Effects of Criteria Pollutants on Agriculture

Appendix F

Introduction

One potential impact of air pollutants on economic welfare is their effect on agricultural crops, including annual and perennial species. Pollutants may affect processes within individual plants that control or alter growth and reproduction, thereby potentially increasing or decreasing yields of agricultural crops. Possible physiological effects of pollutants include: decreased photosynthesis; changes in carbohydrate allocation; increased foliar leaching; decreased nutrient uptake; increased sensitivity to climatic stress, pests, and pathogens; decreased competitive ability; and decreased reproductive efficiency. These physiological effects, in conjunction with environmental factors and intraspecies differences in susceptibility, may affect crop yields.

Air pollutants that might damage plants include SO_2, NO_x, peroxyacetyl nitrate (PAN), and volatile organic compounds (VOCs). These pollutants may have direct effects on crops, or they may damage crops indirectly by contributing to tropospheric (ground-level) ozone and/or acid deposition, both of which damage plants. Tropospheric ozone is formed by photochemical reactions involving VOCs and NO_x, while SO_2 and NO_x cause acidic deposition.

While all of these air pollutants may inflict incremental stresses on crop plants, in most cases air pollutants other than ozone are not a significant danger to crops. Based primarily on EPA's National Acid Precipitation Assessment Program (NAPAP),[1] this analysis considers ozone to be the primary pollutant affecting agricultural production.

[1] Shriner et al., 1990; NAPAP, 1991.

This analysis estimates the economic value of the difference in agricultural production between 1990 and 2010 that is projected to result from passage of the 1990 CAA Amendments (CAAA). The analysis is restricted to a subset of agricultural commodities, and excludes those commodity crops for which ozone response data are not available. Fruits, vegetables, ornamentals, and specialty crops are also excluded from this analysis for a variety of reasons, mostly related to the absence of a national level benefits model (for vegetables and specialty crops) and difficulties in quantifying the physical impacts of air quality changes and their associated effect on welfare (for ornamentals). To estimate the economic value of ozone reductions under the CAAA, agricultural production levels expected from post-CAAA scenario ozone conditions are first compared with those expected to be associated with ozone levels projected under the pre-CAAA scenario. Estimated changes in economic welfare are then calculated based on a comparison of estimated economic benefits associated with each level of production.

Ozone Concentration Data

For this analysis, the SUM06 index – a cumulative index of ozone concentrations over a specified threshold (0.06 ppm) – was selected to conform with the recent EPA ozone NAAQS benefits analysis.[2] The SUM06 index is one of several cumulative statistics that emphasize peak concentrations (in this case by use of a threshold), and may correlate more closely to crop damage than do unweighted indices.[3]

[2] Abt Associates, 1998.

[3] Lefohn et al., 1988.

Because crop production data are available at the county level, the lowest level of aggregation that could be used for ozone indices is also the county level. Therefore, monitor level data needed to be aggregated to a county level.

Three main steps are used in the process of estimating the county-level SUM06 values:

(1) 1990 hourly ozone concentrations obtained for all available monitors from EPA's AIRS system.[4]

(2) For each county centroid, the 1990 hourly data from the closest set of monitors are temporally- and spatially-adjusted using UAM-V modeling data (as described in Appendix C), and the SUM06 is calculated for each monitor for each month.

(3) A distance-weighted average SUM06 is estimated for each month from the temporally- and spatially-adjusted monthly values.

One difference between the agricultural analysis and the health analysis is the treatment of distance extrapolation. The health effects results in this 812 analyses are calculated first for the population living within 50 km of monitors, and then for the whole country by extrapolating the air quality modeling results to provide universal coverage. The air quality modeling results near to monitors are believed to be more certain than the modeling for more remote areas. The less certain air quality modeling results is a very important issue for the agricultural analysis, as the majority of the commodity crops are grown in locations some distance from ozone monitors. Because only a small portion of cropland is within 50km of an ozone monitor, the agricultural analysis is not conducted for the within 50km of a monitor locations. The agricultural analysis is only conducted using the full national extrapolation of ozone modeling results.

[4]The analysis reflects the application of a 50 percent completion criterion, ensuring that included monitors have at least 12 hours of data for at least half the days in the modeling season.

Calculation of the SUM06 Statistic

The hourly ozone concentrations are screened to identify those that equal or exceed 0.06 ppm, and these values are summed to obtain a "raw" monthly SUM06 index:

$$\sum_{j=day1}^{day\,30} \sum_{i=8:00\,AM}^{7:59\,PM} ozone_{i,j}\,,\ for\ all\ ozone_{i,j} \geq 0.06\ ppm$$

In this analysis, the SUM06 statistic was calculated on a monthly rather than a daily basis, reflecting the same hours of the day as if daily statistics had been individually calculated. Although a completeness criterion had been used to select monitors, there were still missing data for some included monitors. Therefore, this "raw" statistic was adjusted by a completeness ratio, the proportion of hours with available data to total hours in the period (either 12 in a day or 360 in a 30-day month), in order to address missing data as follows:

$$raw\ statistic * \frac{maximum\ hours\ per\ month}{actual\ hours\ in\ month}$$

The assumption implicit in using a completeness ratio is that the distribution of hourly ozone values for the missing data is the same as the distribution for the available data.

October to April Ozone Concentration Data

Agricultural crop seasons extend the May to September period used in the health analysis, and the SUM06 index is cumulative, requiring data for the entire agricultural season. To address the need for SUM06 indices in months between October and April, 1990 monitoring data from AIRS were used --

no temporal- or spatial-adjustments were made to reflect potential ozone conditions in future years outside of the modeling season.[5]

Yield Change Estimates

There are several steps involved in generating yield change estimates. The first is the selection of relevant ozone exposure-response functions (minimum and maximum) for each crop in the analysis. Ozone data at the county level are transformed into an index suitable for use in the selected function(s) to estimate county level predicted yield losses for both the post-CAAA and pre-CAAA scenarios. In the next step, the proportion of each county to the national production of each crop is calculated to permit national aggregation of estimated yield losses. Finally, the post-CAAA scenario percentage relative yield loss (PRYL) is compared to the minimum and maximum PRYL for the pre-CAAA scenario. Each step is discussed in more detail below.

Exposure-Response Functions

Yield impacts resulting from changes in from ozone concentrations are estimated using exposure-response functions that are specific to each crop being analyzed. This analysis was restricted to estimating changes in yields for those commodity crops for which consistent exposure-response functions are available and that are included in national agricultural sector models. Consistent with EPA's ozone NAAQS benefits analysis, we used National Crop Loss Assessment Network (NCLAN)-based exposure-response functions that were derived using a Weibull distribution for available data, and a 12-hour SUM06 ozone index.

[5]AIRS data for all U.S. monitors were screened using the 50 percent completeness criterion for each month. All hourly data was converted to parts per million and rounded to the nearest 0.0001 ppm.

Minimum/Maximum Exposure-Response Functions

Experimental data to evaluate the response of crops to ozone has been collected for a limited number of crops under the NCLAN program. The objective of this program was to employ a consistent experimental methodology to provide comparable results across crops. The crops included in the NCLAN experiments are corn, cotton, peanuts, sorghum, soybeans, winter wheat, potatoes, lettuce, kidney beans, tomatoes, and hay. For many crops, the NCLAN program evaluated the effects of ozone on several different cultivars. Although not necessarily representative of the full range of variability in crop response, the results for different cultivars do permit identification of a range of responsiveness. The most tolerant and responsive response functions are used to represent minimum and maximum impacts, *within the limits of available data*.

Use of cumulative exposure-response functions is relatively recent, and few experiments have been designed or reported in terms of the SUM06 index. Because the NCLAN program used a consistent protocol and developed a database of experimental conditions and results for all of its studies, U.S. EPA's Environmental Research Laboratory (ERL) was able to use original data from NCLAN studies to develop SUM06 exposure response functions for most NCLAN crops[6] (Lee and Hogsett, 1996). In addition, the agricultural model used in this analysis does not reflect non-commodity crops such as lettuce, tomatoes, potatoes, alfalfa, tobacco, turnips, and kidney beans. Table F-1 presents the exposure-response functions used in this analysis. Finally, one commodity crop, spring wheat, was excluded because the NCLAN exposure-response function was only developed for winter wheat.

Estimated responsiveness of a given crop to ozone varies within the NCLAN data. This range of response is partially explained by the program's

[6]Data were not sufficient to develop functions for tomatoes or hay.

evaluation of several cultivars for some crops; ozone sensitivity varies across cultivars. In addition, the conditions for different experiments varied due to variations in location, year, and additional treatments included in some experiments. No one exposure-response function can be assumed to be representative of all cultivars in use, or of all environmental conditions for crop production. To develop a range of benefits estimates that reflects this variation in responsiveness, a minimum responsiveness and a maximum responsiveness function were selected for each crop. In actuality, a number of different cultivars are planted by producers, and so actual ozone response will be a weighted average of the responsiveness of each cultivar to its ozone condition and its proportion of total acreage. It is important to note that these values do not necessarily bound the analysis, since the number of cultivars evaluated by NCLAN is small relative to the number grown for many crops.

For the crops used in this study, ERL conducted an analysis to identify the ozone concentration required to reduce yields by 10 percent for each crop cultivar using its 12-hour SUM06 exposure-response function. For each crop, the function demonstrating the lowest ozone concentration at a 10 percent yield loss represents the maximum response, and the function with the highest concentration at 10 percent yield loss represents the minimum response. Table F-1 reports the minimum and maximum exposure-response functions for each crop. Two crops, peanuts and sorghum, did not have multiple NCLAN experiments on which to base a comparison of the responsiveness of different cultivars or the variation in response with different experimental conditions.

In this analysis, the maximum and minimum yield change results are used to bound a uniform distribution of possible yield change, recognizing that this distribution reflects only *known* potential yield losses. Each percentile change in yield, including the minimum and the maximum, is used to estimate a distribution of possible changes in economic welfare (see below).

Table F-1
Ozone Exposure-Response Functions for Selected Crops (SUM06)

Ozone Index	Quantity	Crop	Function	Median Experimental Duration (Days)	Median Duration (Months)
SUM06	Max	Cotton	1-exp(-(index/78)^1.311)	119	4
SUM06	Max	Field Corn	1-exp(-(index/92.4)^2.816)	83	3
SUM06	Max	Grain Sorghum	1-exp(-(index/177.8)^2.329)	85	3
SUM06	Max	Peanut	1-exp(-(index/99.8)^2.219)	112	4
SUM06	Max	Soybean	1-exp(-(index/131.4)^1)	104	3
SUM06	Max	Winter Wheat	1-exp(-(index/27.2)^1.0)	58	2
SUM06	Min	Cotton	1-exp(-(index/116.8)^1.523)	119	4
SUM06	Min	Field Corn	1-exp(-(index/94.2)^4.307)	83	3
SUM06	Min	Grain Sorghum	same as max (see above)	85	3
SUM06	Min	Peanut	same as max (see above)	112	4
SUM06	Min	Soybean	1-exp(-(index/299.7)^1.547)	104	3
SUM06	Min	Winter Wheat	1-exp(-(index/72.1)^2.353)	58	2

Source: Lee and Hogsett (1996)

Calculation of Ozone Indices

The SUM06 index is cumulative, and so is sensitive both to the duration over which it is calculated and to the specific month(s) within a growing season that are included in it. For each crop included in NCLAN ozone exposure-response experiments, the period of ozone exposure reflected only a portion of the crop's growing season. The duration of the NCLAN experiments was provided by ERL, and reflects the duration of the function that provides the median responsiveness to ozone exposure. Because cropping seasons vary across the U.S., the ozone index used to calculate county-level changes in yield due to ozone must reflect the local season for each crop. To calculate the SUM06 index for the appropriate growing season, state-level data on planting and harvesting dates was used in this analysis.[7] To calculate the cumulative SUM06 index, the experimental duration for each crop was anchored on that crop's harvest date in each state in order to most closely approximate the relevant period of exposure for yield analysis. The harvest date was assumed to be the first day in the month of harvest, so that the SUM06 index includes the months up to but not including the harvest month. Because the baseline and regulatory ozone data were developed as monthly SUM06 values, for the first month of the duration period the proportion of remaining days to days in the month were used to adjust the monthly SUM06 value. The SUM06 index was calculated using the county level ozone data developed in the prior section, summed for the number of months of NCLAN experimental duration, with the exposure period anchored on the usual harvest month for each crop.[8]

The form of the exposure response functions is an exponential function based on a Weibull distribution of the original NCLAN data, estimated to predict a yield loss relative to conditions of "clean air" (charcoal filtered/zero ozone) , or a zero SUM06 value. The resulting equation is in the form of:

$$Y = 1 - e^{\left[-(SUM06/B)^{C}\right]}$$

where:

Y	=	predicted relative yield loss (PRYL), expressed as a decimal value (i.e., not multiplied by 100 to report as a percent loss), and relative to a zero SUM06 (or clean air) condition
SUM06	=	cumulative SUM06 ozone statistic at a specified level of spatial representation, in ppm
B, C	=	statistically estimated parameters, unitless

Calculation of County Weights

Because the benefits analysis did not require a regional level of disaggregation and to minimize computational burdens the economic analysis was conducted at a national level. Ozone data and estimated yield responses, however, were developed at a county level. To conduct a national analysis, the county level yield change estimates were weighted to develop a single national percent relative yield loss for each crop relative to the post-CAAA scenario, for both the minimum and the maximum yield responses. Weights based on 1997 crop production data[9] were used to represent all years in this analysis (1990 to 2010). Because weather and other conditions may change the proportion of counties' production to the total national production in each year, weights based

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[7] USDA, 1984. Some states did not have explicit growing seasons reported for certain crops due to the low production in these states. In these cases a proxy state growing season was used. In most of these cases the proxy growing season was taken from a state with an adjoining boundary within the same geographic region. Peanut emergence and harvest dates were taken from the U.S. EPA Pesticide Root Zone Model-2 (PRZM) data, US EPA 1993.

[8] This analysis required "rounding" some months: if a harvest date was specified to be from the 15th to the end of a month, the W126 index was calculated using that month's data; if the harvest date was specified to be from the first to the 14th of a month, the W126 index was calculated using the prior month's data as the final month in the exposure period.

[9] USDA 1998a.

on a single year may bias the estimates to some extent. The weights were calculated by dividing the production level of a crop in a county[10] by the sum of all states' reported production for that crop.[11] These county weights were applied to the percent relative yield loss results for each county, as discussed below, to develop a national level yield change estimate.

Calculation of Percent Change in Yield

There is an issue associated with applying the yield loss functions to analysis of alternative regulatory profiles. The functions provide a predicted yield loss relative to "clean" air, while policy analysis needs to compare policy options with a baseline, non-zero ozone condition. Therefore, the yield change resulting from the Clean Air Act Amendments is evaluated as the yield loss relative to clean air under the CAAA scenario being evaluated compared to the yield loss under baseline (no-CAAA) conditions.

The change in yields, relative to "clean air" is calculated as:

$$PRYL_{Post-CAAA} - PRYL_{Pre-CAAA}$$

and, if yield under clean conditions is 100 percent of possible yield, then baseline yield in this context is 1 minus baseline yield loss. Thus the change in yield under clean air conditions can be divided by the baseline yield, and the change in yields relative to the baseline can be given as:

$$PRYL_{Post-CAAA} - PRYL_{Pre-CAAA} / 1 - PRYL_{Post-CAAA}$$

To create the national percent change in yield for each crop, the results of this equation are multiplied by the county level weights and summed for each scenario (maximum and minimum) and for each year. Table F-2 presents the resulting percent yield changes that were used as inputs to the economic model.

[10] USDA, 1995.

[11] The national total does not include USDA areas designated "other counties". These areas are groups of counties that for one reason or another (disclosure rules, low amount of production, etc.) are not individually listed. Because we did not have ozone values for these groups, we did not use their production levels in the calculation of the total national production.

Table F-2
Relative Percent Yield Change

		Corn	Cotton	Peanuts	Sorgham	Soybeans	Winter Wheat
2000	Minimum Response	0.01%	1.66%	0.61%	0.01%	0.26%	0.20%
	Maximum Response	0.05%	3.79%	0.61%	0.01%	2.75%	5.07%
2010	Minimum Response	0.01%	2.84%	1.36%	0.02%	0.42%	0.39%
	Maximum Response	0.10%	6.58%	1.36%	0.02%	4.38%	9.11%

Economic Impact Estimates

To estimate the economic benefits of controls on ozone precursor pollutants implemented pursuant to the 1990 CAAA Amendments, we evaluated the changes in yields resulting from additional, post-1990 controls in terms of their effect on agricultural markets. To do this, yield changes can be incorporated into an economic model capable of estimating the associated changes in economic surpluses within the agricultural economy, preferably one that reflects changes in producers' production decisions and demand substitution between crops. This type of dynamic analysis is needed because even small changes in yield or price expectations can cause large shifts in the acreage allocated to specific crops, and the degree to which alternative crops will be substituted (particularly for feed uses).

The modeling approach used in this analysis is to use an econometric model of the agricultural sector, which estimates demand and supply under different production technologies and policy conditions. The AGricultural SImulation Model (AGSIM©) has been used extensively to evaluate air pollution impacts, as well as a number of other environmental policy analyses. The version of AGSIM© used in this analysis reflects production conditions and projections for three discrete periods: 1990, 2000, and 2010. Projections of the 2000 and 2010 baseline are essentially those reported by USDA/ERS (USDA 1998b). A few endogenous variables in AGSIM© were not included in the USDA baseline. In those cases, the 1997 Food and Agricultural Policy Research Institute (FAPRI) baseline was used (FAPRI 1997).[12]

The AGSIM© baseline production and price data serve as the post-CAAA scenario baseline. Percent relative yield losses (PRYLs) between the post-CAAA and pre-CAAA scenarios are the relevant input parameter for this analysis, from which AGSIM© calculates new yield per planted acre values. Based on these values (as well as on lagged price data, ending stocks from the previous year, and other variables), AGSIM© predicts acreage, production, supply, and price parameters for each crop for each year, as well as calculating yield per harvested acre. From these results and the demand relationships embedded in the model, AGSIM© calculates the utilization of each crop (i.e., exports, feed use, other domestic use, etc.), as well as the change in consumer surplus, net crop income, deficiency payments and other government support payments. Net surplus is calculated as net crop income plus consumer surplus, less government payments.

Table F-3 presents the net *changes* in economic surpluses in nominal terms for our two target years, 2000 and 2010. The positive net surpluses are a result of the increase in yields associated with lower ozone levels than those predicted to occur under the pre-CAAA scenario. The annual value of the estimated agricultural benefits of the CAAA in 2010 ranges between $7.5 million in the minimum response case to approximately $1.1 billion in the maximum response case, with a median response of $550 million. It

[12] Documentation for this version of AGSIM can be found in Abt Associates, 1998.

should be reiterated that this range represents the impacts that would occur if all of the acreage planted to a given crop had an ozone response function similar to either the minimum *available* response function or the maximum *available* response function. The available response functions do not necessarily bracket the true range of potential crop responses, and it is unrealistic to anticipate that all acreage will be planted in cultivars with a uniform response to ozone exposure. These considerations notwithstanding, these values do indicate the likely magnitude of agricultural benefits associated with post-CAAA of ozone precursors under the CAAA, but not the precise value of those benefits.

Table F-3
Change in Net Crop Income, Consumer Surplus and Net Surplus Under the Post-CAAA Scenario (millions of 1990$)

	Change in Net Crop Income		Change in Consumer Surplus		Change in Net Surplus	
	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum
1990	$0	$0	$0	$0	$0	$0
2000	-$320	-$1,901	$367	$2,763	$46	$862
2010	-$736	-$4,555	$743	$5,643	$7.5	$1,088

Conclusions

Agricultural benefits associated with post-CAAA levels of ozone precursors under the Clean Air Act are likely to be fairly large. Because it is possible that over time producers have adopted more ozone-resistant cultivars, it may be appropriate to consider the lower end of the range of predicted benefits to be more indicative of the likely total benefits for those crops included in the analysis. The estimates developed in this analysis, however, do not represent all of the likely benefits accruing to agriculture, in that many high-value and/or ozone sensitive crops could not be included in the analysis due to either exposure-response data limitations or agricultural sector modeling limitations. The second consideration implies that benefits will likely be larger than estimated. The minimum case may be the most appropriate starting point, however, due to the first consideration: the current crop mix may be biased toward higher ozone responsiveness. Therefore, we anticipate that cumulative net present value agricultural benefits from the Clean Air Act Amendments over the period 1990 to 2010 are on the order of $4 billion dollars.

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