Chapter 4

Effects of Ozone on Crops and Forests

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INTRODUCTION

At concentrations that occur in rural areas throughout the southern and eastern halves of the United States, ozone reduces yields of economically important crops by from 1 to 20 percent, compared to yields that would be expected if natural background concentrations were not exceeded [10]. Analyses performed for OTA show that annual agricultural benefits in the range of $500 million to $1 billion (1986$) would be expected to result from increased productivity of major crops, if ozone concentrations throughout the country were reduced by 25 percent of the difference between current and background levels [1,21]. These benefits include lower prices for consumers, and increased profits for crop producers in at least some parts of the country. Crop producers in California, the South, and the Northeast would be most apt to benefit from nationwide reductions in ozone, as current concentrations are highest in these areas.

Severe damage to ponderosa and Jeffrey pines in southern California forests, and foliar injury and growth reductions in sensitive strains of eastern white pine, have been clearly linked to exposure to ozone. Ozone has been hypothesized as partially responsible for declines of other tree species that have been observed in the Eastern United States, southern Canada, and Europe. In several cases, the location and timing of the declines suggest that air pollutants might have played a role. In controlled experiments, ozone has been shown to produce foliar injury and/or reduce growth rates in young trees of numerous species.

The forest-related benefits of reducing ozone concentrations cannot currently be estimated. Exposure-response information for major annual crops was developed through research coordinated by an 8-year program, the National Crop Loss Assessment Network. Research on exposure-response relationships for trees is being conducted under the National Acid Precipitation Assessment Program, and a new 10-year effort was established by the Forest Ecosystems and Atmospheric Pollution Research Act of the 100th Congress. However, developing exposure-response information for trees is more difficult and takes longer than for crops, due to the comparatively slow growth and long lifetimes of trees, and to complicating factors in their natural settings.

This chapter first shows the magnitude of ozone concentrations at rural locations across the United States. Then, current understanding of the effects of ozone on trees is reviewed, and the major cases in which ozone has been suggested as a cause of decline are discussed. Finally, the effects of ozone on crops are reviewed, and new estimates of the agricultural benefits of reducing ozone presented.

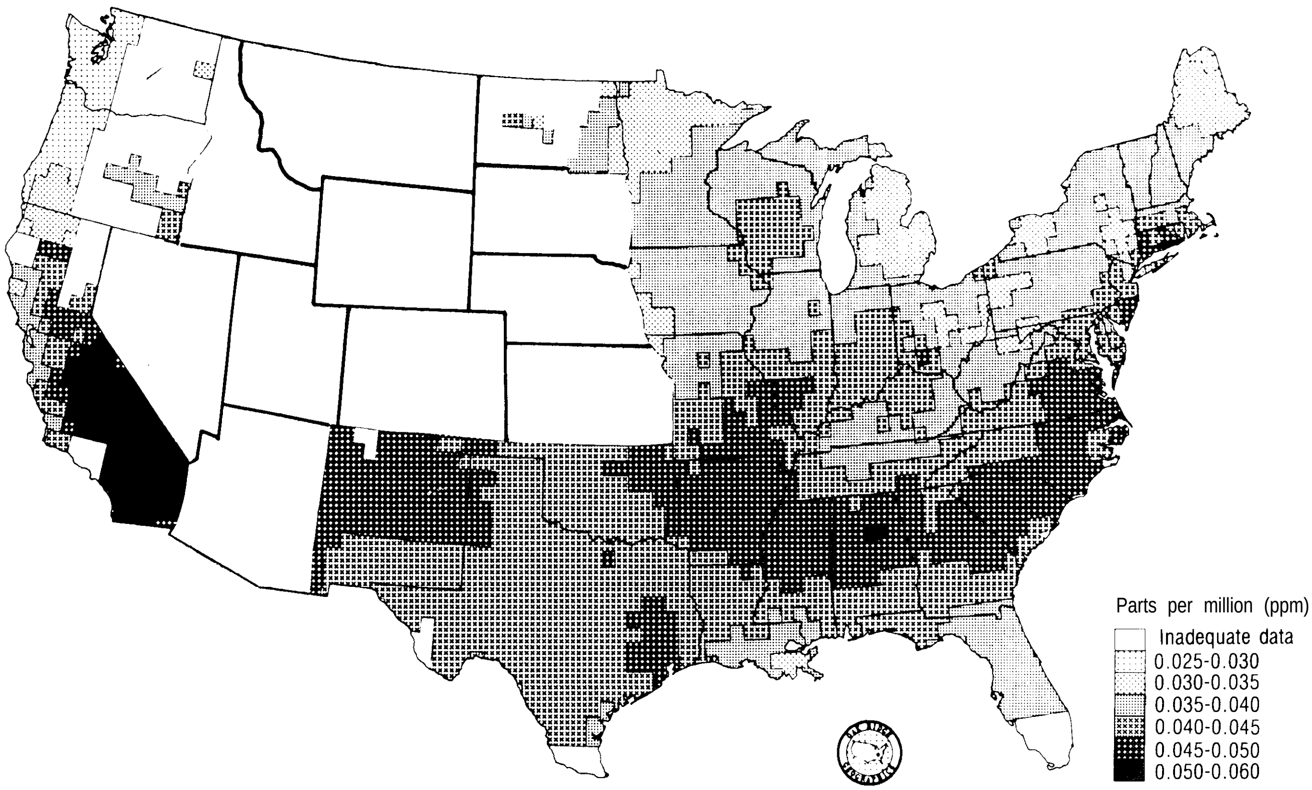
CONCENTRATIONS OF OZONE IN RURAL AREAS

Figure 4-1 shows estimated daily 7-hour average (9 a.m. to 4 p.m.) ozone concentrations averaged over the months April to October and the years 1978-82 [28].[1] For comparison, the natural background value of the statistic shown is estimated to be on the order of 0.030 parts per million (ppm), although this value is highly uncertain [23]. Figure 4-1 was prepared by interpolating data from over 300 selected monitors, generally including suburban monitors but excluding those at urban sites. Because this chapter addresses the effect of ozone on crops and forests, figure 4-1 also shows where rural monitors are located [26]. There are fewer than 100 ozone monitors located at rural sites across the United States, and a number of States do not have any. Because the reliability of a concentration estimate is extremely sensitive to the density of monitoring sites in the area, no estimates are shown for most Western States,

Ozone concentrations vary from one growing season to another as a consequence of year-to-year differences in weather patterns. An analysis of ozone data from the years 1978-83, for forested subregions of the Eastern United States, gives an indication of

[1] Recent studies have suggested that for many crops, a measure of cumulative exposure to ozone would be a better measure of exposure than the 7-hour seasonal average ozone concentration [44]. However, the 7-hour seasonal average concentration has been reported most often.

Figure 4-1-Estimated Daily 7-hour Average Ozone Concentrations During the Growing Season



Location of **Rural Ozone Monitors**

Daily 7-hour daytime ozone concentrations are average over the months April through October and the years 1978-82. The lower map shows the location of rural ozone monitors in 1984.

SOURCE: a) Adapted from R.J. Olson, L.J. Allison, and I.L. McCullough, Addnet *Notebook: Documentation of the Acid Deposition Data Network (ADDNET) Data Base Supporting the National Add Precipitation Assessment Program,* Environmental Sciences Division publication no. 2755 (Oak Ridge, TN: Oak Ridge National Laboratory, August 1987). b) Adapted from National Acid Precipation Assessment Program, *Interim Assessment: The Causes and Effects of Acidic Deposition, vol.* III (Washington, DC: October 1987).

how much April to October, daily 7-hour average concentrations change from one year to the next [32]. Data from major cities were excluded from the analysis. As examples, during the 6-year period concentrations averaged over sites in the upper Great Lakes region (northeastern Minnesota, northern Wisconsin, and northern Michigan) ranged year to year from 0.035 to 0.043 ppm; and concentrations averaged over sites in Pennsylvania, New York and western Maryland ranged year to year from 0.036 to 0.042 ppm. Concentrations for individual sites varied more than these multi-state averages: concentrations at Whiteface Mountain, NY, ranged from 0.037 to 0.049 ppm, for example.

POTENTIAL EFFECTS OF OZONE ON FORESTS

Exposure to ozone has been suggested as a factor in several confirmed or reported cases of tree species decline in the United States, Canada, and Europe. In two cases-the decline of ponderosa and Jeffrey pines in the San Bernardino Mountains east of Los Angeles, and the decline of sensitive strains of eastern white pine trees throughout the Eastern United States-exposure to ozone has been established as a primary cause.

Ozone-induced injury in trees shows up primarily as foliar injury, including leaf or needle discoloration and premature loss. In advanced cases, needles or leaves and then branches of injured trees die back. For example, ozone injury to eastern white pine needles appears as a "chlorotic" or yellow mottle, with needles ultimately dying back from the tips. Reduced growth rates may precede or follow foliar injury. Increased susceptibility to diseases and other stresses may result from reduced photosynthesis and decreased allocation of carbohydrates to tree roots [34]. Ultimately trees may die prematurely. All of these effects have been observed in forests of the San Bernardino Mountains as a result of exposure to high concentrations of ozone originating from NO_x and VOC emissions in the Los Angeles basin. In addition to trees, ozone injures a variety of other plants that occur in forest ecosystems. Examples include wild grape, blackberry, milkweed and poison ivy [30,42].

Some of the symptoms of exposure to ozone can also have other causes. And inmost cases of decline, it is likely that multiple stresses contribute, so it is difficult to sort out primary causes and even tougher to predict the gains that might be made if one stress is mitigated. Controlled exposure studies indicate that seedlings of many species are sensitive to ozone. However, the responses observed in studies conducted to isolate the effects of ozone do not always match symptoms observed in natural environments. Moreover, for the most part, programs to monitor air pollution levels at forest sites where injury has been observed, and controlled studies of the effects of ozone on mature trees, are only now being initiated. So, although exposure to ozone has been suggested as an explanation for several declines, in most of these cases scientists have not yet established whether or not ozone is in fact, an important contributor.

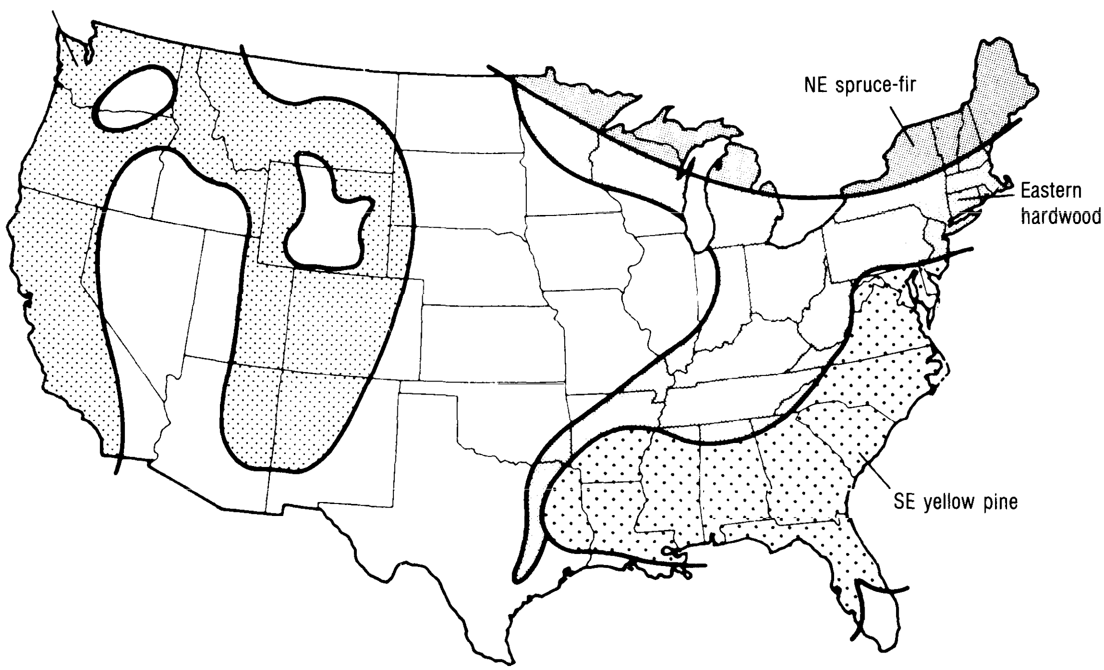
Figure 4-2 shows the major forested areas of the United States, and identifies the dominant types of trees in each area. Comparing figure 4-2 with figure 4-1 indicates that elevated ozone concentrations are generally present in the western conifer region of California, and the eastern hardwood and southeastern yellow pine regions. Below, we discuss whether ozone is contributing to major declines in each of these areas of the United States, as well as to widespread damage in Central European forests.

Ponderosa and Jeffrey Pine Trees in the San Bernardino National Forest and Other Locations in California

Ozone is generally held to be the principal cause of visible injury and accelerated mortality of ponderosa and Jeffrey pine trees in the San Bernardino and San Gabriel Mountains of southern California. White fir, incense cedar, and California black oak trees have also been affected, but are less sensitive than the pines. The symptoms observed in the forests have been duplicated in controlled exposure studies. At some sites in the San Bernardino National Forest east of Los Angeles, daytime (14 hour) average ozone concentrations of 0.10 ppm are typical during June, July, and August [26]. The decline of ponderosa and Jeffrey pine there has been so severe that if current trends persist, incense cedar and white fir are expected to replace them as dominant species [25].

The National Park Service has reported extensive ozone injury in national parks in California [42]. Average summer, daytime ozone concentrations at some sites along the western slopes of the Sierra Nevada, including a site in western Sequoia National Park, range from 0.060 to 0.085 ppm [31]. Over 75 percent of the ponderosa and Jeffrey pine trees surveyed at the western border of Sequoia National Park in 1984 showed foliar injury attributed to ozone [42], with associated growth reductions in Jeffrey pine trees [31]. Foliar symptoms that match symptoms of ozone exposure have been observed on giant sequoia seedlings in Sequoia National Park, as well [41]. Injury to ponderosa and Jeffrey pines has also been documented in Yosemite National Park [42].

Figure 4-2-Major Forested Areas and Dominant Tree Types of the United States



SOURCE: National Acid Precipitation Assessment Program, *Interim Assessment: The Causes and Effects of Acidic Deposition*, vol. IV (Washington, DC: October 1987).

Sensitive Strains of White Pine Trees in the Eastern United States

Foliar injury, reduced growth rates, and increased mortality due to exposure to ozone are apparent in some eastern white pine trees throughout the Eastern United States.[2] Symptoms of ozone injury have been observed in some eastern white pine trees in Acadia and Great Smoky Mountains National Parks [42]. Controlled exposure studies and field studies support the hypothesis that concentrations of ozone observed throughout the East are high enough to injure the most sensitive white pine trees (as with other species of trees, not all strains of white pine are equally sensitive to ozone) [45]. Reductions in growth rates have been shown to be positively correlated with the degree of foliar injury in individual trees [5]. Preliminary evidence in Great Smoky Mountains National Park suggests that the most sensitive strains of eastern white pine may be disappearing [42]. However, considering all eastern white pines, not just sensitive strains, regionwide reductions in productivity have not been observed [4].

Red Spruce Trees at High-Elevation Sites in the Eastern United States

Reductions in radial growth rates, dieback, and increased mortality have been observed in red spruce trees at high-elevation sites in the northern Appalachian Mountains of New York and New England and the southern Appalachians of North Carolina, Tennessee, Virginia, and West Virginia [26].[3] The populations of red spruce trees in some high-elevation forests in the Northeast have declined by 40 percent to over 70 percent since the mid 1960s, and the decline is continuing [16]. Red spruce mortality in the southern Appalachians is much lower, within normal limits for high-elevation forests [9]. Different foliar symptoms are observed in northern and southern trees, suggesting that different factors must be involved. Less severe foliar injury,

[2] The eastern white pine ecosystem comprises about 10 percent of the forested area in the Northeast, and less than 1 percent in the Southeast [39].

[3] "High-elevation" refers t. sites above about 2,500 feet in the Northeast and above about 5,800 feet in the Southeast.

Photo credit: U.S. Depertmenf of Agriculture

Above photograph shows a stand of ponderosa pine trees. Ozone is generally held to be the principal cause of visible injury and accelerated mortality of ponderosa and Jeffrey pine trees in the San Bernardino and San Gabriel Mountains of southern California.

mortality, and growth reductions have also been observed in red spruce trees at low elevations in the Northeast [26]. The growth reductions observed at most low-elevation sites are thought by some scientists to be consistent with natural-trends associated with aging [12].

It is not clear which stresses are responsible for the decline of high-elevation red spruce, and it is likely that more than one factor is involved. Scientists have noted that soil and climate conditions at high elevations are often marginal for red spruce. They suggest that under these marginal conditions, increased pollution levels, winter damage and/or drought that have occurred since the 1960s could be pushing the trees into decline [16].

Heavy mortality from pest infestation (by the balsam woolly adelgid) and unexplained reductions in growth rates have occurred in Fraser fir trees that are mixed with red spruce at high-elevation sites in the southern Appalachians [12,9]. Although the balsam woolly adelgid does not affect red spruce directly, it has been suggested that heavy Fraser fir mortality leaves co-occurring red spruce more exposed to harsh climatic conditions at high elevations [9]. Balsam woolly adelgid infestation is not a particularly severe problem in the Northeast.

Air pollution has been considered as a possible cause of red spruce decline in high-elevation forests because no insects and diseases are ubiquitous (although various pathogens are present at different sites), and because the affected forests are exposed to high concentrations of ozone and other gaseous air pollutants, and to strongly acidic cloud water. However, the question of whether exposure to high pollutant levels has actually damaged red spruce is still under study. In the Eastern United States, water carried by the clouds intercepted by high-elevation forests is up to 100 times more acidic than "clean" rainwater, and some high-elevation sites are shrouded in clouds up to 40 percent of the time [26]. For two reasons, forests at high elevations are also likely to be exposed to more ozone than nearby low-elevation forests. First, nighttime and early morning ozone concentrations are often much greater at high-elevation sites in rural or remote areas than concentrations measured at adjacent sites at lower elevations.[4] Second, the frequent presence of clouds and consequent high humidity enhances ozone uptake through leaves and needles [26].

Yellow Pine Trees in the Southeastern United States

The southeastern part of the United States is a major timber-producing region, containing 20 percent of the Nation's commercial softwood. More importantly, the region typically contributes about half of the Nation's annual growth in softwood stocks [40]. To illustrate the importance of southern softwood, hypothetical simulations have been performed with a model used by the U.S. Forest Service to project future timber resources. The simulations suggest that a 15-percent reduction in growth rates throughout the Southeast would reduce softwood stocks in the contiguous United States by almost 10 percent after 25 years, and by about 15 percent in 45 years, compared to a base case with no growth rate reductions [8]. The study estimated that a 15-percent reduction in growth rates of eastern softwoods would cost the Nation about $500 million per year. (The Southeast accounts for about 60 percent of the softwood trees grown in the East.)

Southern softwood production is dominated by yellow pine varieties such as loblolly and shortleaf. In Florida, Georgia, North Carolina, South Carolina, and Virginia, radial growth rates of yellow pine trees in natural stands (which comprise about 70 percent of the yellow pine forests in these States) have been reduced by up to 50 percent compared to rates observed in the late 1950s [38]. The causes of the widespread growth reductions, which have occurred without visible injury, have not been definitely established. However, drought, the natural aging of the stands, and increased competition from hardwoods, are all thought to be involved. Root rot pathogens have been shown to cause growth reductions in loblolly pine [7], in some cases without apparent symptoms. Exposure to air pollution may be a contributing stress. Recent studies using controlled exposures have shown that ozone injures needles and reduces growth of loblolly pine seedlings [11,35,19,36,37]. However, additional research is needed to determine whether ozone is involved in the reductions in growth rates that have been observed in mature trees in the field.

Sugar Maple Trees in Pennsylvania, New York, New England, and Southeastern Canada

Dieback of tree crowns and elevated mortality rates became apparent in stands of sugar maple and associated hardwoods at some locations in southeastern Canada in the late 1970s. A 1985 survey indicated that 40 percent of the area of the sugar maple forests in Quebec had some foliar injury, with associated growth reductions in cases of moderate to severe injury [26]. Injury to sugar maples has been noticed more recently in the Northeastern United States. Pest infestation or disease are apparent causes in all of the cases in this country, although some of the cases in Canada have not been explained [26]. Air pollution has been suggested as a contributing factor. Recent experiments conducted in chambers have indicated that exposure to ozone reduced growth rates of sugar maple seedlings without

[4] After sunset, when ozone production ceases, ground-level ozone concentrations fall off as the pollutant is deposited onto vegetation or the ground. In layers of air hundreds of yards above the ground, however, deposition is not a factor, and ozone concentrations can remain high. Where ridges or hill tops intercept pollution carried aloft, high-elevation forests can be exposed to high concentrations of ozone at night.

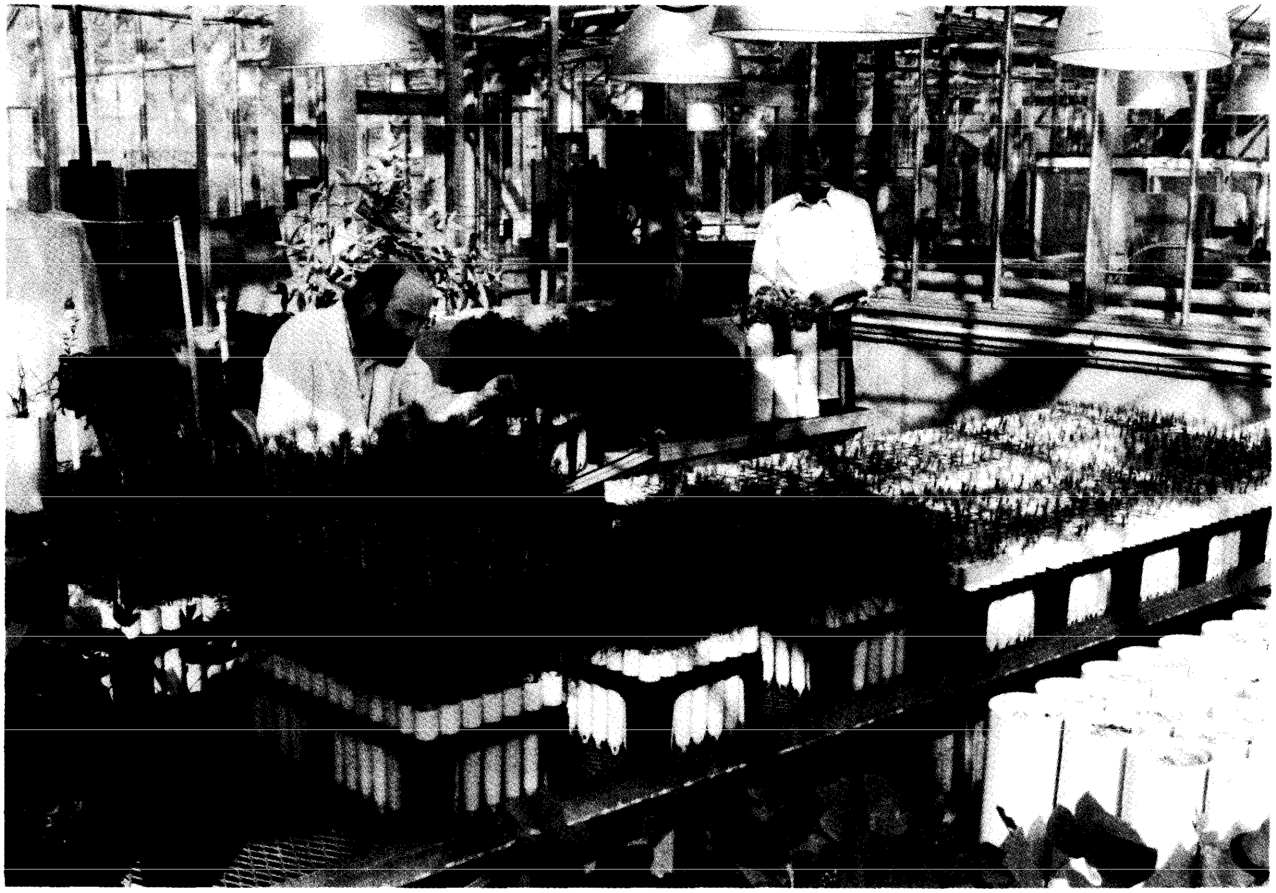


Photo credit: Grady Neely, Environmental Research Laboratory, U.S. Environmental Protection Agency, Corvallis, OR

Two scientists inspecting yellow-poplars and slash pine for sensitivity to, and symptoms of damage from, ozone exposure under controlled experimental conditions.

observable foliar injury [15]. However, no reduction in regionwide average growth rates of sugar maples has been observed in the United States [13].

European Forests

Forest survey data indicate that 15 percent of the conifers in 17 European countries have lost more needles than normal (i.e., more than 25 percent), and that 17 percent of the deciduous trees have lost more leaves than normal (i.e., more than 10 percent) [27]. Although damage to trees in Europe is popularly attributed to air pollution, other factors are understood to contribute, including climate, soil conditions, and stand aging.

At least in West Germany, the country with the longest forest survey record, the extent of damage appears to have stabilized. Since 1984, the overall percentage of trees in West Germany with more than 25 percent foliar loss has held constant at about 18 percent. In fact, the condition of some species, and of trees in some regions, has improved [6].

The most significantly affected species in central Europe is Norway spruce, which comprises about 40 percent of central European forests. Needle chlorosis associated with magnesium deficiency in foliage and soils is the most prominent symptom observed in Nonway spruce growing at high elevations, while thinning of tree crowns is the main symptom observed at lower elevations [33]. Poor soil conditions and magnesium deficiency have also been observed in association with chlorosis in Norway spruce at some sites in the United States [17].

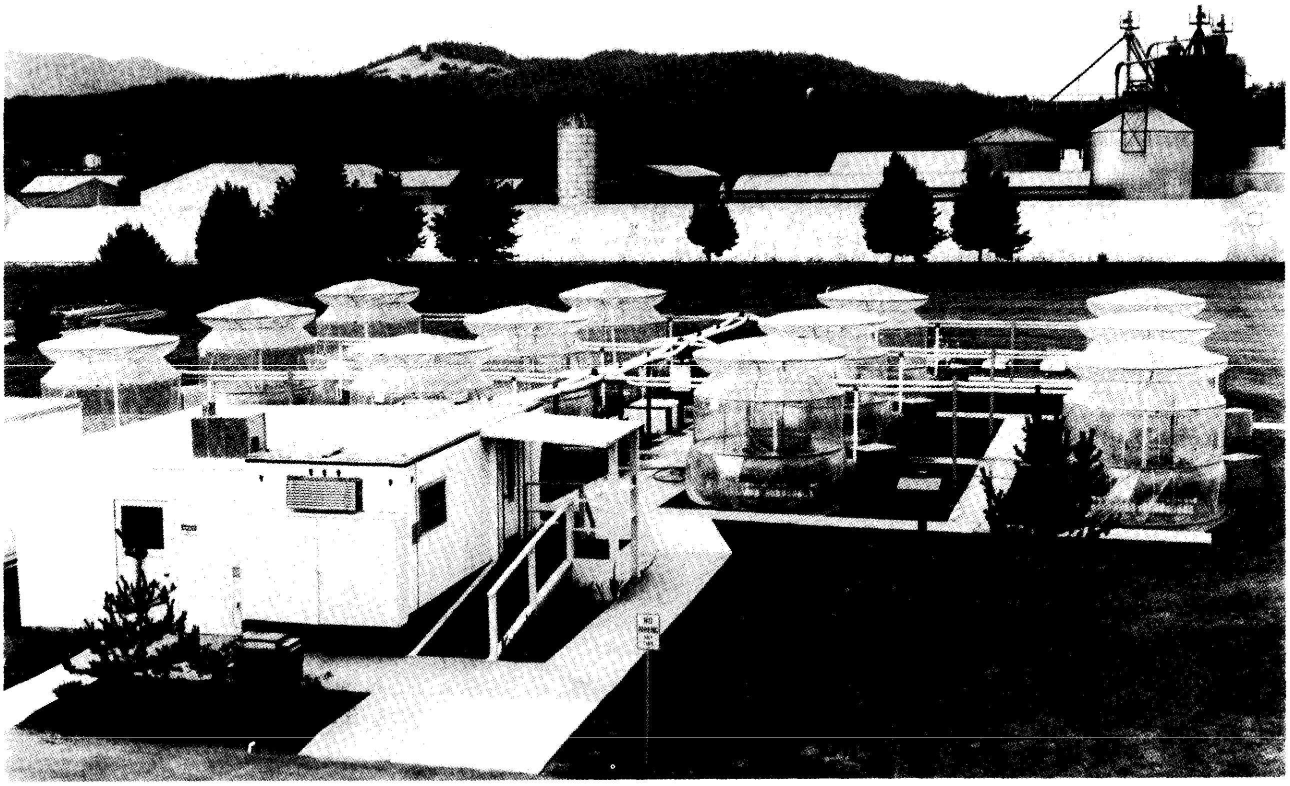


Photo credit: Grady Neely, Environmental Research Laboratory, US. Environmental Protection Agency, Corvallis, OR

Outdoor exposure chambers are used to study the effects of ozone on various crop and tree species under controlled experimental conditions.

One hypothesis that has been suggested to explain the chlorotic symptoms of high-elevation Norway spruce was that chronic exposure to ozone might damage cell membranes, exacerbating nutrient losses, which might also be occurring due to the leaching action of acidic deposition. If uptake from the soil was inadequate to replenish essential nutrients, damage might result [33]. However, laboratory studies testing this hypothesis have not reproduced the symptoms observed in the field, and some scientists now discount it [6].

EFFECTS OF *OZONE ON* CROPS

In annual crops, visible symptoms of exposure to ozone typically include light flecks, dark stipples, and yellow spots or patches on leaves. Chronic exposure to ozone can induce premature aging and loss of foliage. The minimum concentrations of ozone that produce acute foliar injury in susceptible plants exposed for 4 hours range from 0.04 to 0.09 ppmn, depending on the plant species [14]. Among other environmental factors, light conditions, temperature, relative humidity, and soil water content affect how plants respond to ozone exposures.

For field and cash crops, the most important responses to ozone are reduced growth rates and yields. These effects may occur without the visible injury usually associated with exposure to ozone, but they are often accompanied by premature loss of foliage. Reduced growth and yields result primarily from reduced photosynthesis and transport of carbohydrates within plants. Table 4-1 displays reductions in yields predicted to occur for various crops exposed over the growing season to average daily 7-hour mean ozone concentrations of 0.04 and 0.06 ppm [43]. The predictions are from the National Crop Loss Assessment Network (NCLAN), an 8-year study in which crops were grown in the field

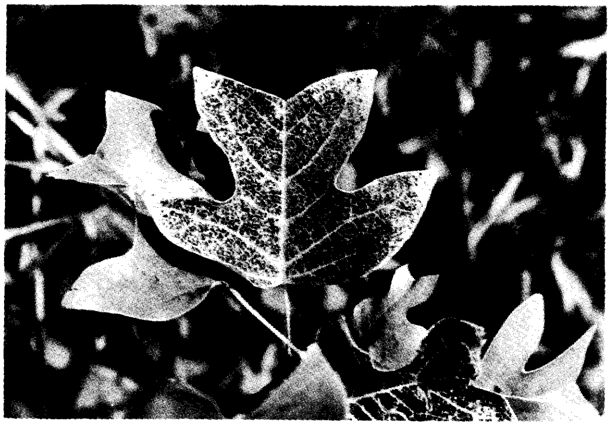


Photo credit: U.S. Department of Agriculture

Dark pigmented stipple on upper surface and general chlorosis of yellow-poplar leaves exposed to ozone.

either in ambient air, air that had been filtered to remove ozone, or air to which extra ozone had been added. The reductions shown in the table are relative to the yields obtained for crops exposed to assumed background ozone concentrations. The range of reductions given for each crop indicates differences among varieties. In addition to the major crops listed in table 4-1, yield reductions have been seen with a wide variety of other crops including alfalfa, clover, sorghum, barley, dry bean, root crops, tomatoes, spinach, lettuce, and other produce.

Figure 4-3 shows State-level production of each of the four crops listed in table 4-1. As shown in figure 4-1, daytime, growing-season average concentrations of 0.04 ppm were widely exceeded over the 1978-82 period, and a few locations saw concentrations higher than 0.06 ppm. Due to year-to-year variability in weather, concentrations at a given site would be higher in some years and lower in others, if data for individual years were shown [32]. Elevated ozone concentrations throughout the South may damage cotton. The major soybean-producing regions of the Mississippi and Ohio River valleys and corn-producing regions throughout the eastern half of the United States are also exposed. Unfortunately, only scant ozone data are available for most areas where wheat is grown.

Table 4-l-Yield Losses Predicted to Occur for Seasonal Average 7-hour Mean Ozone Concentrations of 0.04 and 0.06 ppm

Crop	0.04 ppm ozone percent yield reduction	0.06 ppm ozone percent yield reduction
Cotton	4.6 to 16	16 to 35
Wheat	0.0 to 29	0.9 to 51
Soybeans	1.7 to 15	5.3 to 24
Corn	0.0 to 1.4	0.3 to 5.1

NOTE: As shown in figure 4-1, the 0.04 ppm level exceeded overlarge portions of the southern and Eastern United States. The 0.06 ppm level is more extreme, with few areas having multi-year averages that reach it.

SOURCE: U.S. Environmental Protection Agency, Office of Air Quality Planning and Assessment "Review of the National Ambient Air Quality Standards for Ozone Preliminary Assessment of Scientific and Technical Information," draft staff paper (Research Triangle Park, NC: November 1987).

Economic Estimates of Agricultural Benefits

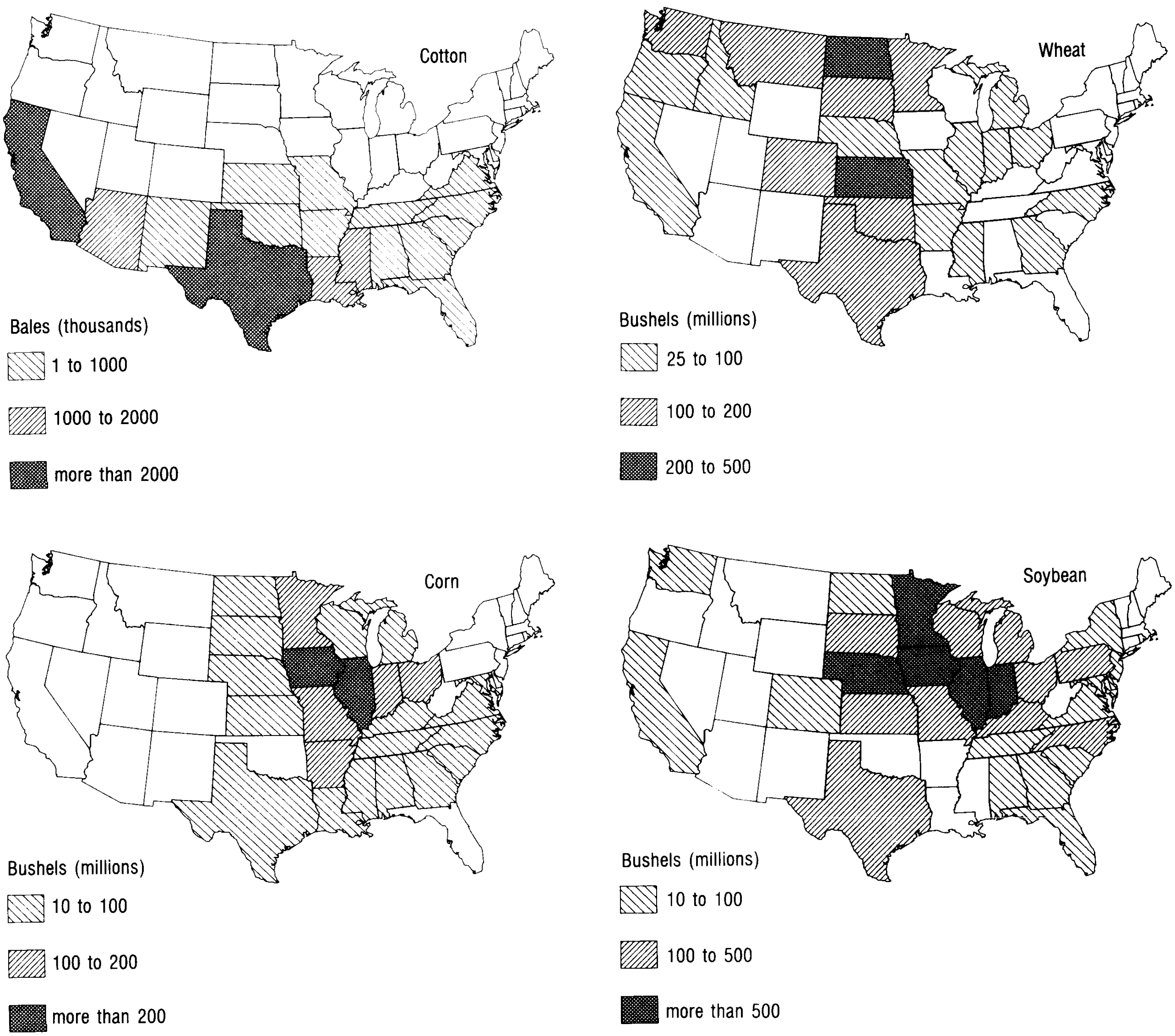
By using relationships between ozone levels and crop yields estimated from the NCLAN experiments, together with models of the Nation's agricultural economy, it is possible to estimate how much crop producers and consumers would benefit from reducing ozone. If ozone concentrations were reduced, crop yields would increase and prices fall, benefiting consumers (and some livestock producers). Crop producers' profits could either rise or fall, depending on whether local yield increases reduced their unit production costs enough to offset the lower prices they would receive. Crop producers in areas where ozone concentrations are currently highest would benefit the most from nationwide reductions, or conversely continue to incur the largest losses if concentrations are not reduced.

In this section we present estimates of the agricultural benefits of a range of plausible reductions in ozone, based on models developed by two different groups of researchers (21,1). At present, it is not possible to reliably predict the impact that VOC and NO_x control measures would have on ozone concentrations in rural areas. So, for the purposes of this analysis, we assume that currently available control measures could reduce rural ozone concentrations by some amount between 10 and 50 percent of the way to an estimated background concentration of 0.030 ppm.[5]

The two models used to estimate agricultural benefits for this report use different exposure-

[5]This estimate is based on surface measurements at rural cites in Canada [23]. The appropriate concentration to use for background is very uncertain, so calculations were performed to investigate the sensitivity of the benefits estimates to this parameter.

Figure 4-3-1984 Crop Production at the State Level



SOURCE: U.S. Department of Agriculture, Agricultural Statistics 1965 (Washington, DC: U.S. Government Printing Office, January 1980).

response functions (mathematical expressions of the relationship between ozone concentrations and crop yields) and economic parameters, and base case ozone concentrations from different years. They also adopt different assumptions about how farmers will change the number of acres of each crop that they plant in order to optimize their operations, as crop prices decline in response to higher yields and increased production.

Agricultural Benefits of Reducing Ozone By 10 to 50 *Percent*

Estimates of agricultural benefits associated with reductions in ozone of 10, 25, and 50 percent of the difference between base levels and background, are given in table 4-2. Both sets of estimates include benefits associated with corn, soybean, wheat, cotton, barley, alfalfa, and sorghum production and

Table 4-2-Estimates of Agricultural Benefits That Would Result Under Market Conditions, if Ozone Concentrations Ware To Be Reduced Nationwide by the indicated Amounts Relative to a Background Concentration of 0.03 ppm

Ozone reduction	Krupnick and Kopp ($ millions [19861)	Adams and Glyer ($ millions [19861)
10%	230	390
25%	540	990
50%	10%	1910

SOURCES: A.J. Krupnick and R.J. Kopp, The *Health and Agricultural Benefits of Reductions in Ambient Ozone in the United States,* contractor report prepared for the Office of Technology Assessment, June 1988. R.M. Adams and J.D. Glyer, An Assessment *of the Agricultural Benefits of Tropospheric Ozone Reductions Using Office of Technology Assessment (OTA) Assumptions,* contractor report prepared for the Office of Technology Assessment, August 1988.

consumption. Krupnick and Kopp’s estimates also include benefits for oats and peanuts. Adams and Glyer’s estimates additionally include benefits for grass-legume hay and rice. Crops that are important in limited areas, like citrus fruit and produce grown in Florida and California, were not included.[6]

As shown in table 4-2, the estimates of total benefits range from $230 million per year for a 10 percent reduction in ozone to about $1.9 billion per year for a 50 percent reduction.[7] In all cases, corn, soybeans, wheat, and cotton account for over 90 percent of the total benefits. At each reduction level, Adams and Glyer’s estimates of total benefits are almost double Krupnick and Kopp’s estimates. An important result predicted by Krupnick and Kopp is that on a nationwide basis, crop producers might suffer a net loss due to lower prices, if ozone concentrations are reduced. Adams and Glyer’s model lumps livestock producers (who benefit from reduced feed prices) together with crop producers, and predicts that together they would benefit. It is not possible to separate crop producers from livestock producers, in Adams and Glyer’s model.

Underlying the nationwide estimates are benefits to crop producers that vary by region. The largest improvements in yields in both analyses occur in California, the South, and the Northeast, where ozone concentrations in agricultural areas are currently highest. Accordingly, crop producers in these areas would benefit the most from reducing ozone. For the 25-percent reduction scenario, for example, in Adams and Glyer’s analysis, corn yields increase by about 3 percent or more in California and in some Northeastern States, whereas in some Midwestern States, corn yields increase by half a percent or less.

The first reason for the discrepancy between Adams and Glyer’s and Krupnick and Kopp’s results is the different changes in yields that are predicted in the two analyses, due to their use of different baseline ozone concentrations and different exposure-response functions. Comparing them on a State-by-State basis, for the 25-percent reduction scenario, the yield changes for corn tend to be about 3 times larger, for cotton and wheat about 2 times larger, and for soybeans about 2.5 times larger, in Adams and Glyer’s analysis than in Krupnick and Kopp’s. Baseline ozone concentrations were generally higher (uncertainties in the baseline ozone concentrations are discussed in a subsequent section), and crop yields more sensitive to ozone (as shown for corn in figure 4-4), in Adams and Glyer’s analysis than in Krupnick and Kopp’s.

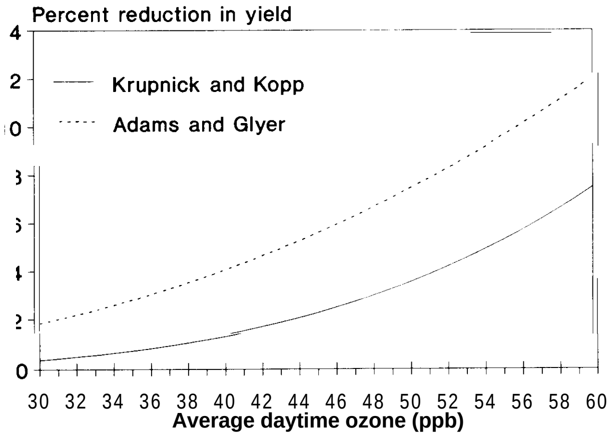
The exposure-response functions used by Krupnick and Kopp were estimated by averaging results from NCLAN experiments conducted through 1982. Additional experiments conducted by NCLAN through 1986 were also averaged into the exposure-response functions used by Adams and Glyer. Some of the crop varieties used in the later experiments were apparently more sensitive to changes in ozone concentrations than those tested earlier [20]. Incorporating the more recent data, the exposure-response functions used by Adams and Glyer represent a broader sample of the crop varieties grown in the United States than those used by Krupnick and Kopp. However, it is not clear how

[6] Yield losses due to ozone at current levels may be significant for some of these crops. For example, yield reductions of almost 20 percent are estimated for California oranges, grapes, and lemons, compared to yields with 12-hour seasonal average ozone concentrations of 0.025 ppm [29].

[7] Previous analyses have estimated that if ozone concentrations in rural areas were reduced by a straight 25 percent, without adjusting for background ozone, total benefits would be on the order of $2 billion per year [3,18,2]. The estimates of the benefits of reductions above a 0.030 ppm background given here are roughly consistent with previous estimates, since ozone is reduced by smaller absolute amounts in our scenarios. For example, for an initial ozone concentration of 0.045 ppm, the change in the ozone concentration corresponding to a straight 25-percent reduction would be three times larger than that corresponding to a reduction of 25 percent of the way to a background concentration of 0.030 ppm.

[8] Adams and Glyer [1] used base case ozone concentrations averaged over the period 19 81-83. Krupnick and Kopp [21] used concentrations averaged over the period 1979-82.

Figure 4-4—Dose-Response Functions for Corn Used in the Two Agricultural Benefits Analyses Performed for OTA



The dose-response function used by Krupnick and Kopp was estimated from experiments conducted by the National Crop Loss Assessment Network through 1981. The function used by Adams and Glyer was estimated from experiments conducted through **1986.**

SOURCE: A.J. Krupnick and R.J. Kopp, The *Health and Agricultural Benefits of Reductions In Ambient Ozone in the United States,* contractor report prepared for the Office of Technology Assessment, June 19S8; and R.M. Adams and J.D. Glyer, An Assessment *of the Agricultural Benefits of Tropospheric Ozone Reductions Using Office of Technology Assessment (OTA) Assumptions,* contractor report prepared for the Office of Technology Assessment August 19SS.

well the exposure-response functions used by either group represent the average responses of the actual mix of varieties planted by farmers.

The structure and assumptions of the economic components of their models is also a reason for discrepancy between Adams and Glyer's and Kopp and Krupnick's results. First, Adams and Glyer's model is based on economic conditions for the 1981-83 period, whereas Krupnick and Kopp's model reflects the target price provisions established by the Food Security Act of 1985 for crops grown in 1986.[9] Incorporating 1986 target prices into Adams and Glyer's analysis reduces their total benefits by about 10 percent, to $880 million.

Finally, as ozone concentrations are reduced and crop prices tend to decline in response to higher yields, Adams and Glyer assume that farmers would change the number of acres sown with each crop to maximize their profits under the new conditions. Krupnick and Kopp assume that planted acreage would stay constant at 1986 (base case) levels. Krupnick and Kopp's assumption seems reasonable in the short term, before a steady trend in market prices is observable. So the prediction that producers would not gain from reducing ozone seems to be reasonable for the first few years after ozone concentrations are reduced. Adams and Glyer's assumption that farmers will eventually adjust their acreage seems more reasonable as a prediction of what would occur after several years if ozone concentrations remain low.

Agricultural Benefits Under Current Price Support Programs

In order to stabilize supplies and prices, and to supplement farmers' incomes, the Federal Government currently pays farmers the difference between the price they obtain on the market and a higher ''target" price established by law, for several major crops. The target prices encourage surplus production, at some expense to society because the cost of producing the surplus exceeds its value. Increased yields due to reduced ozone can be viewed as adding to the surplus, and some economists argue that the benefits estimates presented in the previous section need to be adjusted for this effect. Given 1986 target prices, and adjusting the benefits estimates to account for the loss to society associated with surplus production, Krupnick and Kopp estimate that for corn, cotton, soybeans, and wheat, the benefits of the 25-percent reduction scenario would be $380 million, about 20 percent lower than the benefits associated with those four crops when the cost of the surplus is not taken into account. However, others argue that subsidy programs could be adjusted to reflect the yield changes, so that surpluses would not necessarily increase above desirable levels [24].

Sensitivity of Benefits to Uncertainty in Ozone Concentrations in Agricultural Areas

An important source of uncertainty in agricultural benefits is the estimation of current ozone concentrations in areas across the country where crop production takes place. Baseline ozone concentrations are estimated by extrapolating from both suburban and rural monitors to agricultural areas. Unfortunately,

[9] In order to stabilize supplies and prices, and to supplement farmers' incomes, the Federal Government currently pays farmers the difference between the price they obtain on the market and a higher 'target" price established by law, for several major crops.

in many States, appropriate data are only available from one or two monitors, and significant errors are apt to be introduced by extrapolating from these data [22]. The natural background concentration of ozone is also uncertain, because it cannot be measured anywhere—areas that are similar to the continental United States are invariably affected by human activity. When the benefits of a 25-percent reduction in ozone were recalculated with 0.005 ppm either uniformly added to or subtracted from the baseline concentrations, the total benefits were correspondingly increased or reduced by about 50 percent. A similar degree of sensitivity to the assumed background ozone concentration was found.

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