Determining crop yield losses from air pollutants

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Measurements in field chambers reveal losses to pollution

Air pollution is a major stress causing yield losses in California crops. Statewide monitoring indicates that ozone, the main component of air pollution, is transported from urban to agricultural areas, many of which lie within or near high-ozone regions. The South Coast Air Basin (Los Angeles area) typically has the highest ozone concentrations in the state, although the San Francsico Bay and Fresno areas can also develop significant levels.

Many crops are sensitive to ozone, showing reduced yield and quality when exposed to pollutants. Early assessments of yield losses used visible injury symptoms on leaves to estimate the effect of pollutants. Visible symptoms are not reliable, however, because growth effects may occur in the absence of visible injury. Leafy crops are an exception, since visible injury directly affects marketability and might be used for loss estimation. In recent years, several methods have been used successfully for rough estimates of crop yield losses due to air pollutants.

In 1971, the Statewide Air Pollution Research Center at the University of California, Riverside, entered into a cooperative agreement with the California Department of Food and Agriculture (CDFA) to identify and assess the effect of air pollutants on California agriculture. Early research included the use of bioindicator plants and field plots within specific regions of the South Coast Air Basin that received differing amounts of atmospheric pollutants throughout the year. Plants grown throughout the basin were therefore exposed to a gradient of pollutant doses. Injury, growth, yield, and quality of crops grown in these plots were related to the pollutant dose level at each site, resulting in dose response regression equations. The differences in temperature, solar radiation, and relative humidity were statistically removed to enable development of loss functions.

Current crop loss assessment

In 1981, to reduce site-to-site variability and reduce travel and maintenance costs, the yield-loss assessment program built a single-site gradient facility at the UC Riverside Citrus Research Center. The 18-chamber field fumigation facility consists of 8-foot diameter, 7.5-foot-high octagonal chambers covered with Teflon film and has a closed top to exclude atmospheric pollutants outside the chambers. All 18 chambers are connected by a common air-handling system, which delivers both charcoal-filtered and unfiltered air. Regulating the proportions of filtered and unfiltered air in individual chambers results in a gradient of concentrations of atmospheric pollutants.

Plants grown in the chambers are exposed to different pollutant doses, but without the differences in temperature, relative humidity, and solar radiation that occur at separate field locations. Crops are grown inside the chambers in a common soil with standard field cropping methods. Environmental conditions inside the chambers are similar to those in the widely used open-top chambers and are closer to the outside atmosphere than greenhouse fumigation chambers. Chamber yield and chamber pollutant dose are used to produce a regression equation of yield as related to dose.

Dose-response equations are converted to a percentage of crop reduction relative to a specific dose and compiled in a manual for distribution to county agricultural commissioners and other interested individuals. Pollutant dose levels from agricultural regions of California can be used with the loss equations to determine the

Visible signs of pollutant injury to leaves of some crops are not a reliable measure of yield loss, because growth effects may occur in the absence of visible damage.

Regulating the proportions of filtered and unfiltered air in individual octagonal closed-top chambers permitted varying concentrations of atmospheric pollutants.

estimated yield loss due to pollutants in that specific area. Yield-loss functions can also be used in each region for economic assessment, land use planning, and development of appropriate air quality criteria. Yield-loss functions generated from the chamber fumigation facility are added as supplements to the manual as they are developed. The manual includes loss functions from both early field plots and the current chamber program.

Ozone is the only pollutant currently addressed in the crop yield-loss assessment, but it accounts for most agricultural losses in California from air pollutants. Ozone doses used in the loss equations are determined for crops grown in specific agricultural regions by summarizing ozone data from air quality monitoring sites in or near those areas.

Ozone doses are calculated from atmospheric data by subtracting 0.10 part per million (ppm) from the hourly ppm ozone values and accumulating the resultant values for the period of time when the crop is exposed to pollutants. This threshold was chosen for the project because it was the California state standard for ozone. Removal of the initial 0.10 ppm from each atmospheric ozone value eliminates the low levels that are less likely to affect plant growth and yield in California, and it removes low night background levels that cause no plant response. The threshold also helps to avoid equal mathematical weighting of dose accumulated from many low concentration exposures and few high concentration exposures. High levels of ozone are not limited to metropolitan areas and concentrations above 0.10 ppm occur in many major agricultural areas of California. Threshold values below 0.10 ppm ozone are being investigated for applicability to loss assessment of California crops.

Once typical ozone dosage values for an area and time of year are determined, the amount of predicted yield loss can be calculated from the loss equations. The ozone summaries can be periodically updated to reflect recent monitoring data.

Yield-loss functions have focused on field and vegetable crops. Perennial fruit and nut crops have not yet been investigated, because they entail more difficult experimental procedures. Although yield loss for a particular crop can be determined for specific ozone doses, no economic assessment is made. Economic loss depends on factors besides yield, incorporating supply and demand economics. The air pollution loss function equations should be used with economic models to generate economic loss assessments.

Air pollution crop yield-loss equations have been determined for 12 crops (table 1), including a ranking of some crop varieties for sensitivity. A typical loss conversion function (table 2) includes ozone dose, predicted reduction, confidence belts surrounding the function, and varietal ranking for ozone resistance. Loss functions for additional crops are currently being generated.

TABLE 1. Yield-loss functions developed for California crops

Crop	Ozone dose - yield-loss function*
Alfalfa (yield)	$y = 9.258 \times 10^{-3} \times$ dose
Alfalfa (defoliation)	$y = 3.034 \times 10^{-3} \times$ dose
Bean (Red Kidney)	$y = 2.40 \times 10^{-2} \times$ dose
Beet (dark red)	ozone not correlated with yield
Beet (sugar)	ozone not correlated with yield
Cotton (yield)	$y = 6.947 \times 10^{-3} \times$ dose
Cotton (uniformity index)	$y = 1.90 \times 10^{-3} \times$ dose
Lettuce (leaf)	$y = 5.19 \times 10^{-2} \times$ dose
Onion (Green)	$y = 5.97 \times 10^{-2} \times$ dose
Parsley	$y = 4.8 \times 10^{-2} \times$ dose
Potato	$y = 1.03 \times 10^{-2} \times$ dose
Spinach	$y = 4.006 \times 10^{-2} \times$ dose
Strawberry	ozone not correlated with yield
Tomato (pole)†	$y = 2.327 \times 10^{-2} \times$ dose
Tomato (processing)	$y = 2.29 \times 10^{-2} \times$ dose
Turnip	ozone not correlated with yield

*y = percent yield reduction.
† = Based on lugs harvested; includes 2-layer and 3-layer flats.

TABLE 2. Excerpt from *Air Pollution Manual - California Crop Yield-Loss Functions* showing representative crop loss function data

OZONE DOSE TOMATO YIELD FUNCTION

Ozone dose-yield reduction conversion function for 6718 VF pole tomatoes. Containers are defined as units representing 2-layer flats and 3-layer flats.

Percent reduction (lugs* harvested) = .0237 × dose

Ozone dose	Predicted % reduction	Range of reduction at 95% confidence: Upper belt	Range of reduction at 95% confidence: Lower belt
0.	0.0	0.0 -	25.4
250.	5.9	0.0 -	28.7
500.	11.8	0.0 -	32.2
750.	17.8	0.0 -	36.0
1000.	23.7	7.1 -	40.3
1250.	29.6	14.1 -	45.1
1500.	35.5	20.5 -	50.6
1750.	41.4	26.0 -	56.9
2000.	47.4	30.9 -	63.9
2250.	53.3	35.2 -	71.4
2500.	59.2	39.0 -	79.4
2750.	65.1	42.5 -	87.8
3000.	71.1	45.8 -	96.3
3250.	77.0	49.0 -	105.0

*Lugs include 2-layer flats and 3-layer lugs.

Varietal ranking for ozone resistance
Ozone susceptible: Ace, Polepak, F_2VF, Earlypak 7
Ozone resistant: H-11, 6718 VF

Conclusions

Pollutant episodes regularly exceed state and national standards in California agricultural areas. It is important to determine the extent of pollution-caused yield reductions in agriculturally important crops. The loss assessment program described here produces yield functions that are helpful in crop-loss estimates. Loss functions can be used in estimating economic losses from ozone. The National Crop Loss Assessment Network (NCLAN) uses such an approach to provide nationwide crop loss estimates, and the California Air Resources Board (ARB) is also using these techniques in their economic analysis of air pollutant impacts in California. The data produced by this program along with assessments from other programs (NCLAN, ARB) help in evaluating the severity of the pollution problem to California agriculture.

All available crop yield-loss functions with current ozone data for monitoring sites throughout California are listed in the *Air Pollution Manual - California Crop Yield-Loss Functions* from the California Department of Food and Agriculture's Environmental Hazards Assessment Program. Information in the manual is available free through County Agricultural Commissioner offices or from the authors.

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