This paper describes field experiments conducted using the antioxidant technique in New Brunswick, NJ, from 1982 to 1984 to determine if ambient oxidant caused reductions in the yields of two of the more commonly grown soybean cultivars in New Jersey, Williams and Cutler 71.

MATERIALS AND METHODS

The two cultivars chosen for the study were Williams (maturity group III) and Cutler 71 (maturity group IV). These cultivars are well adapted to New Jersey growing conditions and are economically important. In 1982, Cutler 71 was replaced by Beeson (maturity group II) because the latter had been reported to be very sensitive to ozone (21). In 1983, Corsoy (maturity group II) was added to the test for a similar reason (12). Soybean seeds were planted in loam soil in replicated field plots at the Rutgers Research Farm in New Brunswick, using standard agronomic practices. The fields were disked, limed, and fertilized as required. Preemergence herbicides

Paper of the Journal Series, New Jersey Agricultural Experiment Station (NJAES), Cook College, Rutgers University. This work was performed as a part of NJAES Project D-11151-1-86.

Accepted for publication 9 September 1986 (submitted for electronic processing).

The publication costs of this article were defrayed in part by page charge payment. This article must therefore be hereby marked *"advertisement"* in accordance with 18 U.S.C. § 1734 solely to indicate this fact.

alachlor and linuron were applied to the soil, and seed was inoculated with a commercial preparation of *Rhizobium japonicum* before planting. In 1982, the planting procedure was as follows: Seeds were planted at the rate of 180/6.10-m row. There were 0.76 m between rows and three rows per plot, one center row for evaluation and a border row at each side. Each plot was replicated four times in a randomized complete-block design, and blocks were separated by 1.52-m alleyways. In 1983 and 1984, the inoculated seed was planted as described, except the block design was systematic and plot size within blocks was expanded to five rows with three center rows for evaluation. Weeds were controlled by hand hoeing. In 1982, several applications of thiram were needed to control rabbit feeding, and in 1983, a foliar application of orthene was needed to control thrips. All plants were grown to maturity without irrigation, consistent with common practice of soybean production in New Jersey.

The antioxidant (EDU) was applied biweekly as a soil drench (500 ppm; 4 L/row) to one-half of the field plots from June to September. Plots that did not receive EDU were given an equal volume of water. During the growing season, the plantings were examined for typical foliar symptoms of ozone toxicity, i.e., stipple of the upper surfaces of newly expanded leaves. In July and August of each year, the percentage of foliar injury on five to eight plants randomly selected from each yield row was estimated. By September, it was difficult to rate the amount of stipple on plants that were becoming senescent. Because there was an obvious difference in the onset of senescence between the EDU-treated and untreated plants in September 1983, the percentage of chlorotic leaves was rated in each treatment.

When the plants matured, a 3.05-m section of each yield row was hand-harvested, threshed, and bagged. After 2 wk at ambient temperature, the bagged seeds were cleaned and weighed, and the weight was converted into kilograms per hectare. Average seed size per plot was calculated from the weight of three 100-seed lots from each plot. A germination test was performed as a measure of seed quality. In 1982, 36 seeds from each yield row were planted in a flat (30.5 × 30.5 × 5.1 cm) containing a 1:1:1 sand/perlite/vermiculite mixture. The flats were watered and placed in a humid environment at 25 C for 4 days. The number of germinated seeds was recorded, and a mean value expressed on a percent basis was calculated for each plot. This germination test was replicated three times. In 1983, the procedure was changed as follows: 100 seeds from each plot were wrapped in damp muslin, placed in plastic bags, and stored in a humid environment at 25 C for 1 wk. After 7 days, the number of germinated seeds was recorded. As in 1982, a mean value expressed on a percent basis was calculated for each plot.

Ozone concentrations in ambient air were continuously monitored at the Rutgers Research Farm 0.80 km north of the soybean plots by the New Jersey Department of Environmental Protection using an EPA-approved standard ozone monitor (Model 1003-AH Dasibi Environmental Corporation, Glendale, CA). Data on daily rainfall for the experimental site were obtained from the Department of Meteorology, Cook College.

All plant data were subjected to analysis of variance (ANOVA), and treatment means were separated using Duncan's multiple range test.

RESULTS

Ozone injury symptoms on Williams and Cutler 71 foliage were generally rated less than 13% during the experiment, and application of EDU to the plants did not significantly alter the amount of injury (Table 1). Beeson showed more foliar injury than the other cultivars, and EDU treatment tended to reduce symptom expression. As the plants approached physiological maturity in 1983, the effect of EDU on senescence was observed. Williams plants had 88% yellow leaves in the untreated plots and 58% in EDU-treated plots, whereas Cutler 71 had 69 and 46%, respectively.

Table 1. Percentage of leaves showing ozone toxicity symptoms in EDU-treated[a] and untreated soybeans

	Williams		Cutler 71		Beeson		Corsoy	
Year	+EDU	−EDU	+EDU	−EDU	+EDU	−EDU	+EDU	−EDU
1982	10[b]	10	–	–	10	25	–	–
1983	13	8	6	6	–	–	6	15
1984	10	10	10	10	–	–	–	–

[a] Applications of ethylenediurea (500 ppm) were made biweekly from seedling emergence to growth stage R7.

[b] Each number represents the maximum percentage of leaf injury observed when five or eight plants randomly selected from four yield rows were rated for ozone injury in July and August.

Table 2. Comparison of seed yield (kg/ha) in EDU-treated[a] and untreated soybeans

	Williams		Cutler 71		Beeson		Corsoy	
Year	+EDU	−EDU	+EDU	−EDU	+EDU	−EDU	+EDU	−EDU
1982	2,613[b]	2,587	–	–	2,740	2,567	–	–
1983	2,013	2,133	1,840	2,233	–	–	2,080	1,953
1984	2,820	2,667	2,953	2,860	–	–	–	–
Av.	2,760	2,600	2,460	2,613	–	–	–	–

[a] Applications of ethylenediurea (500 ppm) were made biweekly from seedling emergence to growth stage R7.

[b] Means based on 3.05-m section of yield row, replicated four times. The data were statistically analyzed by ANOVA and no significant differences were found between treatments.

Table 3. Seed size and germination rate in EDU-treated[x] and untreated soybean plants

		Williams		Cutler 71		Beeson		Corsoy	
Year	Size and germination	+EDU	−EDU	+EDU	−EDU	+EDU	−EDU	+EDU	−EDU
1982	Size (g/100 seeds)	19.52[y] a[z]	19.13 a	–	–	20.71 a	20.22 a	–	–
	Germination (%)	98 a	97 a	–	–	95 a	96 a	–	–
1983	Size (g/100 seeds)	16.88 a	15.87 a	17.20 a	15.91 a	–	–	15.10 a	14.29 a
	Germination (%)	98 a	94 a	96 a	78 b	–	–	98 a	100 a
1984	Size (g/100 seeds)	19.75 a	19.79 a	19.83 a	19.75 a	–	–	–	–

[x] Applications of ethylenediurea (500 ppm) were made biweekly from seedling emergence to growth stage R7.

[y] Mean based on 3.05-m section of yield row, replicated four times.

[z] Pairs of means in a row followed by the same letter are not significantly different ($P = 0.05$) according to Duncan's multiple range test.

There was no significant ($P = 0.05$) difference in yield between soybeans grown in EDU-treated and untreated plots (Table 2). The results were similar during the 3 yr Williams was evaluated and during the 2 yr Cutler 71 was evaluated (the more commonly grown New Jersey cultivars).

There was no significant ($P = 0.05$) difference in seed size resulting from EDU treatment in any of the cultivars, and the percentage of germination was similar in EDU-treated and untreated plots for the Williams, Beeson, and Corsoy cultivars (Table 3). In the only year that Cutler 71 was tested, the seed germination rate was lower in the untreated than in the EDU-treated plots.

The amount of ozone pollution that the soybean plants were exposed to at the New Brunswick test site varied considerably from year to year (Table 4). The total cumulative ozone doses experienced by the soybean plants during each growing season were of the following order: 1983 > 1984 > 1982. There was considerable variability of the 7-hr daily ozone mean in ambient air both in terms of its magnitude and also temporally in relation to the growth stages of the soybean crop (Fig. 1). In 1983, soybeans were exposed to frequent ozone episodes from early vegetative stages through pod fill to maturity, whereas in 1984, frequent ozone episodes were confined to the period before pod fill. In 1982, there were no clusters of ozone episodes, only widely separated occurrences at early vegetative and pod fill. All types of exposure statistics calculated from the ozone data (Table 4), except the 7-hr mean, indicated that year 1983 had the greatest pollution followed by 1984 and 1982. The 7-hr daily mean (1100–1800 hours EST) for the growing season was 0.054 ppm in 1982 and 0.062 ppm in 1983 and 1984. The numbers of hours that the National Air Quality Standard of 0.12 ppm was exceeded were 20, 72, and 20 for 1982, 1983, and 1984, respectively.

The volume and frequency of rainfall at the experimental site also are shown in Figure 1. Daily and yearly variation in amount and distribution of rainfall was evident. The years 1983 and 1984 illustrated the extremes: a very dry and a very wet growing season.

DISCUSSION

Two soybean cultivars Williams and Cutler 71 showed little ozone injury to the foliage during any stage of development in any of the 3 yr of the test. The application of EDU did not alter the amount of injury. These results are unlike those obtained with potato in 1980, when a cumulative dose of 110 ppm·hr (in the range of the 1983 cumulative dose) caused 75% leaf injury in untreated plots and 20% in EDU-treated plots (4). Compared with potato, soybean appears to be much more ozone-tolerant and would not therefore be expected to show any visible improvement in the condition of the foliage with antioxidant application.

None of the soybean cultivars tested in this field experiment showed a significant difference in total seed yield between antioxidant-treated and untreated plants. The year-to-year variability in seed yield was much greater than that between antioxidant-treated and untreated plants in any given year. For Williams and Cutler 71 and all other soybean cultivars grown at the New Brunswick site (Century, Pella, Elf, Asgrow 3129, and MS 250), yield was lowest in 1983, highest in 1984, and intermediate in 1982. The average soybean yield for the state, including all cultivars, conformed to that same trend. The New Jersey Crop Reporting Service (17) attributed the low yield in 1983 to a cool spring followed by high temperatures in summer and a lack of rainfall except for a few local showers. A plot of soybean yield in New Jersey over the last 30 yr illustrates the extreme yearly variability in yield (Fig. 2). The lowest points all correlate with drought conditions (17). The notion that rainfall is crucial to the productivity of soybeans in New Jersey is well documented by the work of Flannery of the New Jersey

Table 4. Various measures indicating degree of ozone pollution at the soybean experimental site during the growing season

	Year[a]		
	1982	1983	1984
Measures of ozone	2 Jul.–28 Oct.	3 Jun.–19 Oct.	12 Jun.–25 Sept.
Cumulative dose (ppm·hr)	81.2	103.3	85.6
7-hr mean (ppm)	0.054	0.062	0.062
No. days 7-hr mean ⩾0.07 ppm	31	53	40
No. days 7-hr mean ⩾0.10 ppm	5	20	7
No. hr ⩾0.12 ppm (NAAQS)[b]	20	72	20
No. hr ⩾0.10 ppm	50	154	67
Hourly maximum (ppm)	0.160	0.197	0.189

[a] Dates represent day of soybean planting to day of harvest for each year.
[b] NAAQS = National Ambient Air Quality Standard.

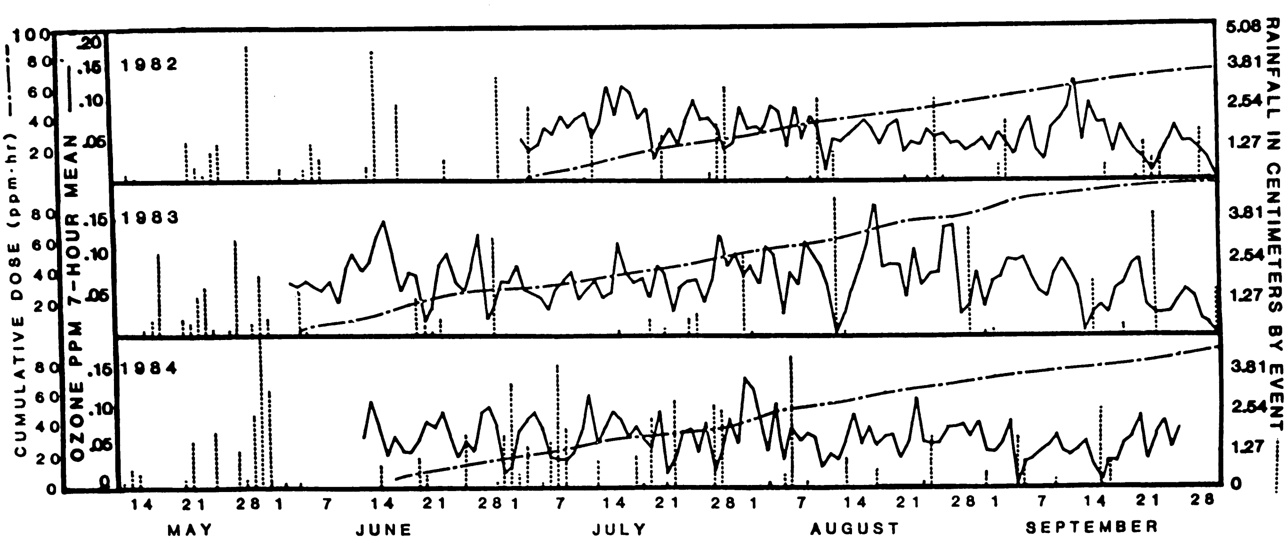

Fig. 1. Ozone exposure statistics and daily rainfall data for the 1982–1984 soybean growing seasons at the Rutgers Research Farm, New Brunswick, NJ. Cumulative ozone (ppm/hr) during each growing season indicated by broken line, 7-hr daily mean (ppm) by solid line, and daily rainfall (cm) by dotted line.

Agricultural Experiment Station (6). In his efforts to maximize the yield of soybean, he has studied some 32 combinations of management variables and has found irrigation to have the greatest influence. From 1980 to 1985, soybean yield in his field plots 20 mi. south of the New Brunswick test site averaged 4,600 kg/ha in nonirrigated field plots and 6,867 kg/ha in irrigated plots.

Superimposed on the yearly yield fluctuations, our data show that ambient ozone pollution did not reduce soybean yield in New Jersey during 1982, 1983, and 1984. Ozone pollution in New Jersey was as severe in 1983 as it was during the past 10 yr, and the ozone levels of 1982 and 1984 were more comparable to those described in an earlier paper (4) for 1977, 1978, and 1979. From our experimental evidence, we conclude that the yield of commercially grown Williams and Cutler 71 soybean will not be adversely affected by ambient ozone in New Jersey.

We are cautious about drawing conclusions related to the effect of ozone on seed size and germination because of the limited amount of data. Inasmuch as there were no statistically significant differences in seed size between EDU-treated and untreated plants, we assume that ozone had no influence on seed size. From 3 yr of data for Williams, it was evident that seed size was smaller in 1983 than in 1982 or 1984, probably because of the drought. It may be more than coincidence that EDU tended to increase seed size of all three cultivars in 1983. It may represent an interaction that bears further study.

Our results do not support the predictive model for evaluating soybean losses advanced by researchers using the open-top chamber technique (9). According to their model ($Y = -11.8 + 472\,x$, where y = percent yield reduction and x = 7-hr daily mean for the growing season) the percent yield reduction should have been 13.7% in 1982 and 17.5% in 1983 and 1984. The disparity between the predicted and actual soybean yield loss attributable to ozone may have several explanations. Ozone episodes in "naturally" polluted ambient air occur randomly (Fig. 1), and it is possible that in the field a stage of growth might escape exposure (as in August 1982 when ozone was relatively low), or having been exposed, the plants might have time to repair the injury (as in 1–14 July 1983, when ozone was relatively low after two high-ozone peaks). Ozone treatments, in open-top chambers, are uniformly supplied at a constant concentration for 7-hr/day over the entire growing season, and there is no opportunity for plants to "escape" or recover. In polluted ambient air, sunny days with elevated air temperatures (about 85 C) that promote photochemical activity also induce stomatal closure, causing plants to be less responsive to atmospheric gases. In contrast, artificially generated ozone may be introduced into open-top chambers, when environmental conditions that cause stomatal closure do not necessarily prevail. Moreover, a higher airflow rate carrying the pollutant into the chambers (16,23) would increase ozone uptake by the plants by reducing the foliar boundary layer.

Another significant difference between soybeans grown for production and those grown in chambers pertains to the soil moisture status. Commercially grown soybeans are not irrigated; soybeans in chambers are given an optimum water supply (9). The consensus of the past 20 yr is that water-stressed plants are less susceptible to ozone injury than nonstressed plants (5,20). Soybean plants in New Jersey test plots were under moisture stress (Fig. 1) a great percentage of the time in 1983, occasionally throughout the growing season in 1982, and occasionally during August and September in 1984. In chamber studies, plants are probably never under moisture stress. Recently, Heagle (8) made the observation that the yield of soybeans grown in the Raleigh, NC, area in 1984 did not conform to the NCLAN model. Whereas the predicted loss was 19%, he suggested that because of soil moisture stress resulting from a drought during July and September, the loss was only one-half of the estimate.

In using the NCLAN model to predict soybean yield in ozone-polluted areas, there is still another confounding factor. In open-top chambers, plants are subjected to ozone by artificial generation of the pollutant. In the field, plants are exposed to a complex mixture that includes precursors in the photochemical generation of ozone. Also, as a result of high-pressure systems and associated photochemical smog episodes, high levels of sulfate, nitric acid, hydrocarbons, aldehydes, and particulates (15,22) can be found concurrently with ozone peaks in polluted ambient air. Open-top chamber research has not addressed this complicated but practical issue. The antioxidant-field approach, therefore, in our opinion, more realistically represents the effects of ozone and other oxidants in a polluted environment.

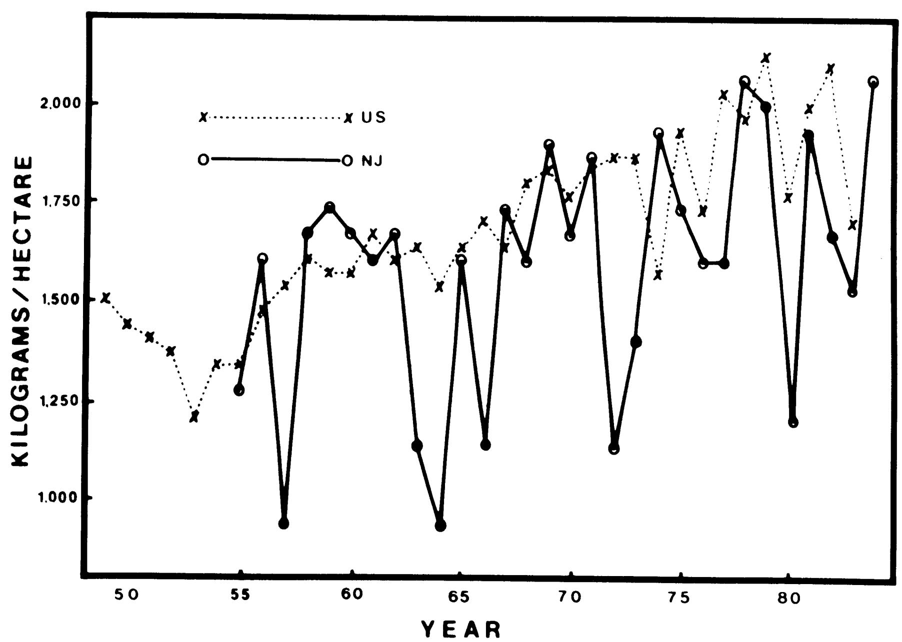

Fig. 2. Average yield (kg/ha) of soybeans harvested in New Jersey and in the United States each year from 1949 to 1984.

ACKNOWLEDGMENTS

We thank the E. I. du Pont de Nemours Company for providing the experimental chemical EDU, the New Jersey Soybean Industry Council for partial support, and Andrew Mikula of the New Jersey Department of Environmental Protection for ozone-monitoring data. We also thank Professor Ida A. Leone and Ronald S. Harkov for their comments on the research as well as review of the manuscript.

LITERATURE CITED

1. Bisessar, S. 1982. Effect of ozone, antioxidant protection and early blight on potato in the field. J. Am. Soc. Hortic. Sci. 107:597-599.
2. Bisessar, S., and Palmer, K. 1984. Ozone, antioxidant spray, and *Meloidogyne hapla* effects on tobacco. Atmos. Environ. 18:1025-1027.
3. Carnahan, J., Jenner, E., and Wat, E. 1978. Prevention of ozone injury to plants by a new protectant chemical. Phytopathology 68:1225-1229.
4. Clarke, B., Henninger, M., and Brennan, E. 1983. An assessment of potato losses caused by oxidant air pollution in New Jersey. Phytopathology 73:104-108.
5. Dean, C. E., and Davis, D. R. 1967. Ozone and soil moisture in relation to the occurrence of weather fleck on Florida cigar-wrapper tobacco in 1966. Plant Dis. Rep. 51:72-75.
6. Flannery, R. 1985. Maximum yield soybean experiment in 1984. Soils Crops Res. Cent., Rutgers Univ., Adelphia, NJ. 15 pp.
7. Foster, K. W., Guerard, J. P., Oshima, R. J., and Timm, H. 1983. Differential ozone susceptibility of centennial russet and white rose potato as

demonstrated by fumigation and antioxidant treatments. Am. Potato J. 60:127-139.
8. Heagle, A. 1985. 1984 Estimates of Crop Losses in North Carolina Due to Plant Diseases and Nematodes. C. E. Main and S. M. Nasser, eds. Dep. Plant Pathol. N.C. State Univ. Spec. Publ. 4.
9. Heck, W. W., Cure, W. W., Shriner, D. S., Olson, R. J., and Heagle, A. S. 1982. Ozone impacts on the productivity of selected crops. In: Effects of Air Pollution on Farm Commodities. Izaak Walton League of America, Washington, DC.
10. Heck, W. W., Taylor, O. C., Adams, R., Bingham, G., Miller, J., Preston, E., and Weinstein, L. 1982. Assessment of Crop Loss from Ozone. JAPCA 32:353-361.
11. Hofstra, G., Littlejohns, D. A., and Wukasch, R. T. 1978. The efficacy of the antioxidant ethylene-diurea (EDU) compared to carboxin and benomyl in reducing yield losses from ozone in navy bean. Plant Dis. Rep. 62:350-352.
12. Howell, R., Koch, E., and Rose, L., Jr. 1979. Field assessment of air pollution-induced soybean yield losses. Agron. J. 71:285-288.
13. Kress, K. W., and Miller, J. E. 1983. Impact of ozone on soybean yield. J. Environ. Qual. 12:276-281.
14. Legassicke, B., and Ormrod, D. 1981. Suppression of ozone injury on tomatoes by ethylenediurea in controlled environments and in the field. HortScience 16:183-184.
15. Lioy, P. J., Daisey, J. M., Reiss, N. M., and Harkov, R. 1983. Characterization of inhalable particulate matter, volatile organic compounds and other chemical species measured in urban areas in New Jersey. Atmos. Environ. 17:2321-2330.
16. MacDowall, F. D. H., Mukammai, E., and Cole, A. 1964. Direct correlation of air polluting ozone and tobacco weather fleck. Can. J. Plant Sci. 44:410-417.
17. New Jersey Crop Reporting Service. 1985. New Jersey Agriculture 1984. Circ. 507. N.J. Dep. Agric./U.S. Dep. Agric., Trenton, NJ.
18. Olszyk, D., Tibbitts, T., and Hertzberg, W. M. 1980. Environment in open-top field chambers utilized for air pollution studies. J. Environ. Qual. 9:610-615.
19. Temple, P., and Bisessar, S. 1979. Response of white bean to bacterial blight, ozone, and antioxidant protection in the field. Phytopathology 69:101-103.
20. Tingey, D., Thutt, G., Gumpertz, M., and Hogsett, W. 1982. Plant water status influences ozone sensitivity of bean plants. Agric. Environ. 7:243-254.
21. Troiano, J., Colavito, L., Heller, L., and McCune, D. C. 1982. Viability, vigor and maturity of seed harvested from two soybean cultivars exposed to simulated acidic rain and photochemical oxidants. Agric. Environ. 7:275-283.
22. Tuazon, E. C., Winer, A. M., and Pitts, J. V., Jr. 1981. Trace pollutant concentrations in a multiday smog episode in the California South Coast Air Basin by long path length Fourier-transform infrared spectrophotometry. Environ. Sci. Tech. 15:1232-1237.
23. Unsworth, M., Heagle, A., and Heck, W. 1984. Gas exchange in open-top field chambers. I. Measurement and analysis of atmospheric resistance to gas exchange. Atmos. Environ. 18:373-380.
24. Weinstock, L., Kender, W., and Musselman, R. 1982. Microclimate within open-top air pollution chambers and its relation to grapevine physiology. J. Am. Soc. Hortic. Sci. 107:923-929.
25. Wukasch, R., and Hofstra, G. 1977. Ozone and *Botrytis* spp. interaction in onion leaf dieback field studies. J. Am. Soc. Hortic. Sci. 102(5):543-546.