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Volume III, A Preliminary Assessment of Air Pollution Damages for Selected Crops Within Southern California

OTHER VOLUMES OF THIS STUDY

Volume I, Experiments in the Economics of Air Pollution Epidemiology, EPA-600/5-79-001a.

This volume employs the analytical and empirical methods of economics to develop hypotheses on disease etiologies and to value labor productivity and consumer losses due to air pollution-induced mortality and morbidity.

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This volume includes the empirical results obtained from two experiments to measure the health and aesthetic benefits of air pollution control in the South Coast Air Basin of Southern California.

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The research detailed in this volume explores various facets of the two central project objectives that have not been given adequate attention in the previous volumes.

Volume V, Executive Summary, EPA-600/5-79-001e.

This volume provides a 23 page summary of the findings of the first four volumes of the study.

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METHODS DEVELOPMENT FOR ASSESSING AIR POLLUTION CONTROL BENEFITS

Volume III

A Preliminary Assessment of Air Pollution Damages for Selected Crops Within Southern California

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ABSTRACT

This study investigates the economic benefits that would accrue from reductions in oxidant/ozone air pollution-induced damages to 14 annual vegetable and field crops in southern California. Southern California production of many of these crops constitutes the bulk of national production.

Using the analytical perspective of economics., the study provides an up-to-date review of the literature on the physical and economic damages to agricultural crops from air pollution. In addition, methodologies are developed permitting estimation of the impact of air pollution-induced price effects, input and output substitution effects, and risk effects upon producer and consumer losses. Estimates of the extent to which price effects contribute to consumer losses are provided. These consumer losses are estimated to have amounted to $14.8 million per year from 1972 to 1976. This loss is about 1.48% of the total value of production for the included crops in the area and 0.82% of the value of these crops produced in the State of California. Celery, fresh tomatoes, and potatoes are the sources of most of these losses.

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CHAPTER I

INTRODUCTION

1.1 The Problem Setting

Agricultural production, even in the most advanced countries, is heavily influenced by factors that are beyond the producer's control. Despite a tremendous increase in per unit agricultural yields during the past three decades due, in part, to successful breeding of high yield and disease resistant varieties of plants, favorable weather conditions, substantial uses of fertilizer, insecticides, and modern farm machinery, aggregate world food production has not kept pace with world population growth. Further, within the more industrialized countries yield plateaus appear to have been reached for specific crops. On a site specific basis, such a leveling of yields may be partially attributed to man-induced environmental factors, such as shifting production to soils of lower inherent productivity and the general degradation of environmental quality, including ambient air quality levels. The existence of such environmental problems may not be critical in developing or non-industrialized countries where agricultural production is still largely at a subsistence level. However, within industrialized nations, the encroachment of urban and industrial growth into regions of agricultural production bring attendant problems for agriculture, including those associated with air pollution. The problem of air quality and agricultural production is partially pronounced on a regional basis.

Some agricultural crops, such as vegetables and fruits, tend to display highly concentrated geographical production patterns due to specific climatological requirements. An example of such a region is the South Coast Air Basin of California. Given the concentration of such production, and the adverse effects of air pollution on vegetables and fruits (which are highly perishable), one might expect price fluctuations for such commodities in response to changes in air quality. Any depression of yields due to the presence of air pollution may affect consumers and producers of those commodities differentially, depending on the price elasticity of demand (or the price flexibility coefficients, if emphasis is on direct price effects). That is, if the price elasticity of demand for, say, celery is inelastic, consumers would suffer a net income loss, while producers on the aggregate will benefit from the increase in price of celery due to the reduction in celery supply.

The fact that air pollution poses problems in certain delineated basins in California is well documented. Such air pollution problems appear most severe in the South Coastal Air Basin of the state. Injury to vegetation from photochemical oxidants was first characterized in 1944 in the Los Angeles area [Middleton, Kendrick and Schwalm, 1950], but was soon recognized over a large part of Southern California as well as in the San Francisco Bay area [Middleton, Darley and Brewer, 1958]. Moreover, the high level of such potentially harmful photochemical oxidants and particulate observed in the South Coast Air Basin are no longer confined to the delineated.area but rather extend east into the Mojave Desert and Imperial Valley as well as northwest into the Ventura-Oxnard Plain. Areas of previously low air pollution concentrations, such as the San Joaquin and Central Coast valleys, are experiencing potentially damaging levels of concentration.

The general effects of air pollution on vegetation are also well documented.1/ While some effects, at the individual level, may be primarily aesthetic, substantial economic costs to society in terms of deleterious effects on production relationships are also incurred. These effects, as applied to agricultural crops, may be pronounced in terms of depressed yields and resultant increases in output prices.

Within agricultural crops, different species vary over a considerable range in their susceptibility to injury by air pollution. These differences appear to be due primarily to differences in the absorption rate of toxic substances by plant leaves. Succulent leaf plants (with the exception of corn) of high physiological activity are generally sensitive, whereas those with fleshy leaves and needles are resistant. For these reasons, it is necessary to find the appropriate air pollution response function for each crop so that the level of yield reduction, if any, due to different levels of air quality can be determined within the specified area.

The physical effects of air pollutants on agricultural crops have long been recognized [Brandt and Heck, 1968]. The adverse effects of air pollution were recorded as early as 1874 [Cameron]. However, most research in this area has concentrated on physical damages. There have been relatively few research efforts directed at the economic impacts of air pollution on agricultural crops. Perhaps one reason is that individuals who traditionally carry out such studies are primarily biologists, biochemists, plant pathologists, or other scientists more interested in physical rather than economic or monetary losses to plants and agricultural crops due to air pollution. Another reason is that it is more difficult to adequately evaluate economic losses due to a wide range of stochastic factors, such as possible input and output price fluctuation, for the commodities being considered. To date, there does not appear to be a theoretically acceptable means of measuring such economic losses. Of those studies directed at economic losses, most employ the survey method and calculate the damages quantitatively by simply multiplying the estimated reduction of yield by a fixed price [see Middleton and Paulus, 1973;2/ Lacasse, Weidensaul and Carroll, 1969; Benedict, Miller and Smith, 1973; Thompson and Taylor, 1969; Thompson, Kats and Hensel, 1971; Thompson, 1975].

Given the importance of the South Coastal and contiguous regions in the production of specific crops, increasing (or even constant) levels of air pollution such as photochemical oxidants, may portend significant changes in this regional agricultural production. Such agricultural adjustments may adversely affect consumers, given the general range of income elasticities and price flexibilities observed for many crops grown in this area. The effects of air pollution on producers are uncertain, as some compensating variation in the form of changes in output prices may offset some production effects. Nevertheless, it is likely that resource owners and input suppliers would experience lower rates of return.

As mentioned above, farm-level prices of some agricultural crops fluctuate widely, due in part to changes in production levels. The prices of some agricultural commodities may rise or drop more than 50% within a certain time period [see Tomek and Robinson, 1972, p. 2], depending on the magnitude of the price flexibility coefficient. Therefore, prices, under such situations, cannot reasonably be taken as given. In addition, most studies do not consider distributional effects due to air pollution, such as welfare gains and losses across consumers and producers. Such effects may be of more interest to policymakers than just the dollar value of agricultural losses.

1.2 Scope of the Study Analysis

Vegetable production in the United States is dominated by California in the aggregate and on a seasonal basis. Within certain regions of California, air pollution in the form of oxidants has been a chronic problem. This is particularly pronounced in parts of the South Coastal region encompassing Los Angeles and surrounding areas. The South Coastal region is also an important vegetable producing region on a seasonal basis.

In addition, levels of oxidants have been increasing in contiguous production regions, such as the Imperial Valley, Southern San Joaquin Valley and Central Coast (Salinas Valley). These regions, when combined with the South Coast, constitute the principal fresh vegetable production region in the U.S. These regions are included in this analysis in an attempt to capture the comparative advantage across regions; i.e., increasing levels of air pollution in one region vis a vis contiguous regions may result in structural changes in the agricultural sector as growers attempt to ameliorate for the presence of air pollution. Such modifications in behavior may be in the form of changed cropping mixes, increased costs or shifts in location of production. The net effect may be reduced market shares for the affected region and altered producer revenues. Thus, for the purpose of this study, the delineated study area contains four production regions identified as the South Coast, Central Coast, Southern San Joaquin and Southern Desert.3/ These regions appear to constitute an appropriate area in which to analyze the interface between air pollution and crop production.

At present, the economic analysis of crop damage is limited to 14 annual vegetable and field crops. Perennials, such as alfalfa, citrus and fruits, are excluded due to the complex time horizons associated with such crops. Also, from the standpoint of substitution possibilities (one aspect of the analysis), annual crops offer a more diverse set of opportunity. The annual crops selected for inclusion represent the major vegetable and field crop commodities grown within the region. All had gross values in excess of $8 million in 1976. The list of vegetable crops includes: beans (lima), brcccoli, cantaloupes, carrots, cauliflower, celery, lettuce (head), onions (fresh and processed), potatoes and tomatoes (fresh and processed). In addition to the 12 vegetable crops, two field crops are included: cotton and sugarbeets. Acreage and production figures for the included crops, by subregion and for the state, may be gleaned from Tables 1.1 through 1.4.

While a number of air pollutants are known to cause physical damage to plants, the emphasis of this study is on one specific type of air pollutant oxidants/ozone. The selection of ozone concentration as the ambient air quality parameter is based on the magnitude of ozone in terms of total air pollutants. Within California, oxidants/ozone comprise approximately 50% of total pollutants. Further, ozone appears to be the most significant pollutant in terms of vegetation damage.

The procedures used within this analysis, while specific to the included set of crops and type of pollutant, should be sufficiently general to be applicable to a wide range of crops and pollutants. Further, in terms of policy implications, results derived from the empirical analysis concerning the included set of variables should fill the most pressing informational needs of policymakers.

1.3 The Agricultural Sector: An Overview

The agricultural sector of California has experienced a significant growth during the past few years. Gross on-farm revenues have increased from $5.1 billion in 1972 to $9.1 billion in 1976 (U.S.D.A. Agricultural Statistics). While due partly to higher prices for vegetables in the period, there are several factors which continue to contribute to the overall growth of California agriculture. Among them are favorable environmental and technological conditions. The temperate Mediterranean type climate in California, a well-developed system for tapping the water resource base, relatively productive soils in some areas, high application of chemical fertilizers, pesticides and advanced mechanical aids enable growers to harvest a diverse high yielding and high value crop mix [Adams]. As a result, 38 of California's 61 agricultural commodities rank number one in the nation and only five of the 61 fail to rank nationally in the top ten.4/

Total economic values of California's principal vegetable crops5/ for 1974, 1975 and 1976 are: $1.24 billion, $1.38 billion and $1.28 billion, respectively. These values represent 44.23, 43.42 and 43.02% of total national vegetable marketing. Total acreages for the same period are 808,470 acres (24.36% of the U.S.), 865,920 (25.46%) and 768,160 (24.19%).6/ Value, acreage and percentages for specific crops are presented in Table 1.1.

Table 1.1

United States and California Crop Production:
Specific Vegetable and Field Crops, 1976

	United States[a]			California[b]				
	Acreage (1000 acres)	Production (1000 cwt)	Value ($1000)	Acreage (1000 acres)	Production (1000 cwt)	California Production as % of U.S.	Value ($1000)	California Value as % of U.S.
Vegetable Crop								
Beans, Green Lima	48.0	55.81	16,007	15.7	25.751	46.15	8,317	51.96
Broccoli	53.8	4,280.0	63,761	50.4	4,133.0	96.56	63,123	99.00
Cantalopes	73.2	10,005.0	108,075	39.0	6,623.0	66.20	70,442	65.18
Carrots	75.5	20,089.0	117,424	33.0	10,100.0	50.28	58,291	49.64
Cauliflower	33.8	3,218.0	52,575	26.5	2,558.0	79.49	40,400	76.84
Celery	33.3	16.821,0	137,374	19.8	11,110.0	66.05	78,922	57.45
Lettuce, Head	222.5	54,047.0	473,837	155.1	39,640.0	73.34	327,665	69.16
Onion, Fresh	31,7	7,172.0	44,466	5.9	1,652.0	23.03	7,814	17.57
Onion, Processing	n.a.	n.a.	n.a.	19.5	7,215.0	n.a.	27,524	n.a.
Potatoes	1,374.1	353,336.0	1,182,816	66.0	24,188.0	6.85	110,161	9.31
Tomatoes, Fresh	128.9	21,492,0	425,897	29.4	6,765.0	31.48	137,904	32.38
Tomatoes, Processing	309.0	6,471.8[1]	375,401	233.8	5,066.5[1]	78.29	284,734	75.85
Field Crop								
Cotton	10,869.1	10,095.9:	3,267,560	1,120.1	2,382.7[2]	23.60	835,192	25.56
Sugarbeets	1,480.5	29,427.0	582,655	312.0	8,892[1,3]	30.22	267,649[3]	45.94
							2,318,158	

[1] 1000 tons

[2] 1000 bales of 500 lbs each

[3] 1975 figures since the 1976 figures were not available at the time of compiling the table.

[4] Information on processing onions not readily available. However, it is generally assumed that California produces the bulk of U.S. processing onion production.

Sources:

%. S.D. A. Agricultural Statistics and [b] California Crop and livestock Reporting Service

Table 1.2

Crop Acreage Harvested, by Region
1972-76 and 1976

Crop	Southern Desert		Southern Coast		Central Coast		Southern San Joaquin		Study Region	
	1972-76 Average	1976	1972-76 Average	1976	1972-76 Average	1976	1972-76 Average	1976	1972-76 Average	1976
Vegetable Crops										
Beans, Green Lima			10,778	6,911	2,847	995	2,281	3,000	15,906	10,906
Broccoli			2,918	3,497	18,712	19,900			21,630	23,397
Cantaloupes	9,330	8,850	2,294	3,067			3,872	2,600	15,496	14,517
Carrots	5,102	5,510	10,233	11,302	4,803	4,674	9,440	10,000	29,578	31,486
Cauliflower			4,281	5,419	8,676	9,990			12,957	15,409
Celery			10,905	11,852	7,273	8,210			18,178	20,092
Lettuce, Head	44,380	43,900	17,714	18,939	69,206	73,565	4,430	5,100	135,730	141,504
Onion, Green	1,678	1,790	1,773	952	1,279	2,090	0	0	4,730	4,832
Onion, Dehydrated	2,007	925	3,794	4,000	1,602	1,250	6,230	6,500	13,713	12,675
Potatoes			8,839	9,438	4,803	4,376	34,907	36,023	48,549	49,837
Tomatoes, Fresh	1,765	1,766	8,882	9,924	3,895	4,332	2,342	2,023	17,252	18,045
Tomatoes, Processing	1,110	1,430	9,504	8,776	10,094	9,500	8,226	7,950	30,139	27,6[illegible]
Field Crops										
Cotton	54,400	71,000	18,257	23,562			413,320	447,000	485,977	541,562
Sugarbeets	62,600	58,000	9,811	9,015	18,258	24,390	27,896	29,891	118,565	121,296

Sources: County Commissioner's Annual Reports

Table 1.3

Average Annual Crop Production and Market Shares, by Region, 1972-76

Crops	United States (Total Production) 1/	California 1/3/		Southern Desert 3/			South Coast 2/			Central Coast 3/			Southern San Joaquin Valley 3/			Study Area	
			% of the U.S.	Production	% of the U.S.	% of California	Production	% of the U.S.	% of California	Production	% of the U.S.	% of California	Production	% of the U.S.	% of California	Production	% of California
Vegetable Crops																	
Beans, Lima (tons)	86,010	42,930	49.91	-			23,256	27.04	34.17	6.S44	7.3s	14.11	4,144	7.86	15.76	26.244	44.71
Broccoli (Cwt.)	3,959,800	3,597,000	90.s9				22s,171	6.07	4.62	1,012,1s0	25.56	28.13	.			1,250.334	54.15
Cantaloupes (Cwt.)	10,759,400	7,155,600	44.50	1,1s9,400	11.15	16.76	310,123	2.98	4.4s	.		.	728,400	6.77	10.18	2,248.823	11.42
Carrots (*C.)	20,648,200	10.321,200	49.99	1,703,400	1.25	16.50	3.193,959	15.47	30.95	1,402,420	4.79	13.59	3,220,000	15.59	31.20	9.519.979	92.24
Cauliflower (Cwt.)	1,035.400	2.383.s00	71.53	.		-	344,599	18.01	22.93	861,370	28.38	36.13				1,407,969	59.06
Celery (cut.)	16,385,600	10.5?9, UKI	64.34				4,201,152	37.84	58.61	4.0s6,5s0	24.94	38.63	-			10.217,732	97.24
Lettuce* (aN.)	S1,65S.800	17,079.800	71.78	11,124,000	21.53	20.00	4,491,817	8.69	12.11	11.14?.544	35.52	49.49	1.1s1.600	2.23	3.11	35,116,7s1	94.71
Onions, Fresh (an.)	5,994,000	1,788,200	29.83	440,400	7.9s	25.75	571,S62	9.54	31.98	386.960	6.44	21.44				1,419,222	79.37
blow, Processing (cut.)	21.456.400	1.%61,100	33.67	548,000	2.44	7.25	1.209,004	5.38	15.99	565,552	'2.51	7.45	2,118,400	9.43	28.01	4,438,952	5s. 70
Potatoes (Cwt.)	322,129.000	22,720,000	7.05				1.s13 ,714	.88	12.43	1.511.160	.49	6.91	9.611,452	1.9s	42.30	34,004.2s6	41.44
Tomatoes, Fresh (cut.)	20.404,400	6,882,000	11.72	384, boo	1.ss	5.59	4,174,195	20.45	40.46	1,19s,2s0	5.07	17.41	674.768	3.31	9.s0	4,431.743	93.44
Tomatoes, Processing (Tons)	7,160,4s0	5,514,440	77.23	24,040	.s4	.44	235,970	5.20	4.11	257,5s9	3.41	4.67	144,940	2.34	1.03	684,559	12.42
Field Crops																	
Cotton (bales of 300 lbs.)	10,8 M.811	2,024,640	18.59	124,568	1.14	6.15	37,212	.24	1.s4				s4s.261	7.79	41.90	1.010,061	69.4S
Sugar beets (tons)	26,832,600	7.842,000	29.23	1.59s.400	5.94	20.38	271,305	1.01	3.49	400,102	2.24	7.65	729.274	2.75	9.43	3,211,0s1	40.95

SOURCES: 1/ U.S.D.A. Agricultural Statistics.
2/ County Commissioner's Annual Crop Report.
3/ California Crop and Livestock Service, Annual Report.

* Regional figures shown above & not include approximately 555,998 cwt. leaf lettuce and 1,012,882 cwt. Romaine lettuce.

Southern Desert - Imperial County

South Coast - Las Angeles County, Orange County, Riverside County, San Bernardino County, Santa Barbara County, San Diego County, Ventura County

Central Coast - Monterey County, San Benito County, San Luis Obispo County, Santa Cruz County

Southern San Joaquin Vail.~ - Kern County, Tulare County

Table 1.4

1976 Regional Crop Production

Region	Unit	Region				Total	% of California
		Southern Desert	South Coast	Central Coast	Southern San Joaquin		
Vegetable Crop							
Beans, Green Lima	(TOSS)		14,087	2,505	9,000	25,592	99.39
Broccoli	(CWT)		292,770	1,207,400		1,500,170	36.30
Cantalopes	(CWT)	1,128,000	461,332		468,000	2,057,322	31.05
Carrots	(CWT)	2,215,000	2,908,021	1,416,800	3,500,000	10,039,821	99.40
Cauliflower	(CWT)		617,877	975,850		1,593,727	62.30
Celery	(CWT)		6,478,100	4,529,800		11,007,900	99.08
Lettuce, Head	(CWT)	11,720,000	4,950,130	20,535,170	1,490,000	38,695,300	97.62
Onion, Fresh	(CWT)	374,000	277,328	596,600		1,247,928	75.54
Onion, Dehydrated	(CWT)	300,000	1,400,000	393,260	2,580,000	4,673,260	64.77
Potatoes	(CWT)		2,900,200	1,428,600	10,630,900	15,039,700	62.18
Tomatoes, Fresh	(CWT)	384,000	5,020,416	872,000	403,480	6,679,896	98.74
Tomatoes, Processing	(TONS)	36,000	178,538	188,980	195,000	598,518	11.81
Field Crops							
Cotton	(BALLS)	141,500	51,122		972,760	1,165,382	46.95
Sugarbeets	(TONS)	1,476,000	256,636	86?,020	849,638	3,449,292	38.79

● Leaf Lettuce: Southern Desert = 0
South Coast = 428,076 CWT
Central Coast = 526,200 CWT
Southern San Joaquin = 0

*Romane Lettuce: Southern Desert = 0
South Coast = 233,320 CWT
Central Coast = 965,800 CWT
Southern San Joaquin = 0

These aggregate characteristics of the California agricultural sector tend to mask SOme rather sharp distinctions observed at the regional level. Although the Certral Valley and Central Coast (Salinas Valley) are considered the most significant Production regions in terms of value of production, other regions such as the South Coast and Imperial Valley (identified by the California Crop and Livestock Reporting Service as Crop Reporting District No. 8) are nationally important in the production of many specialty crops, on both a seasonal and annual basis. This is particularly pronounced in both winter and spring vegetables as well as horticulture crops such as cut flowers. Moreover, the South Coast and Imperial Valley areas also produce significant quantities of avocadoes, strawberries and sugarbeets. Table 1.2 presents a regional breakdown of crop acreages for the period 1972-1976 and for 1976. Tables 1.3 and 1.4 provide regional data on value of production and national market shares for the same periods.

This regional importance is primarily attributable to climatological considerations concerning the product mix that growers may undertake in these regions. For instance, crop production in some climatologically distinct regions, while plagued by higher production costs, remains viable due to higher output prices normally received for winter and spring season production or for some specialty crops. However, in the presence of environmental degradation which results in reduced production (yields) within the region, one would expect the total. output and cropping mix undertaken by growers to be affected (if differential effects across crops are assumed) through substitution effects (e.g., use of lower yielding but more resistant crop varieties) or depressed per unit productivity (caused by diminished air quality or sub-optimal changes in production location). The resultant higher output prices and/or lower yield for certain seasonal production and other specialty crops may then significantly affect consumers' and producers' welfare.

1.4 Purpose and Objectives

The main purpose of this report is to convey the methodological and empirical results realized to date for the agricultural phase of EPA Benefits project. The intent of this project phase is to develop a tractible methodology for the assessment of economic damages to agricultural crops associated with air pollution (oxidants) and apply such a methodology to an actual production region. The empirical basis of this study is derived frcm the application of these methodological constructs to the four delineated regions in the study area (South Coast, Desert, Central Coast, Southern San Joaquin Valley).

Specific objectives of this report are to:

1. Present a current review of literature on physical and economic damages as they pertain to the development of tractible research approach;

2. Present an overview of the incorporated methodology;

3. Estimate and discuss the results of air pollution yield response functions and crop price-forecasting equations required for damage estimation;

4. Present a measure of economic damages for consumers as measured by the above yield and price parameters; and

5. Discuss areas in need of further research to fully capture the effects of air pollution on crop production. These include production substitution (both input and output effects) and risk effects associated with crop production in areas of high levels of oxidant.

1.5 Plan of Presentation

The report contains six major chapters, in addition to the introduction. These include: Chapter II-review of literature; Chapter III-methodological considerations; Chapter IV-yield response functions; Chapter V-price forecasting equations; Chapter VI-estimates of economic damages to consumers; and Chapter VII-areas in need of further research. Each chapter is intended to be independent in content. Thus, readers may skip chapters, depending upon area or extent of interest. Details concerning items within the executive summary may be obtained from appropriate chapters.

FOOTNOTES: CHAPTER I

1/ For more details see Chapter II of this report.

2/ Barrett and Waddell (1973).

3/ The counties included in each region are as follows: South Coast -- San Diego, Orange, Los Angeles, Riverside, San Bernardino, Santa Barbara, Ventura; Desert -- Imperial; Southern San Joaquin -- Tulare, Kern; Central Coast -- Monterey, San Benito, San Luis Obispo, Santa Cruz.

4/ California County Fact Book 1976-1977, pp. 22-23. The ranking is based on quantity produced. These five commodities are corn, for grain (ranks 24th nationally), corn, sweet (11th), oats (16th), red clover seed (17th) and wheat (13th).

5/ For fresh market: artichokes, asparagus, snap beans, broccoli, brussel sprouts, cabbage, cantaloupes, carrots, cauliflower, celery, sweet corn, cucumbers, eggplant, escarole, garlic, honeydew melons, lettuce, onion, green peppers, spinach, tomatoes and watermelons. For processing: lima beans, snap beans, beets, cabbage, sweet corn, cucumbers (pickles), green peas, spinach, and tomatoes.

6/ All figures for 1976 are preliminary.

CHAPTER II

AGRICULTURAL CROP DAMAGES BY AIR POLLUTION - A REVIEW OF LITERATURE

2.1 Introduction

The relationship between plant injury and levels of air pollutants such as oxidants is a subject of significant research effort. The importance of the subject stems from the health and economic implications portended by impacts of air pollution on plants. Also, the measurement of such relationships is controversial because plant injury is due to a wide range of factors. There does, however, appear to be general agreement that plant injury is primarily dependent on the concentration of fumigant and time of exposure, although environmental factors and meteorological conditions also influence this relationship. Moreover, it has been discovered that different varieties of each plant specie have different degrees of susceptibility to air pollution concentration and thus display different degrees of damages, both physically and economically.

The purpose of this section is to briefly review some recent studies concerning both physical and economic damages of agricultural crops caused by air pollution. Concentration will be on those studies dealing with such air pollutants as photochemical oxidant and ozone, within the United States. This literature review is thus not exhaustive. For a more detailed review, the interested reader is urged to pursue the subject by going through the bibliography cited in footnote 1. The review in this section will start with those studies concerning physical damages and then proceed with a review of literature dealing with economic damages.

2.2 Physical Damages of Crops by Air Pollution

Plant pathologists, biologists and other plant scientists have been concerned with effects of air pollutants on vegetation for perhaps a century or more but it was not until the early 1950's that extensive research on the "physical" damages of air pollution on plants was carried out. During the last 25 years the number of publications on the subject in various professional journals has increased significantly.1/

Perhaps the first experimental, evidence of effects of air pollutant on vegetation was that done by Lea in 1864. In his experiment, Lea germinated wheat seedlings on gauze under bell jars with and without ozone generators. The seedlings without ozone developed normal roots but the roots subsequently became moldy. The seedlings in ozone, surprisingly, had very short roots that grew upward and remained free of mold.

Knight and priestly in 1914 damaged seedlings with ozone during their investigation on the effect of electrical discharges on respiration. Homan in 1937 investigated the possibility that ionized air and ozone might be capable of improving plant growth. In 1948, Schemer and McColloch (1948) attempted to use the antifungal properties of ozone to prolong the life of apples in storage. From such an experiment, it was determined that one could deter surface molds for seven months if the apples were kept in 3.25 ppm Of ozone. Unfortunately, results obtained showed many of the ozone-treated apples developed brown sunken areas around the lenticels [Rich, 1964, p. 154].

Middleton, et. al. (1950) were among the first to report that photochemical air Pollutants can damage field crops. Their initial concern was with ozone damage, but later found the primary cause of damage to be PAN. While ozone was not initially thought to be important as a crop damaging pollutant, by 1957 Freebairn had established that crops could be adversely affected by ozone injury. In 1958, grape stipple caused by ozone was verified [Richards, et. al., 1958]. This type of injury had been a major problem in California vineyards since 1954.

The nationwide distribution of ozone as a potential threat to agriculture became apparentin 1959, when ozone was reported to cause damage to many crcps in New Jersey [Dairies, et. al., 1960]. Through fumigation experiments, Ledbetter, et. al. (.1959), and Hill, et. al. (1961) extended the list of plants that can be injured by ozone. Thomas (1961) performed a fairly comprehensive review of the available information on the effects of photochemical oxidants on plants.

Middleton (1961) gave the first comprehensive coverage of the phytotoxic effects of photochemical oxidants. Rich (1964) presented an early and detailed review of ozone effects on plants. The degree of injury to susceptible plants is directly related to the concentration of ozone to which plants are exposed and to the duration of the exposure [Rich]. Although symptoms of ozone injury may vary across species, there are several symptoms that appear to be typical of the ozone syndrome. One of the first symptoms of ozone injury is the appearance of “water-soaked” spots found on tobacco leaves. If the damage is not severe, the injured cells may ultimately recover. The following phase is usually bleaching. With more severe injury, the chlorotic or discolored areas may become necrotic and then collapse. Another symptom of ozone injury in plants is yellowing or premature senescence of older leaves, accompanied by abscission.

Once ozone gets inside the leaf, it attacks the palisade parenchyma first. The symptoms of ozone injury to palisade cells vary. “In grapes, the injured cells become darkly pigmented before they die” [Richards, et. al., 1958, p. 257]. A similar type of pigmentation accompanied by thickening of the cell walls is also found in ozone damaged palisade cells of avocado and Strawberry [Ledbetter, et. al. , 1959]. In tobacco, sugarbeet, and occasionally peanut and sweet potato, the ozone injured palisade cells collapse and then become bleached. The surrounding tissue may be unaffected if the ozone damage is not too severe. Otherwise, the adjoining mesophyll and upper epidermis may die [Povitailis, 1962]. In tomato and potato there is complete collapse of the tissue within the lesion caused by ozone.

A series of experiments abcut effects of air pollutants on citrus trees carried out by Thompson and Taylor, Thompson and Taylor and Associates in the 1960's in the Los Angeles Basin [Thompson and Ivie, 1965; Thompson and Taylor, 1966; Thompson, et. al. 1967; Thompson and Taylor, 1969] show that the photochemical smog complex present in that area reduced water use and the apparent photosynthesis of citrus trees. Ambient levels of fluoride had no significantly measurable effects.

> "The smaller total leaf drop in trees which received filtered air was compared to the unfiltered treatments is somewhat significant but when measured for long periods tends to become equal in all trees because all leaves become senescent and fall eventually. The much more revealing work was the study in which the separate lemon branches with tagged, dated leaf flushed were counted periodically. These showed, after 18 months that the trees receiving filtered air had lost 28% of their leaves while the unfiltered treatments had lost 66%" [Thompson and Taylor, 1969, p. 940].

Effects of ozone (comprising almost all the oxidants in the South Coast Air Basin) on some crops such as corn, tomato, lettuce and cabbage in the South Coast area have been studied and reported by Oshima (1973). In that study, a short-term fumigation study was undertaken in order to determine oxidant effects on young seedlings. A long-term fumigation study was then used to determine effects on crop quality and yield and to develop criteria for field studies. Seedlings of the Golden Jubilee variety were exposed to 0.24 ppm ozone concentrations for 1.5% of the growing period. Fumigations were initiated upon emergence and discontinued after a 30-day period. Results from the experiment indicated that ozone injury was observed on the seedling corn leaves of the ozone treatment throughout the fumigation. At harvest, the size and weight of the fumigated plants were reduced when compared to controlled plants. In summary, Golden Jubilee corn was seriously affected by ozone in the 0.20-0.35 ppm concentration range under greenhouse conditions-. The general effect of the ozone exposures was a reduction in the size and weight of the corn plants. A higher concentration of ozone, say, 0.35 ppm, reduced the dry weight of the ears by 22.3% which is twice the 12.5% reduction found in the 0.20 ppm treatment. However, ozone does not seem to influence the quality of field grown Golden Jubilee corn ears to any great extent. The only quality criterion possibly associated with ambient oxidant dosages was the extent of blemishes on harvested ears. This might be due to the fact that this variety of corn is somewhat resistant to disease and air pollution injury.

The same procedure described shove was used on tomato, lettuce and cabbage; the results obtained are described below. Ozone exposures at a moderate level (0.24 ppm) reduced the size and weight of H-n variety tomato seedlings. Reductions in height of plant, weight, and number of leaves indicate that the fumigated seedlings were not as fully developed as controlled plants. Higher levels of ozone concentrations (0.35 ppm) significantly affected fruit yield. Although ozone injury was observed on field-grown tomato plants, no quality reductions attributed to ozone were detectable on harvested fruit.

Prizehead lettuce was found to be resistant to ozone and other pollutants at all stages of growth. Ozone fumigated seedlings were reduced in percent solids from Controlled plants, but only the high concentration (0.35 ppm) level of ozone over a period of time produced detrimental effects on the mature stages of growth. Dark green Boston lettuce was selected for long-term fumigation studies as a comparison to Prizehead lettuce. This variety proved to be far more susceptible to ozone than the Prizehead variety. The percentage of leaves affected by oxidants would make these plants unacceptable for marketing. Ozone also produced a reduction in the overall SiZe Of plants in both fumigated treatments. It should be noted, however, that lettuce is regarded as a cool weather crop and is thus generally grown in the spring or fall, a period when it would not be subjected to the high exposures of ozone which affect summer grown crcps [Oshima, 1973, p. 80].

Long-term fumigations indicated that ozone does not affect the quality of Copenhagen Market cabbage heads. Greenhouse grown Copenhagen Market cabbage was found to be sensitive to ozone leaf injury at all stages of growth. However, injury to wrapper leaves by ozone did not always reflect reduced yields or quality. Plants exposed to a lower level of ozone (say, 0.20. ppm) displayed considerable leaf injury but no reduction in either the size or the weight of harvested heads. Leaf injury was also observed in the 0.35 ppm level of ozone concentration but there were no significant yield reductions. This variety apparently tolerates a degree of ozone leaf injury without any significant effect on size or weight of the head. Jet Pack cabbage, a commercial hybrid, was then introduced in the long-term fumigation studies as a comparison with Copenhagen Market cabbage. Effects of ozone injury were essentially the same as Copenhagen Market.

Brewer and Ferry (1974) carried out a study on effects of photochemical air pollution (smog) on cotton in the San Joaquin Valley in 1972-73. The experiment consisted of placing pairs of filtered and non-filtered plastic covered greenhouse shelters over established plots of cotton in some selected locations in the valley. All greenhouses were equipped with electric motor driven blowers which changed the air in each house twice every minute. One of each pair of blowers was equipped with activated carbon filters which effectively removed oxidants, ozone and nitrcgen dioxide. Plant height, squares, bloom and boll set were then recorded for each plant at about two-week intervals. The experiment shows that one obvious effect of the carbon-filtered air on cotton plant growth at all locations was the retention of vigor and color during late summer and early fall. Moreover, plants in the filtered air were green and continued to bloom and mature bolls weeks after those in the outdoor plot and non-filtered greenhouse had colored and become senescent.

Plant injury by air pollution not only depends on the level of concentration of each pollutant and environmental factors but also depends on differential variety of each crop. Many plant pathologists and vegetable crop specialists and other plant scientists have conducted studies in order to test the degree of susceptibility of each variety of crop to air pollutants at certain locations. Results from such experiments have then served as suggestions to farmers as to which variety of crop should be used for the next growing season. An experiment of this type was conducted on sweet corn hybrids by Cameron, et. al. (1970) in Riverside and Los Angeles, California. The study showed a marked differential in injury from air pollution in different sweet corn hybrids; e.g., at Riverside, leaf damage by oxidants ranged from nearly zero in 11 hybrids to slight to severe in 23 others. This was also true in the Los Angeles area.

> "Thus, it appears that among the cultivars there were great differences in injury which cannot be attributed to cultural factors such as fertilization or irrigation, or to high temperature alone. Genetic resistance to air pollution damage is apparently present in some cultivars, but not in others." [Cameron, et. al., 1970, p. 219]

Experiments by Thompson, et. al. (1976) on two varieties of sweet corn in the Los Angeles Basin also showed different degrees of susceptibility to ozone injury. Studies by Reinart, et. al. (1969), Clayberg (1971, 1972) and Oshima, et. al. (1975) on different varieties of tomato found both resistant and susceptible cultivars to ozone concentration. These varieties were then ranked in order of degree of susceptibility. Finally, Davis and Kress (1974) selected six varieties of bean from those recommended for commercial production in Pennsylvania in their study concerning the relative susceptibility of each variety to ozone. Plants were exposed to 0.25 ppm ozone for 4 hours at a temperature of 21°C, 75% relative humidity, and a light intensity of 25,000 lux. In each variety, five plants were exposed from 8:00 am to 12:00 noon, and the remaining five from 1:00 pm to 5:00 pm on the same day. Such exposures were conducted on three different days, each 30 days from the respective planting date. Results showed that ozone symptoms differed slightly across varieties, but were generally a dark stipple or a light tan fleck on the upper surface of the leaf.

From the literature reviewed, one can conclude that air pollutants such as oxidants or ozone cause damages to various plants and crops. The degree of injury to susceptible plants depends directly on the concentration of ozone and the duration of the exposure. Minor injury may result only in yellowing or premature senescence of older leaves and the injured cells may ultimately recover. If, however, the damage is severe, the chlorotic or discolored areas may become necrotic and collapse, followed by leaf-drops, fruit-drops, reduction in growth and yield and may finally result in the death of the plant.

Empirical studies indicate that various types of agriculturally important vegetables such as beans, cabbage, corn, lettuce and tomatoes and some field crops such as cotton are susceptible to ozone concentrations. Selected exposures reduced the size and weight of fruit, the height of plant and the number of leaves. Higher levels of ozone concentrations significantly affected fruit yield. However, effects of ozone on the quality of fruit is not well established. Finally, it is evident that varieties of each crop respond differently in terms of degrees of susceptibility to a specific type of air pollution. Farmers, based mainly cn past experience, usually choose the variety that has the highest degree of tolerance to air pollution in that area.

2.3 Economic Damages of Crops by Air Pollution

As reported in the preceding section, the effects of oxidant on vegetation have been intensively studied over the past 25 years. Oxidant or smog type symptoms were identified with the reaction product of ozone and reactive hydrocarbons (automobile exhaustion). Generally speaking, the adversary effects of air pollution on agricultural plants are reductions in the quantity of output (yields] and/or degradation of the quality (nutritional content) of the product. In terms of measurement of economic damages, the scope and content of research efforts are somewhat more limited, particularly with respect to methodologies. Waddell (1974) identified some general approaches for such measurement purposes. One approach is to actually survey the damage loss on a statewide basis. This approach has been used in studies by Middleton and Paulus (1956), Weidensaul and Lacasse (1970), Millecan (1971), Feliciano (1972), Naegele, et. al. (1972), Pen (1973), and Millecan (2976). Another approach is to construct predictive models relating data on crop losses to crop values, pollution emission and meteorological parameters. The most comprehensive attempts using such an approach are studies done by Benedict and Associates (1970, 1971, 1973) at the Stanford Research Institute (.SRI). A third approach to assessing economic damage of crops by air pollution is to estimate the "dose-response function" and then relate it to the calculation of losses for each crop. This approach has been attempted by O'Gara (1922), Guderian, Van Haut and Stratmann (1960), Stratmann (1963), Zahn (1963), Larsen and Heck (1976), Oshima (1975), Oshima, et. al. (1976. 1977), and Liu and Yu (1976). This method will be described in the section on air pollution response function estimation presented later.

Economic assessment of air pollution damages by investigators on a site-specific basis was first done in a California survey conducted in 1949. A somewhat similar survey in 1955, reported by Middleton and Paulus (1956), was designed to show the location of injury, the crops injured, and the toxicant responsible for the damage. Agricultural specialists throughout the state were trained as crop survey reporters with the survey covering four categories of crops: field, flower, fruit, and vegetable.

A program similar to that in California was established in Pennsylvania in 1969 [Weidensaul and Lacasse, 1970]. The objectives of that survey were: (1) to estimate the total cost of agricultural losses caused by air pollution in Pennsylvania; (2) to determine the relative importance of the various pollutants in Pennsylvania; (3) to survey the extent of the air pollution problem in Pennsylvania; (4) to provide a basis for estimating the nationwide impact of air pollution on vegetation; and (5) to provide a basis for guiding research efforts.

The Pennsylvania study included both commerical and non-commercial plants. Past air pollution episodes were investigated for purposes of detecting possible trends. Estimates of losses obtained were based on crop value and production costs incurred by harvest time. Direct losses to producers and growers included only production costs, whereas indirect losses included profit losses, costs of reforestation, grower relocation costs, and the cost of substituting lower value (highly resistant) crops for higher value (but very sensitive) crops. Other costs such as those associated with destruction of aesthetic values, erosion and resultant stream silting, damage to watershed retention capacity, and farm abandonment were not considered.

Of the 92 field investigations made within the Pennsylvania study, 60 revealed damages that were attributable to air pollution. Damage resulting from pollution was observed in 23 counties, primarily located in southeastern and western Pennsylvania. Direct losses estimated in the survey exceeded $3.5 million. The air pollutants responsible for the damage, in order of decreasing importance were oxidants, sulfur oxide, lead, hydrogen chloride, particulate, herbicides, and ethylene. The vegetation most affected (also in lawns, shrubs, woody ornamental, timber, and commercial flowers. Indirect losses were estimated at $8 million of which $7 million reflects profit losses, $0.5 million reflects reforestation costs, and the remainder reflects costs for grower relocation.

The approach used in the Pennsylvania study may be criticized on several aspects. First, the method used in assessing losses is somewhat questionable because grower profit losses are not included as direct costs (since profit is normally the main objective of producers, such losses may be direct). Second, methods of translating physical damage into economic loss have not been standardized. Third, not much is known of the extent to which home garden plantings and flowers are being affected by air pollution and, if they are affected, then what value should be assigned to these losses.

There are certain advantages, however, of this procedure, such as: (1) existing manpower used in the initial survey can be used to achieve continual coverage over an area; (2) local agents have rapport with growers in that area, are familiar with crop peculiarities, and are probably knowledgeable about local sources of pollution in the area; and (3) a field coordinator supplies expertise to the reporting personnel and also provides some degree of standardization in reporting losses.

A similar study was carried out for Pennsylvania in 1970 [Lacasse]. Using the same concepts of cost (direct and indirect) as in the previous year's survey, Lacasse estimated direct losses to be $218,630 and indirect losses of $4,000. The relatively low damage figure for that year was due to:

> "fewer inversions and to no unfavorable growing conditions when air stagnation did occur." [Lacasse, 1971]

Similar surveys have also been carried out by Feliciano in New Jersey and in the New England States in 1971. Feliciano (1972) estimated that agricultural losses due to air pollution in New Jersey were $1.19 million. However, as in the Pennsylvania surveys profit losses were not included.

In the course of the New Jersey surveys a total of 315 air pollution incidence were investigated and documented. A "rule of thumb" evaluation method developed by Millecan (1971) was used for estimating losses, i.e., if visual inspection Of the overall leaf surface of the plants indicates 1-5% injury a 1% loss was applied for that crop. A leaf surface injury of 6-10% was assigned a 2% loss; 11-15% injury, a 4% loss; and 16-20% injury, an 8% loss. Estimates of total losses were then based on the crop value of the acreage affected.

Naegele, et. al. (1972) reported on a field survey of agricultural losses in the New England region resulting from air pollution. The survey contains 83 investigations in 40 counties covering the six New England states. Direct economic losses for the 1971-72 season were estimated at approximately $1.1 million. Economic loss estimates were based on grower costs, crop value at the time of harvest and the possibility of crop recovery following the pollution incident. The direct losses in this study, in contrast to the Pennsylvania and New Jersey cases, include grower profit losses. Among the crops studied, fruit, vegetables, and agronomic crops suffered the greatest losses, with over 90% of the damage being attributed to oxidant air pollution.

An approach similar to that used in Pennsylvania, New Jersey and New England was used by Millecan (1971) to survey and assess the damage of air pollution to California vegetation in 1970, Prior knowledge about the distribution of air pollution problems placed concentration of the study in the Los Angeles Basin, San Joaquin Valley, and the San Francisco Bay area. Estimates of losses were confined to 15 of the 58 counties in the State, even though plant injury from air pollution was observed in 22 counties. Ventura County, on a county-wide basis, suffered the greatest economic crop loss (approximately $11 million). Losses of citrus production in the Los Angeles Air Basin accounted for over $19 million of a total monetary loss of almost $26 million. Such a monetary loss estimate does not include losses attributed to reduction in crop yield or growth (except for losses of citrus and grapes) nor losses to native vegetation including forests, nor to landscape (horticultural) plantings. Photochemical smog accounted for most of the economic losses. Specifically, the percentages of plant injury caused by each type of air pollutant are as follows: ozone, 50%; PAN, 18%; fluorides, 15%; ethylene, 14%; sulfur dioxide, 2%; and particulates, 1%.

In order to obtain a better understanding of the year-to-year variation in plant losses caused by air pollution, Pen (1973) continued the research initiated by Feliciano in 1971. The direct losses of agronomic crops and ornamental plantings estimated by Pen for the 1972-73 growing season were approximately $130,000. As in the study by Feliciano, costs associated with crop substitution and yield reductions were not considered. In decreasing order of importance the damaging pollutants were: oxidants, 47% of crop losses; hydrogen fluoride, 18%; ethylene, 16%; sulfur dioxide, 4%; and anhydrous ammonia, 1%. The damage reported in this sruvey, surprisingly, was only 11% of that reported by Feliciano in the 1971-72 New Jersey survey. Perhaps one explanation is that the significant year-to-year variation observed may be attributed to altered environmental conditions rather than to decreased air pollution concentrations. As an example, it is believed that the unusual rainfall patterns in 1972 placed the plants under water stress and thus protected them from air pollution injury.

A detailed survey and assessment of air pollution damages for California vegetation covering the period 1970-74 was again conducted by Millecan (1976). The survey was done in 10 counties2/ and covered four types of crops: fruit and nut, field crops, vegetable, and nursery and cut flowers. Within the framework of this study, a method known as the crop-dose conversion scale was developed to measure monetary losses to alfalfa. This method is asserted to represent an improvement in determining monetary loss values related to the effects of air pollution on agricultural crops. The conversion scale method is viewed as providing accuracy since it utilizes actual pollution doses within the growing areas in a county and does not have to apply averaging techniques as are needed in the general survey method. In addition, the conversion scale method is able to produce standardized annual crop loss estimates, i.e., yearly estimates of crop losses taken from the conversion scale would differ only from variations in ambient ozone dose and would therefore provide a uniform basis of annual comparisons. In deriving the loss figures three factors were considered: (1) the value of the crop, taken from the respective County Agricultural Commissioner's annual crop production reports or crop production reports of the California Department of Food and Agriculture; (2) the pollution index, which represents a measure of oxidant readings observed throughout the year, differences in air pollution levels among individual counties can then be compared by means of this index; (3) the percentage of crop damage using the 1970 loss figures [Millecan, 1971] as a reference point, as related to the increase or decrease in the air pollution index.

The overall monetary losses in the ten counties caused by air pollution have increased from 1970 to 1974. Such losses are reported as about $16.1, $19.1, $17.4, $35.2, and $55.1 million respectively. Such increases may be due partly to the increased per unit value of agricultural crops in each year, i.e., the physical damages to individual crops may not necessarily have increased. The large increase in losses in 1973 and 1974 was attributed to an increased level of air pollution, a larger crop and an increase in crop value [Millecan, 1976, p. 7]. Almost half of the monetary loss in 1974 was in cotton in the San Joaquin Valley. In conclusion the author noted that:

> "Monetary loss from air pollution damage to agricultural crops will generally increase yearly because of several factors such as: an increase in knowledge of plant susceptibility, an increase in the ability to assess more correctly the effects of air pollution, an increase in population and possibly an increase in air pollution levels." (p. 22)

Perhaps the most comprehensive research effort on economic damages was performed by the Stanford Research Institute.3/ The objectives of the SRI Nationwide Survey were to develop a model for estimating dollar losses to vegetation resulting from the effects of pollutants, and to make such estimates. The procedures and results of the study were as follows:

1. Selection of those counties in the United States where major air pollutants -- oxidants (ozone, PAN, and oxides of nitrogen), sulfur dioxide, and fluorides -- were likely to reach plant-damaging concentrations. The counties selected were those in the Standard Metropolitan Statistical Areas, under the assumption that damaging concentrations of oxidants and sulfur dioxide were more likely to occur in the most populous areas.

2. The potential relative severity of pollution in each county was then estimated. The severity of oxidant pollution was then derived by first estimating, from fuel consumption data, the emissions per square kilometer per day of tons of hydrocarbons and oxides of nitrogen (the precursors of oxidants). These emissions values were then multiplied by a concentration rate factor and a factor related to area of the county or SMSA. The results obtained yielded a value indicative of the relative concentration of oxidant that might be reached in a single pollution episode. These values were then multiplied by the number of days involved in pollution eFisodes to obtain a value indicative of the overall plant-damaging potential for oxidant pollution in the various counties.

The same procedures were used for estimating the plant-damaging potential for sulfur dioxide. In the case of fluorides, the relative plant-damaging potential was based on the number, type, and size of large single source emitters present.

The counties were then arranged and grouped into classes in order of the severity of the plant-damaging pollution potential.

3. The dollar values of commercial crops, forests, and ornamental plantings were then determined or calculated by the following procedures:

a. Commercial crop values for 1964 and 1969 were taken from data in the Census of Agriculture and supplemented, for 1969, by yearly reports of the states or individual counties involved.

b. Values of forests were calculated from Federal and State records.

c. For ornamental plantings, maintenance and replacement costs were the representative values. The dollar values for the states were first determined and these values were then prorated to the polluted counties based on their proportionate area, population, or combination of area and population of the state.

4. To arrive at the loss to each plant that might occur in each class of plant-damaging pollution potential, the following methods were used:

a. Each group of ornamental were classified, based on literature reviews, as sensitive, intermediate or resistant to each pollutant. They were also classified as to whether the part of the plant directly affected by the pollutant (i.e., leaves, roots, fruit) had high, medium, or no economic use.

b. The next step was to obtain the percentage loss occurring to the most sensitive plants in the high-use category in the most severely polluted counties.

c. Using the above two types of information, tables were prepared showing the percentage economic loss that would occur to plants in each sensitivity use category in each pollution potential class for each pollutant associated with those described in (2).

5. These factors were then applied to value of the crops, forests, and ornamental grown in the polluted counties, and recorded the dollar loss value for each crop in each county. These values were added to arrive at the state, regional, and national values.

6. In obtaining the 1969 estimates, 687 of the 3,078 counties in the United States (excluding Alaska) were selected as having exposure to potentially plant-damaging levels of oxidants, sulfur dioxide, and fluorides. Of these counties, 493 would be exposed to oxidants, 410 to sulfur dioxide, and 87 to fluorides (some counties would be exposed to damaging levels of two or more pollutants). On the basis of area and population, about 14.6% of the area and 68.9% of the population were likely to have plant-damaging oxidant pollution. For sulfur dioxide, the respective values were 16.2% and 53.0%, and 4.2% and 6.8% for fluorides. For the 1964 estimates, these values were: 11% and 62% for oxidants, 13% and 54% for sulfur dioxide, and 4% and 9% for fluorides.

The analysis used in the 1969 estimates indicates that 40% of the gross values of agricultural crops, 36% of the value of forests, and over 50% of ornamental value lies within polluted areas of the United States. The study also indicated that as much as 40% of the crops in a county could be lost due to oxidants, 12% due to sulfur dioxide, and 12% due to fluorides.

When the loss factors for the various pollution intensities were applied to the values of crops and ornamental, the total annual dollar loss to crops in the United States in 1969 was calculated to be about $87.5 million, of which $77.3 million was due to oxidants, $4.97 million to sulfur dioxide, and $5.25 million to fluorides. The value of loss to ornamental was estimated to be about $47.1 million, of which $42.8 million was attributable to oxidants, $2.7 million to sulfur dioxide, and $1.7 million to fluorides. These estimated values are not greatly different from those found for the 1964 estimates (total loss was $85.4 million, of which $78.0 million was due to oxidants, $3.2 million to sulfur dioxide, and $4.2 million to fluorides).

For 1971, it was estimated that the losses to vegetation for the United States were $123.3 million due to oxidants and $8.2 million to sulfur dioxide. No attempt was made to calculate losses due to fluorides in 1971.

In summary, the dollar loss as estimated for the 1969 and 1964 crop values represented, respectively, 0.44 and 0.46% of the total crop value of the United States in those years.4/

"On a regional basis, the greatest percentage of crop losses occurred in the heavily populated and industrialized areas of southwestern anti middle Atlantic and Midwestern states. The lowest percentage loss occurred in the plains and mountain states." [Benedict, Miller and Smith, 1975, p. 8]

2.4 Measurement of Air Pollution Damages: Air Pollution Response Functions

The approaches and estimates of air pollution crop damage outlined above are representative of earlier research in this area. A more general set of literature exists which deals with all types of air pollution damages. This section briefly discusses the more important contributions in the area and introduces explicitly the concept of an air pollution response function. Such functions serve to quantify the relationship between a particular variable and levels of air pollution. These relationships are extremely important in the assessment of crop damages.

The literature on air pollution contains six general methods for estimating damages from air pollution. These methods are: (1) technical coefficients of production and consumption; (2) market studies; (3) opinion surveys of air pollution sufferers; (4) litigation surveys; (5) political expressions of social choice; and (6) the Delphi method. These methods have been used with different degrees of success and are not necessarily mutually exclusive [Waddell, 1974, p. 22]. Among these methods, the technical coefficients of production and consumption and the Delphi methods have been used substantially in agricultural studies in forecasting crop production levels at different levels of air pollution. The market studies method is used widely in determining the adverse effect of air pollution on human activity and behavior such as the relationship between air quality and consumer behavior or the consumption of recreation-related activities [Vars and Sorenson, 1972]. Another type of market study is the use of the concept of property values to estimate air pollution damages [Ridker and Henning, 1967; Anderson and Crocker, 1970; Peckham, 1970; Crocker, 1971; and Spore, 1972]. The method incorporating opinion surveys of air pollution sufferers is perhaps closest to the classical economic approach in that it focuses on estimating utility and demand functions for such individuals, but it also suffers from at least two problems, i.e., the "free-rider" aspect and the possibility that a respondent might not understand fully the consequences of air pollution on his health [Waddell, 1974, p. 30]. The litigation surveys and the political expressions of social choice methods are rather subjective and limited, since the information gathered represents opinions of special groups of people such as lawyers, court clerks, state and local control officials, politicians, and representatives. Their opinions might be quite different from people who actually suffer from air pollution.

In general, the estimation of technical coefficients concerning production and consumption is facilitated by: (1) the use of experimental data on subjects under conditions simulating their natural environment; (2) estimation of the physical or biological damage-function which relates damage to different levels of air pollution; (3) translation of the physical damage function into economic terms via "damage functions;" and (4) extrapolation of the function to the population if an aggregate damage estimate is required.

Because of a lack of adequate dose-response functions, a variation of the basic method outlined above is typically followed. The researcher uses a "damage factor approach" to estimate what proportion of a damage category can be identified as being related to or caused by air pollution. Such a proportionality factor will then be used to estimate the required air pollution damage. However, one problem of this method is that, while the magnitude of the physical and biological damages can be predicted with some degree of accuracy, in many cases the attempts to translate these damages into meaningful economic relationships are not very accurate. Perhaps one reason is that controlled laboratory conditions are not usually representative of the real world. To solve such a problem, the normal practice is to hold everything constant except one factor - a single pollutant or mix of pollutants. Other problems are those of aggregation and substitution. It is very unlikely that the aggregation process involves a straight arithmetic summation over, all individuals [Anderson and Crocker, 1971, p. 147]. Besides, the substitution of one factor of production by an individual will not normally affect relative prices; but if the same substitution is carried out by all receptors, relative factors prices will often be changed.

The Delphi method is a method of combining the knowledge and abilities of a diverse group of experts for the purpose of quantifying variables which are either intangible or display a high level of uncertainty [Pill, 1971, p. 58]. Essentially, the method is a type of subjective decision-making. It is an efficient way to arrive at "best judgments," where both the knowledge and opinion of experts are extracted, i.e., those who are considered experts in the relevant area are asked to give their best solution to any given problem. This method is one that has been used by the U.S. Department of Agriculture in forecasting crop production levels [Waddell, 1974, p. 34]. The Delphi method appears to be an approach that can provide answers in a short period of time. However, due to the subjective nature of this method, many of the air pollution damages created in this manner have been questioned [Waddell, 1974, p. 35].

2.5 Air Pollution Response Functions and Crop Loss Equations

Several variants of air pollution response functions have been developed for the purpose of measuring physical and economic damages of crops due to air pollution. Perhaps the earliest one is that formulated by O'Gara (1922) for alfalfa, taking the general form of:

$$(C - 0.33t) = 0.92 \tag{2.1}$$

where C is the estimated concentration level and t is time in hours. The constant 0.33 ppm is the concentration level (or the threshold level) that a plant is presumably able to endure indefinitely.

In order to generalize O'Gara's equation, Thomas and Hill (1935) proposed the following equation for measuring any degree of leaf destruction at any degree of susceptibility:

$$t(c - a) = b \tag{2.2}$$

where t = time in hours, c = pollution concentration level in ppm exceeding a, a is the threshold concentration below which no injury occurs, and b is the constant.

The levels of leaf destruction are then given as follows:

if $t(c - 0.24) = 0.94$, only traces of leaf destruction are observed

if $t(c - 1.40) = 2.10$, there is a 50% chance of leaf destruction

if $t(c - 2.60) = 3.20$, there is a 100% chance of leaf destruction.

Zahn (1963) modified the O'Gara equation and developed a new equation which provides a better fit for a longer time period. This equation takes the following form:

$$t = \frac{1 + 0.5C}{C(C - a)} \times b \quad (2.3)$$

where be is the dimensional resistance factor which includes effects of environmental conditions.

An alternative experimental formula was proposed by Guderian, Van Haut (1960) and Stratmann (1963). This formula provided a "best" fit to a set of observations over both short or long periods of exposures. The proposed formula is:

$$t = Ke^{-b(C - a)} \quad (2.4)$$

where K = vegetation life time, in hours; t is time; and a, b, and C are the same as in the Zahn equation. These parameters may vary with plant species, environmental conditions, and degree of injury.

Benedict, et. al. (1973) derived crop loss estimates by the following formulation:

Crop Loss = crop value x crop sensitivity to the pollutant x regional pollution potential (2.5)

where the relative sensitivity of various plant species to the pollutant was determined by using information provided in secondary sources. The regional pollution potential is defined as a relative severity index of pollution estimated for each county, arising from fuel consumption.

Larsen and Heck (1976) analyzed data on the foliar response of 14 plant species (two cultivars of corn) to ozone concentration. They used a mathematical model with two characteristics: a constant percentage of leaf surface injury caused by air pollution concentration level, that is, the inverse proportion of exposure duration raised to an exponent and, for a given length of exposure, the percentage leaf injury as a function of pollution concentration level fit to a log-normal frequency distribution. This relationship takes the following form:

$$c = m_{g\,hr}\, s_g^{z}\, t^{p} \quad (2.6)$$

where c is pollutant concentration, in parts per million, $m_{g\,hr}$ is geometric mean concentration for a one-hour exposure, s_g is the standard geometric deviation, t is time (hour), p is the slope of the line (logarithmic), and z is the number of standard deviations that the percentage of leaf injury is from the median.

In equation (2.6), $m_{g\ hr}$, s_g and p are known constants. They vary according to type of crop. Thus c is the function of two exogenous variables, z and t. By substituting different values of z and t into equation (2.6), different values of c will then be obtained. Larsen and Heck (1976), Table 2, p. 329, calculated injury threshold for exposure of 1, ,3, and 8 hours of 14 plant species (two cultivars of corn).

Liu and Yu (1976) proposed a stepwise linear multivariate regression model for determining the economic damage functions for selected crops and plants as follows:

$$CROPL_i = a + b(CROPV_i) + c(TEMB) + d(TEMA) + e(SUN) + f(RHM) + g(DTS) + h(SO_2) + j(OXID) \quad (2.7)$$

where $CROPL_i$ denotes the economic loss (in $1000) of the ith type of crops by a county; $CROPV_i$ is the crop value (in $1000) of the ith type of <reps; TEMB and TEMA are, respectively, the number of days in a year with temperature below 33°F and above 89°F; SUN denotes possible annual sunshine days; RHM is the relative humidity; DTS represents the number of days with thunderstorm; SO_2 is the level of sulfur dioxide concentration and OXID is the relative severity index of oxidant.

Oshima (1975) and Oshima, et. al. (1976, 1977) calculated percentage of yield reduction of alfalfa, tomatoes and cotton due to air pollution by using the ozone dosage-crop loss conversion functions. These functions are presented below.

Alfalfa

i. Yield function

$$\text{percent reduction} = 0 + (9.258 \times 10^{-3} \times \text{dose}) \quad (2.8)$$

ii. Defoliation function

$$\text{percent reduction} = 0 + (3.030 \times 10^{-3} \times \text{dose}) \quad (2.9)$$

Tomato

$$\text{Percent reduction} = 0 + (0.0232 \times \text{dose}) \quad (2.10)$$

Cotton

i. Uniformity Index

$$\text{Percent reduction} = 0 + (1.90 \times 10^{-3} \times \text{dose}) \quad (2.11)$$

ii. Number of harvested bolls

$$\text{Percent reduction} = 0 + (6.947 \times 10^{-3} \times \text{dose}) \quad (2.12)$$

The OZOne dose is derived from oxidant data measured by various types of instrumentation. Hourly averages exceeding 10 pphm, the California standard for oxidantair pollutants, were used in calculating the average weekly dosage in pphm hours for any specified season. Since plants are typically less sensitive to oxidants at night, only the hourly averages for the daylight hours were used.

2,6 Conclusion

For policymakers, economic damage functions *may* be more relevant than physical damage functions. An economic damage function, or a monetary damage function, relates levels of pollution to the amount of compensation which would be needed in order that society (i.e., consumers and producers) not be worse off than before the deterioration of the air quality. The economic damage function is useful to decisionmakers since the multiple dimensions of the decision problem are reduced into one dimension only, i.e., money. It should be noted, however, that transformation of a physical damage function into an economic damage function as has been tried by some researchers, often involves value judgment on the part of the policymaker or researcher. A related question as to the degree of conformity of the values of the policymaker with those of the consumer is largely unresolved [Liu and Yu, 1976, p. 34].

FOOTNOTES: CHAPTER II

1/ For details see the bibliography at the end of Chapter 11 in Committee on Medical and Biologic-Effects of Environmental Pollutants, Ozone and Other Photochemical Oxidants, Washington, D.C.: National Academy of Sciences (1977).

2/ Alameda, Los Angeles, Marin, Orange, Riverside, San Bernardino, San Joaquin Valley, San Mateo, Santa Clara, and Ventura.

3/ Prior to this study, two previous reports have appeared. The first one [Benedict, 1970] was mainly devoted to description of the method or model that was developed and the background information that led to its development. The second report [Benedict, et. al., 1971] described improvements in the model and gave vegetation loss estimates for 1964 crops as related to 1963 emission data.

4/ This loss is expressed as a percentage of the total crop value in both polluted and unpolluted areas. The percentage of crop value lost in the pollution threatened counties for the U.S. is 0.99 and 1.84% in 1969 and 1964 respectively.