In 1982, atmospheric concentrations of ozone reduced tomato yield 4.4 percent relative to yields in charcoal-filtered chambers (table 1). A seasonal seven-hour mean concentration of 0.051 ppm reduced tomato yield over 20 percent relative to charcoal-filtered chambers. In 1981, atmospheric levels of ozone had no apparent effect on tomato yield, but yields were reduced at concentrations above 0.062 ppm. The same seasonal mean concentration of ozone had approximately twice the effect in reducing yield in 1982 as in 1981 (fig. 1). These results were similar to those reported earlier for cotton (*California Agriculture,* September-October 1983).

The 1981 growing season was typical of the Central Valley: high temperatures, low humidity, and little cloud cover. In contrast, the summer of 1982 was cooler, cloudier, and more humid than normal. In 1982, cooling degree-days were 36 percent lower and precipitation 7.5 cm greater than in 1981. Under these conditions, tomatoes were more susceptible to ozone injury and yield reductions were greater in 1982 than in 1981.

In contrast to ozone, sulfur dioxide had no effect on tomato yield, except at concentrations far higher than would be expected in the Central Valley. In addition, sulfur dioxide did not interact with ozone to produce greater yield losses than would be expected of the two pollutants acting alone.

Conclusions

The difference in response of tomatoes to air pollution in 1981 and 1982 was attributed primarily to cooler, more humid growing conditions in 1982, which made plants more susceptible to ozone injury. Tomatoes were very resistant to sulfur dioxide, and there were no interactions between the two pollutants.

These results indicate that tomatoes are more resistant than cotton to yield losses caused by air pollution. However, levels of ozone prevalent in the Central Valley can reduce yield of 'Murrieta' tomato under certain environmental conditions.

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The economic effects of air pollution on annual crops

Richard E. Howitt □ Thomas W. Gossard □ Richard M. Adams

For both consumers and producers, the effects of ozone on agriculture are substantial

The adverse effects of air pollution on California agriculture have been a source of concern for at least three decades. The reasons for concern are California's specialized and highly valued crop production, the documented sensitivity of some crops to air pollution, and the high levels of air pollutants in such major production regions of the state as the South Coast and San Joaquin Valley. This combination of potentially sensitive crops and relatively high concentrations of harmful pollutants suggests that air pollution may be reducing crop yields, with economic effects on both producers and consumers.

Early attempts to assess these effects, either in physical terms, such as reduced crop yields, or in economic terms, such as reduced revenues, were hindered by a lack of biological information linking yields to changes in pollution levels (dose-response data). More information has become available in recent years, as a result of state- and federally-funded research on crop dose-responses to air pollution. Further, the ability to translate these physical changes in yields into economic consequences has improved through the development of detailed economic models of the California agricultural sector. These models can account for a wide range of agronomic and economic conditions critical to the accurate assessment of the effects of environmental change.

This study uses both newly acquired dose-response data and a large-scale economic mathematical programming model to assess the economic effect of ozone on the production of several important annual crops. Ozone is the most pervasive and harmful plant air pollutant found in California. The dose-response information is used to predict changes in yields expected from changes in ozone levels in agricultural regions. These yield changes in turn are used in the economic model to account for price effects, substitution of cropping activities, and differential impacts on producers and consumers. The model, known as the California Agricultural Resources Model (CARM) measures the economic effects of ozone-induced crop yield changes for major annual crops within 14 production regions of the state. The results suggest that even modest changes in ozone levels have substantial economic consequences.

CARM finds the cropping activity that maximizes the sum of consumers' and producers' surplus for 44 annual and perennial crops in all 14 production regions. These surpluses, used by economists to estimate the benefits of alternative policies, are related to the intersection of the supply and demand curves at the equilibrium price. Conceptually, they measure the benefits of a competitive market free of government interference, monopoly power, and outside influences.

With CARM, the impacts of current and alternative ozone levels on crop production are determined through the yield adjustments predicted by the dose-response data. Specifically, for the base run, the model includes yields for various crops in each of the 14 regions realized under actual atmospheric (base) ozone conditions for 1978. The yield effect, measured as changes from these actual yields resulting from differing ozone levels, is then entered into CARM to determine associated changes in cropping activities (acreage), total production, market prices, and economic surplus. Ozone levels in parts per million (ppm) of 0.04 (an improvement in air quality from the actual), 0.05 (a slight degradation in air quality), and 0.08 (a significant degradation) were specified. The levels were based on a seasonal seven-hour average between 9 a.m. and 4 p.m.

The dose-response data are derived primarily from the U.S. Environmental Protection Agency's (EPA) National Crop Loss Assessment Network (NCLAN) program. The NCLAN data are used to estimate crop yields for field corn, cotton (see *California Agriculture,* September-October 1983), grain sorghum, irrigated wheat, dry beans, lettuce, and processing tomatoes (see accompanying article) under alternative ozone levels. Yield response data for an eighth crop — alfalfa hay — were taken from another source.

To more fully account for the effect of ozone on annual crops and make the

TABLE 1. Economic value (surplus) under alternative ozone levels

	Consumers' surplus	Producers' surplus	Total surplus
		$ (millions)	
1978 base year			
17 affected crops	1,518.4	946.6	2,465.0
27 other crops	1,110.6	775.3	1,885.9
All crops	2,629.0	1,721.9	4,350.9
Improvements in air quality (O_3 = 0.04 ppm)			
17 affected crops	1,532.4	968.4	2,500.8
27 other crops	1,110.3	775.5	1,885.8
All crops	2,642.7	1,743.9	4,386.6
Slight degradation in air quality (O_3 = 0.05 ppm)			
17 affected crops	1,519.4	944.2	2,463.6
27 other crops	1,110.4	774.0	1,884.4
All crops	2,629.8	1,718.2	4,348.0
Significant degradation in air quality (O_3 = 0.08 ppm)			
17 affected crops	1,468.0	843.0	2,311.0
27 other crops	1,107.7	774.9	1,882.6
All crops	2,575.7	1,617.9	4,193.6

TABLE 2. Changes in economic surplus with respect to the 1978 base year under alternative ozone levels

	Change in consumers' surplus		Change in producers' surplus		Change in total surplus	
	$	%	$	%	$	%
			$ (millions)			
Improvement in air quality (O_3 = 0.04 ppm)						
17 affected crops	14.0	0.92	21.8	2.30	35.8	1.45
27 other crops	−0.3	−0.03	0.2	0.03	−0.1	−0.01
All crops	13.7	0.52	22.0	1.28	35.7	0.82
Slight degradation in air quality (O_3 = 0.05 ppm)						
17 affected crops	1.0	0.07	−2.4	−0.25	−1.4	−0.06
27 other crops	−0.2	−0.02	−1.3	−0.17	−1.5	−0.08
All crops	0.8	0.03	−3.7	−0.21	−2.9	−0.07
Significant degradation in air quality (O_3 = 0.08 ppm)						
17 affected crops	−50.4	−3.32	−103.6	−10.94	−154.0	−6.25
27 other crops	−2.9	−0.26	−0.4	−0.05	−3.3	−0.17
All crops	−53.3	−2.03	−104.0	−6.04	−157.3	−3.62

TABLE 3. Percent change relative to the 1978 base year in total crop production, market price, and total acreage for two ozone concentrations

	Production		Price		Acreage	
Crops	**0.04**	**0.08**	**0.04**	**0.08**	**0.04**	**0.08**
Alfalfa:						
hay	0.7	− 2.9	−0.3	1.2	− 1.2	5.3
seed	2.6	− 7.8	−0.1	0.4	− 0.5	0.7
Barley:						
dryland	1.4	− 8.5	−0.3	1.1	− 0.2	−0.3
irrigated	4.5	−16.6	−0.3	1.1	− 0.0	−2.8
Beans: dry	1.1	− 5.0	−1.0	4.6	− 5.5	24.5
Celery	0.8	− 1.4	−2.0	3.3	−13.7	18.6
Corn	1.5	− 8.6	−0.0	0.3	− 0.5	2.5
Cotton	4.8	−10.1	−0.2	0.4	− 1.5	1.4
Grain sorghum	1.0	− 3.2	−0.0	0.1	0.1	0.4
Lettuce	0.3	− 1.7	−1.1	5.9	− 5.3	29.4
Onions	1.7	− 5.5	−0.3	0.8	− 3.6	9.6
Potatoes	0.4	− 1.4	−0.2	0.5	− 1.6	4.9
Rice	0.1	− 1.7	−0.0	0.2	− 0.0	2.3
Tomatoes:						
fresh	0.5	− 0.7	−0.6	0.9	− 4.1	8.5
proc.	0.5	− 3.0	−0.1	0.8	− 1.4	8.2
Wheat:						
dryland	1.5	− 5.8	0.2	0.7	0.4	3.4
irrigated	−7.0	−19.4	0.2	0.7	− 9.8	− 4.9

CARM runs more realistic, the eight crops for which response data were available were used as surrogates for other, similar crops. Thus, the relative change in yield of irrigated wheat was assumed to be an acceptable approximation for changes in dryland wheat and in irrigated and dryland barley. Similarly, lettuce was used as a surrogate for celery and onions; processing tomatoes for fresh tomatoes and potatoes; grain sorghum for rice; and hay alfalfa for seed alfalfa. Still, this accounts for only 17 of the 44 seasonal crops in CARM. To the extent that ozone affects any of the 27 for which either data or a surrogate are lacking, the results from the economic model *underestimate* the effect of ozone on total agricultural production. These 27 other crops include eight annuals (broccoli, cantaloupes, carrots, cauliflower, hay grain, safflower, silage, and sugarbeets) and 19 perennials (almonds, apples, apricots, asparagus, avocados, grapefruit, table grapes, raisin grapes, wine grapes, lemons, nectarines, oranges, irrigated pasture, peaches, pears, plums, prunes, strawberries, and walnuts).

Results

The decrease in consumers' and producers' surplus (a quantitative measure of economic well-being) with increasing ozone levels shows the overall cost of decreasing air quality (table 1). When the absolute and proportional changes in surplus are compared with the 1978 base year, the percentage changes are low, but the absolute gain is substantial — $35.7 million a year from improvement to 0.04 ppm versus a loss of $157.3 million a year at the 0.08 ppm level (table 2).

Producers of the 27 other crops whose sensitivity to ozone levels is not known experience losses or benefits from changes in ozone level simply through the effect of market forces. For ozone improvement to 0.04 ppm, the total surplus for these other crops is reduced $0.1 million, which is probably not significant given rounding. But under 0.08 ppm, the total surplus is lowered $3.3 million. The lower valued among the 27 other crops are crowded out by more profitable crops known to be affected by ozone. These more profitable crops now require more land to produce the market equilibrium quantity.

The tables show that, while the producers feel the major impact of changes in ozone concentration, consumers account for about one-third of the change in total surplus. Thus, impact analyses that address only the producers' gains (or losses) or that ignore shifts between crops significantly distort the impacts of deterioration in the ozone level.

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Cylindrical chambers equipped with open-cone tops (frustra) made it possible to measure the actual effects of ozone on cotton in the San Joaquin Valley. Such field tests, on cotton and other crops, were the basis for computer estimates of air pollution damage to other major crops.

The CARM model, like any other, will have errors in projection of acreages. A recent test showed a mean acreage prediction error of 7 percent, which is of the same magnitude as the ozone-induced changes. This does not invalidate the study conclusions, since all the effects are calculated as differences between situations using the same base solution, and the consistent error in the CARM model is cancelled out of the calculations of benefits and costs.

In addition to aggregate economic losses due to ozone, there are effects of ozone level changes on total production, price, and acreage for the 17 affected crops in California (table 3). In general, as air quality improves, total production increases (through better yields), price decreases, and acreage decreases. In contrast, increasing levels of ozone tend to decrease production (poorer yields), increase price, and increase acreage. This pattern does not always hold for barley, sorghum, or wheat, probably because California's total production of these crops is small compared with the total nationwide and yield changes have a small impact on price.

Intuitively, one might not expect aggregate acreage to increase under poor air quality and decrease when quality is improved. The model, however, is following the rational economic process of substituting land and other inputs for air quality. Consider an increase in air quality that increases yield by 20 percent, resulting in a 20 percent increase in quantity supplied. Demand ensures that a lower price will be offered for the increased supply. The decrease in price will cause a cutback in supply. Thus, the increase in quantity sold will be less than 20 percent, ensuring a decrease in that crop's acreage. The magnitude of the acreage reduction depends directly on the elasticity of demand — the purchase changes caused by a change in price — for that particular commodity.

Quantities required of other inputs would also be expected to change when ozone levels increase. The magnitude of all these associated changes will vary widely across crops. But it is certain that reduction in air quality will increase the pressure on California's scarce land and water resources.

Conclusions

Two broad conclusions emerge from these results. First, for both consumers and producers, the effects of ozone on agriculture are substantial for the 17 affected crops. While producers bear the brunt of the effects, consumers are also affected through changes in prices. Under significant air quality degradation (0.08 ppm), producers of crops known to be affected will have their returns to fixed costs reduced by almost 11 percent. Given the slim profit margins for many crops, ozone degradation will have much greater effects on farm profits.

Second, due to the interaction of price and cost effects, the change in acreage, output, or benefits cannot be reduced to a simple relationship over a range of crops. To accurately measure the social costs of environmental degradation, any analysis of economic effects must account for changes in crop mix and the substitution of other inputs (land, labor, and water resources) for deteriorating air quality.

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