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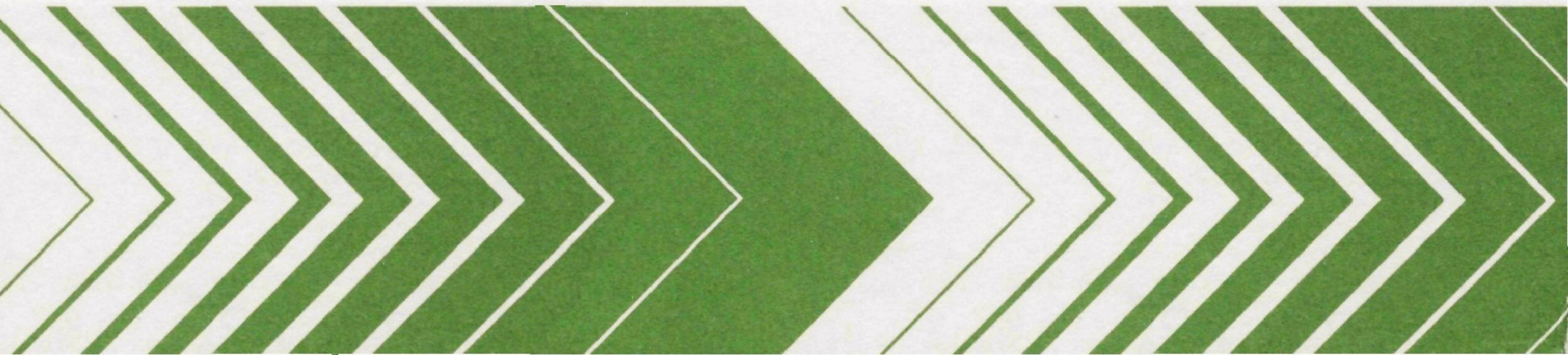
Volume III, A Preliminary Assessment of Air Pollution Damages for Selected Crops Within Southern California



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.

Volume II, Experiments in Valuing Non-Market Goods: A Case Study of Alternative Benefit Measures of Air Pollution Control in the South Coast Air Basin of Southern California, EPA-600/5-79-001b.

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.

Volume IV, Studies on Partial Equilibrium Approaches to Valuation of Environmental Amenities, EPA-600/5-79-001d.

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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PREFACE

This project was initiated in the summer of 1977 when Dr. Alan Carlin urged a research group from the Resource and Environmental Economics Laboratory at the University of Wyoming that was studying the economic benefits of air pollution control in the South Coast Air Basin, to devote some attention to the benefits that could accrue to the nonurban sector. Extensive use has been made of library facilities at the Berkeley, Davis, and Riverside campuses of the University of California. Drs. H. Johnson, O.C. Oshima, O.C. Taylor, and C.R. Thompson of the University of California, Riverside, have been extremely helpful in directing us to specific library materials. The California Air Resources Board provided detailed air pollution data. Computational assistance has been provided by the University of Wyoming Computer Center.

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 particulates 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), broccoli, 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 marketings. 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	55.8[1]	16,007	15.7	25.75[1]	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	327,685	69.16
Onion, Fresh	31.7	7,172.0	44,466	5.9	1,652.0	23.03	7,814	17.57
Onion, Processing[4]	n.a.	n.a.	n.a.	19.5	7,215.0	n.a.	27,524	n.a.
Potatoes	1,374.1	353,386.0	1,182,816	66.0	24,188.0	6.85	110,161	9.31
Tomatoes, Fresh	128.9	21,492.0	425,887	29.4	6,765.0	31.48	137,904	32.38
Tomatoes, Processing	309.0	6,471.8[1]	375,407	233.8	5,066.5[1]	78.29	284,734	75.85
Field Crop								
Cotton	10,869.1	10,095.9[2]	3,267,560	1,120.1	2,382.7[2]	23.60	835,192	25.56
Sugarbeets	1,480.5	29,427.0[1]	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:

[a] U.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
<u>Vegetable Crops</u>										
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
Cantalopes	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	8,240	-	-	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	1,682	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]
<u>Field Crops</u>										
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 2/			South Coast 2/			Central Coast 1/			Southern San Joaquin Valley 2/			Study Area	
		Production	% 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	54.17	6,346	7.38	14.78	6,764	7.86	15.76	36,366	84.71
Broccoli (Cwt.)	3,959,800	3,597,800	90.86	-	-	-	238,178	6.02	6.62	1,012,180	25.56	28.13	-	-	-	1,250,358	34.75
Cantaloupes (Cwt.)	10,759,600	7,155,600	66.50	1,199,600	11.15	16.76	320,823	2.98	4.48	-	-	-	728,400	6.77	10.18	2,248,823	31.42
Carrots (Cwt.)	20,648,200	10,321,200	49.99	1,703,400	8.25	16.50	3,193,959	15.47	30.95	1,402,620	6.79	13.59	3,220,000	15.59	31.20	9,519,979	92.24
Cauliflower (Cwt.)	3,035,600	2,383,800	78.53	-	-	-	546,599	18.01	22.93	861,370	28.38	36.13	-	-	-	1,407,969	59.06
Celery (Cwt.)	16,385,600	10,579,400	64.56	-	-	-	6,201,152	37.84	58.61	4,086,580	24.94	38.63	-	-	-	10,287,732	97.24
Lettuce* (Cwt.)	51,658,800	37,079,800	71.78	11,124,000	21.53	30.00	4,491,817	8.69	12.11	18,349,364	35.52	49.49	1,151,600	2.23	3.11	35,116,781	94.71
Onions, Fresh (Cwt.)	5,994,000	1,788,200	29.83	460,400	7.68	25.75	571,862	9.54	31.98	386,960	6.46	21.64	-	-	-	1,419,222	79.37
Onions, Processing (Cwt.)	22,456,400	7,562,200	33.67	548,000	2.44	7.25	1,209,000	5.38	15.99	563,552	2.51	7.45	2,118,400	9.43	28.01	4,438,952	58.70
Potatoes (Cwt.)	322,129,000	22,720,000	7.05	-	-	-	2,823,774	.88	12.43	1,571,160	.49	6.91	9,611,452	2.98	42.30	14,006,386	61.64
Tomatoes, Fresh (Cwt.)	20,406,400	6,882,000	33.72	384,400	1.88	5.59	4,174,195	20.45	60.66	1,198,380	5.87	17.41	674,768	3.31	9.80	6,431,743	93.46
Tomatoes, Processing (Tons)	7,140,680	5,514,440	77.23	24,060	.34	.44	235,970	3.30	4.28	257,589	3.61	4.67	166,940	2.34	3.03	684,559	12.42
Field Crops																	
Cotton (bales of 500 lbs.)	10,889,817	2,024,640	18.59	124,568	1.14	6.15	37,212	.34	1.84	-	-	-	848,268	7.79	41.90	1,010,048	49.89
Sugar beets (tons)	26,832,600	7,842,000	29.23	1,598,400	5.96	20.38	273,305	1.02	3.49	600,102	2.24	7.65	739,274	2.75	9.43	3,211,081	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.

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

Southern Desert - Imperial County

South Coast - Los 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 Valley - 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		
<u>Vegetable Crop</u>							
Beans, Green Lima	(TONS)	-	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)	-	2,980,200	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
<u>Field Crops</u>							
Cotton	(BALES)	141,500	51,122	-	972,760	1,165,382	46.95
Sugarbeets	(TONS)	1,476,000	256,634	867,020	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 Central 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 from 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, cantalopes, 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, Schomer 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 apparent in 1959, when ozone was reported to cause damage to many crops in New Jersey [Daines, 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 about 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 above 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-11 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 crops [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 nitrogen 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 on 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), Pell (1973), and Millecan (1976). 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, particulates, herbicides, and ethylene. The vegetation most affected (also in lawns, shrubs, woody ornamentals, 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 incidences 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, Pell (1973) continued the research initiated by Feliciano in 1971. The direct losses of agronomic crops and ornamental plantings estimated by Pell 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 episodes 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 ornamentals 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 ornamentals 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 ornamentals, 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 ornamentals 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 and 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:

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

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:

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

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:

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

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:

$$\begin{aligned} CROPL_i = a + b(CROPV_i) + c(TEMB) + d(TEMA) + e(SUN) + f(RHM) \\ + g(DTS) + h(SO_2) + j(OXID) \end{aligned} \qquad (2.7)$$

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 crops; 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

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

ii. Defoliation function

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

Tomato

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

Cotton

i. Uniformity Index

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

ii. Number of harvested bolls

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

The ozone dose is derived from oxidant data measured by various types of instrumentation. Hourly averages exceeding 10 pphm, the California standard for oxidant air 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 II 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.

CHAPTER III

SOME METHODOLOGICAL CONSIDERATIONS ON THE ASSESSMENT OF AIR POLLUTION DAMAGES: A PROPOSED MATHEMATICAL FRAMEWORK

3.1 Introduction

One important aspect of economic analysis concerns the definition of methods or procedures that may be used in addressing a problem or set of problems at hand. When integrated with appropriate assumptions, methodologies constitute the conceptual framework within which to achieve possible solution(s) or provide suggestions for solving such problem(s). The problem statement and justification for this study has been set forth in Chapter I. Given these problem statements and objectives concerning the relationship between air pollution and vegetation, the intent of the analysis is to determine the consequences and the magnitude of such air pollution damage. This quantitative assessment of air pollution damage occurs within the methodological framework defined for this study. Thus, specification of the appropriate technique is central to the success of the analysis.

A number of conceptual issues have been raised implicitly concerning a methodology for estimating agricultural damages associated with air pollution. The approach should have a general equilibrium flavor, in that both producing and consuming sectors are assessed simultaneously. Further, interregional competition and comparative advantage constructs are required, given that all regions considered compete to some extent for shares of national commodity markets. In addition, substitution effects on the production side need to be considered. All of these relationships are dependent to some degree on the physical environment surrounding crop production, including ambient air quality. This section discusses these concepts or components required for such an analysis. The concepts are then extended into a tractible mathematical model.

3.2 Methodological Framework

The conceptual issues outlined above involve a wide range of economic relationships suggested by theory. For the methodology to be tractable in terms of empirical analysis, these relationships must be combined in a logical sequence and given a quantitative interpretation. This section provides a more detailed methodological framework with which the concepts discussed earlier may be quantified.

1. Production Section

a. Production Functions

Assume that a specified area is divided into r heterogeneous regions where r = 1,2, . . .,R. Regions are differentiated by such factors as climatological conditions, soil quality and levels of ambient air quality. Climatological conditions and soil quality determine jointly or separately type(s) of crop(s) suitable for each region, whereas ambient air quality is assumed to have different effects (favorable or unfavorable) on crops. In each region there are i(i = 1,2, . . .,I) farmers (processes) producing j(j = 1,2, . . .,J) agricultural crops. However, it is possible for a region to produce one or more crops and many regions to produce the same crop. Thus, two regions may be viewed as homogeneous; each has identical cropping alternatives, i.e., the same set of crops. Perfect competition is assumed to prevail in the sense that each producer and each consumer acting alone cannot affect the market price of a commodity, regardless of the amount each one supplies and demands; but aggregate supply put forth by all farmers (processes) in the area, due to the nature of the commodity described in the earlier section can affect the market price of that commodity. Assume further that, in the short run, farmers use both fixed and variable inputs. Fixed inputs are land (measured in acreage used in cultivation) and irrigation water. The factor supply function for such inputs may be assumed to be perfectly inelastic. Variable inputs include labor, seeds, fertilizer, and insecticide. These inputs are used in different amounts from one stage of production to another. The factor supply functions for these inputs may be assumed to be perfectly elastic for some (e.g., seed). Labor is a special case, since unskilled labor is assumed to be available at any time and thus has a perfectly elastic supply curve, whereas skilled labor required for some processes of production is relatively scarce. Consequently, its factor supply curve is rather inelastic.

There is another type of input, ambient air quality, which enters into the production function. It would appear reasonable to assume that if air quality deteriorates, production (yield) may be reduced or the costs of production increased. Some of the crops produced are assumed to be perishable and thus have to be sold within a certain period of time, limiting the use of carryover or buffer stocks across seasons. Transportation cost is excluded under the assumption that it is treated as a fixed cost of comparable magnitude for producers and regions within the analysis. Thus, its exclusion from the model may not significantly alter the result of the analysis.

Let lower case letters denote individual units and capital letters aggregate units. Thus, q_{ji}^{rm} denotes total production of crop j at the end of the current season by farmer i in region r using soil type m where m = 1,2, . . .,M. Let l, la, f, is, w, se, k and z be total land, labor, fertilizer, insecticide, irrigation water, seed, capital, and environmental quality, respectively, associated with the production of crop j. The production function of crop j can then be expressed as:

$$q_{ji}^{rm} = q_{ji}^{rm}\,(l,la,f,is,w,se,k,z) \qquad (3.1)$$

If one assumes that the above production function is linear, one will, by taking the first-order partial derivative of q with respect to each input, obtain a constant marginal productivity of each input included in the model. Such a result might be interpreted as the shadow price of each input. This general class of production functions is said to be homogeneous of degree one, i.e., a constant returns to scale production function in which output will be increased by the same proportion as an increase in inputs.

Let P_j be the market price of commodity j. Assume one market price across all regions. $Q_j = \sum_{irm}\sum\sum q_{ji}^{rm}$ is the aggregate production of commodity j. S_j, P_l, and O_j are stocks of commodity j, prices of all other commodities, and all other factors such as income associated with the price of commodity j. We can express the price forecasting equation for commodity j as:

$$P_j = P_j(Q_j, S_j, P_l, O_j), \qquad l = 1,2,\ldots,L. \qquad (3.2)$$

For analytical purposes, assume that the effects of all variables except Q_j in the price forecasting equation can be summed together into the intercept term (by using the mean value of each variable multiplied by its corresponding estimated parameters), yielding a new equation for the price of commodity j:

$$P'_j = P'_j(Q_j) = c + dQ_j, \qquad d < 0 \qquad (3.3)$$

i.e., it is strictly a function of quantity. Such an equation can then be used to estimate changes in commodity price associated with changes in the level of production.

Assuming that each farmer in the area has the same objective of maximizing total revenue (above variable costs) subject to certain constraints, the analytical problem then becomes a quadratic objective function with linear constraints as follows:

$$\max \quad TR = PQ = cQ_j + dQ_j^2. \qquad (3.4)$$

subject to:

$$Q_j = a_1L_j + a_2N_j + a_3F_j + a_4Is_j + a_5W_j + a_6Se_j + a_7K_j + a_8Z_j \qquad (3.5)$$

$$Y_j = \sum_g Y_{jg} = L_j + W_j \qquad (3.6)$$

$$Z_j = \bar{Z}_j \qquad (3.7)$$

$$Q_j \geq 0 \qquad (3.8)$$

Equation (3.5) represents the production function for commodity j. All variables in that equation are the aggregate of those defined earlier. The expectation is that all the estimated parameters will be positive except those for Z_j (environmental quality--ambient air quality). The sign of the estimated coefficient of Z_j, as mentioned earlier, is uncertain. Equation (3.6) states that the amount of fixed inputs available, Y_j, is simply the summation of various fixed inputs (in this analysis only land and irrigation water) used by producing commodity j. Equation (3.7) indicates that environmental quality (as measured by the degree of concentration of specific air quality parameters) is assumed to be given. Finally, Equation (3.8) states that the output of all commodities must be non-negative.

If each producer takes price as given, i.e., the economy is perfectly competitive, the objective function must be modified by the use of the scaler value of "1/2," i.e.,

$$\max \quad TR = cQ_j + 1/2 \; dQ_j^2 \tag{3.9}$$

which then yields the following first-order condition,

$$\frac{dTR}{dQ_j} = MR = c + dQ_j = P_j \tag{3.10}$$

as required for perfect competition.

The Lagrangian equation is:

$$L = cQ_j + 1/2 \; dQ_j^2 + \lambda[Q_j - (\cdot)] + \mu[Y_j - \sum_g Y_{jg}] + \delta[Z_j - \bar{Z}_j] \tag{3.11}$$

Revenue maximization requires that the following first-order partial derivatives

$$\frac{\partial L}{\partial Q_j} = c + dQ_j + \quad = 0 \tag{3.12}$$

$$\frac{\partial L}{\partial \lambda} = Q_j - (\cdot) = 0 \tag{3.13}$$

$$\frac{\partial L}{\partial \mu} = Y_j - \sum_g Y_{jg} = 0 \tag{3.14}$$

$$\frac{\partial L}{\partial \delta} = Z_j - \bar{Z}_j = 0 \tag{3.15}$$

be fulfilled and the Bordered Hessian be negative definite or negative semidefinite.

Using the above procedure, variations in the level of Z should translate into different levels of Q and thus changes in TR, as a result of changes in prices due to such changes in Q. Moreover, it might also be possible to calculate changes in Q resulting from tradeoffs between or among inputs and Z, e.g., mitigative effects of fertilizer. Thus, air pollution damages, as measured by changes in output and price, may be assessed by crop and region.

Another means of measuring damages of air pollution to an agricultural crop is the use of a cost concept. In the presence of air pollution, farmers may increase some other variable inputs such as fertilizer or labor to compensate for the yield depressing effect of some pollutants. Under such a situation, marginal cost and thus total cost will increase, while total yield might decrease, remain constant, or increase, depending upon whether such input adjustments are less than, equal to, or more than offsetting in terms of the impact of air pollution. Assume that the objective function of producers is to maximize total profit, which is defined as the difference between total revenue and total cost where total revenue remains as defined earlier, but total cost is a function of total production and different levels of ambient air pollution concentration in the specified area. In other words, the higher such concentrations, the greater the additional costs producers must bear, in addition to the "normal" cost of production. Mathematically, this again may be expressed as a non-linear objective function with linear constraints, i.e.,

$$\max \quad \pi = TR - TC = cQ_j + 1/2\ dQ_j^2 - C(Q_j, Z_j) \tag{3.16}$$

subject to:

$$Q_j = a_1L_j + a_2N_j + a_3F_j + a_4Is_j + a_5W_j + a_6Se_j + a_7K_j + a_8Z_j \tag{3.17}$$

$$Y_j = \sum_g Y_{jg} \tag{3.18}$$

$$C_j = b_1A_j + b_2B_j + b_3Z_j \tag{3.19}$$

$$Q_j \geq 0 \tag{3.20}$$

where C_j = total cost of producing commodity j

A_j = total fixed cost of producing commodity j

B_j = total variable cost of producing commodity j

Z_j = levels of air pollution concentration (per unit of measurement)

b_1, b_2, b_3 are estimated parameters where $b_1, b_2 > 0$, $b_3 \geq 0$.

All other variables and parameters are as defined earlier.

The Lagrangian equation is:

$$L = cQ_j + 1/2\ dQ_j^2 - C(Q_j, Z_j) + \lambda[Q_j - (a_1L_j + a_2N_j + a_3F_j + a_4Is_j + a_5W_j + a_6Se_j + a_7K_j + a_8Z_j)] + \mu[Y_j - \sum_g Y_{jg}] + \gamma[C_j - (b_1A_j + b_2B_j + b_3Z_j)] \tag{3.21}$$

The first-order conditions for profit maximization require that the following partial derivatives:

$$\frac{\partial L}{\partial Q_j} = c + dQ_j - \frac{\partial C}{\partial Q_j} + \lambda = 0 \tag{3.22}$$

$$\frac{\partial L}{\partial Z_j} = - \frac{\partial C}{\partial Z_j} - \lambda a_8 - \gamma b_3 = 0 \tag{3.23}$$

and the constant maximization equations stated above be fulfilled. The second-order conditions for profit maximization require that the Bordered Hessian be either negative definite or negative semi-definite.

From the first-order partial derivatives obtained above, one will then be able to solve for Q_j by varying the value of Z_j. After solving for the value of Q_j, the values of cost, revenue, and profit can then be obtained. Such results will provide a measure of the damages of air pollution to commodity j.

Risk and Uncertainty

Quadratic risk programming is usually regarded as a theoretically appealing technique for analyzing impacts of risk aversion on farm planning.

Let M be the gross income associated with agricultural crop j. Then $M = P_j q_j$ where P_j is the market price of commodity j and it is assumed to be distributed normally with mean μ and variance σ^2, i.e., $P \sim N(\mu,\sigma^2)$.

Let the utility-of-income function be exponential in the form:

$$U(M) = \propto - \beta \exp(-\lambda M) \text{ where } \propto, \beta, \lambda > 0 \tag{3.25}$$

$\propto$, β are estimated parameters and λ is an arbitrarily assigned degree of risk aversion of the decisionmaker(s) toward commodity j. However, it is possible to directly estimate the value of λ. Wiens (1976) has suggested the following procedure to estimate λ:

Define a quadratic programming problem of maximizing:

$$W = \mu'X - (\lambda/2)\ X'\Sigma X = E(R) - (\lambda/2)\sigma(R)^2 \tag{3.25}$$

subject to:

$$AX \leq C^* \tag{3.26}$$

where X is a vector of activities; R is net income; A is the technology matrix relating units of inputs to one unit of output (activity); C* is the level of resource use; λ is degree of risk aversion; and μ is the mean of income.

The Kuhn-Tucker conditions for an optimal solution to the above quadratic programming problem require that:

$$\mu_i - \lambda\Sigma_i X - A_i'\emptyset = 0 \qquad (3.27)$$

for all non-zero activities i in the solution, where Σ_i, μ_i and A_i are, respectively, the ith row of Σ, the ith element of μ, and the ith column of A. Substituting X*, the actual activity level, for X and r, the actual market prices, for $\emptyset$, λ can be estimated as:

$$\lambda^* = {}^{e}(\mu_i - A_i'r)/\Sigma_i X^* \qquad (3.28)$$

While this should hold for each production activity if all assumptions are exactly fulfilled, empirically an average overall production activity will suffice.

Following the method suggested by Wiens (1976), the expected value of the utility of income function is:

$$E(U(M)] = \alpha - \beta\exp[-\lambda\mu q_j + (\lambda^2/2)\sigma^2 q_j^2] \qquad (3.29)$$

To maximize equation (3.29) with respect to q_j is equivalent to maximizing:

$$W = \mu q_j - (\lambda/2)\ \mathrm{var}\ (q_j) = E(M) - (\lambda/2)\ \mathrm{var}\ (M) \qquad (3.30)$$

where μ can be interpreted as the shadow price of q_j. This is a conventional E,V objective function. Applying Weins' method described above, the values of λ can then be estimated. Hazell (1971) points out the following advantages of using the EV criterion for farm management research:

> "(a) The criterion is consistent with probability statements with respect to the likelihood of occurrence of different levels of income for any given farm plan. If total gross margins can be expected to be approximately normally distributed, and if the variance-covariance coefficients used can be regarded as non-stochastic or subjective parameters, then such probability statements are easily derived by using tables for the normal deviate statistic . . .
>
> (b) The variance V is totally specified by the variance-covariance coefficients; and when subjective values of these parameters are available or can be found, the variance is no longer estimated from the sample of observed gross margin outcomes . . .
>
> (c) The criterion is consistent with the Separation Theorem (see Johnson, 1967, pp. 614-620) and allows more general solution to the farm diversification problem given a riskless option (for the decisionmakers)." [pp. 55-56, expression in the parentheses is added]

Due to the fact that use of EV method requires a special computer algorithm, Thomson and Hazell (1972) suggest that it be replaced by the mean absolute income deviation (MAD) and used to obtain a solution through standard linear programming codes with the parametric option. However, when the sample mean absolute deviation is used rather than the sample variance, the reliability of the estimated efficient, EV, farm plans is necessarily weakened [Thomson and Hazell, 1972, p. 503]. Nevertheless, MAD is still a best substitute when access to such a special computer algorithm is not possible and provided that certain adjustments are also used in order to reduce error due to the use of sample MAD rather than the sample variance. Such an adjustment has been suggested by Thomson and Hazell (1972) by using:

$$\frac{\sum_i (\hat{P}_{1i} - \hat{P}_{2i})(1 - V_i)}{\sum_i (1 - \hat{P}_{1i})(1 - V_i)} \times 100 \text{ percent} \qquad (3.31)$$

where $\hat{P}_{1i}$ and $\hat{P}_{2i}$ are the estimated probabilities of the correct ranking of the ith farm plan for the sample MAD and variance respectively and V_i is the ithe variance ratio as a weight in the MAD model.

Consumer Sector

In aggregate models of the consuming sector, it is convenient to assume that there are n individuals with similar taste and preferences. Each individual has a utility function which is concave and is the function of various goods and services consumed, i.e.,

$$u_n = u_n(q_{n1}, q_{n2}, \ldots, q_{nJ}), \qquad n = 1,2, \ldots, N \qquad (3.32)$$

where u_n is the utility of individual n and q_{nj} $(j = 1,2, \ldots, J)$ is the jth commodity or service consumed by individual n. q_{nj} is, of course, a function of the price of commodity j, prices of all other commodities or services, and income associated with individual n, i.e.,

$$q_{nj} = q_{nj}(P_j, P_o, M_n) \qquad 0 = 1,2, \ldots, 0 \qquad (3.33)$$

Total demand for commodity j is given by:

$$Q_j = \sum_{n=1}^{N} q_{nj}(P_j, P_o, M_n) \qquad (3.34)$$

Individual n then maximizes his utility subject to his budget constraint, i.e.,

$$\max \quad u_n = (q_{n1}, \ldots, q_{nj}) \qquad (3.35)$$

subject to:

$$P_1 q_{n1} + P_2 q_{n2} + \ldots P_j q_{nj} = M_n \qquad (3.36)$$

The Lagrangian equation is:

$$L = u_n(q_{n1}, \ldots, q_{nj}) + \mu[M_n - (P_1 q_{n1} + P_2 q_{n2} + \ldots P_j q_{nj})] \qquad (3.37)$$

The necessary conditions for utility maximization require that:

$$\partial L/\partial q_{nj} = \partial u_n/\partial q_{nj} - \mu P_j = 0 \qquad (3.38)$$

$$\partial L/\partial \mu = \sum_{j=1}^{J} P_j q_{nj} = M_n \qquad (3.39)$$

and the associated sufficient conditions will be fulfilled if the Bordered Hessian is either negative definite or negative semi-definite.

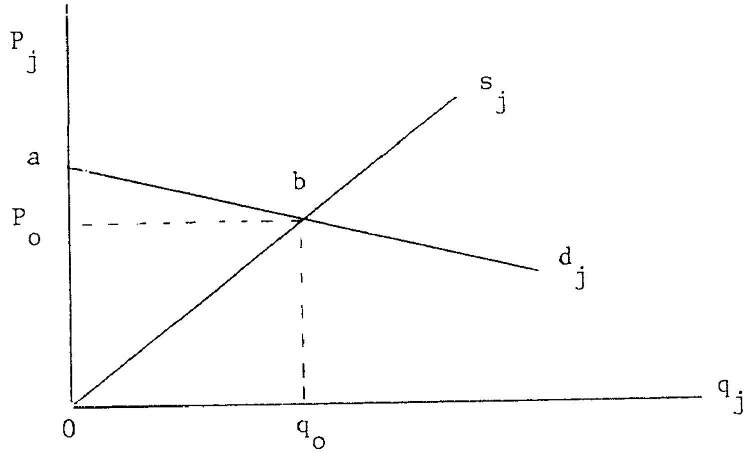
With changes in price due to effects of air pollution on crop production, individual n's demand function will change. If there is no change in his income level (i.e., uncompensated in the case of price increase or taxed in the case of price decrease), his level of well-being will be altered. This alteration of consumer welfare may then be approximated by changes in "consumer's surplus" which will be introduced in the next section.

Consumer's and Producer's Surpluses

Of the three concepts of economic rent the Marshallian concept of consumer's and producer's surpluses is most applicable if one assumes that all other prices and incomes of all individuals concerned are constant. Let:

$$P_j = F(q_j, \theta_j) \qquad (3.40)$$

be the demand function of commodity j denoted by d_j in the following diagram where P_j and q_j are the price and quantity respectively. θ_j is the shift parameter denoting changes in price of commodity j due to, say, changes in total supply arising from air pollution. It is assumed that the demand curve, d_j, is downward sloping.



Let the supply function of commodity j be represented by:

$$P_j = G(q_j, \theta_j) \tag{3.41}$$

The supply curve, s_j, is assumed to be upward sloping. It starts from the origin under the assumption that farmers will not supply any of commodity j if its price is zero. For simplicity the subscript j will be dropped. Market equilibrium for commodity j, as shown in the above diagram, will be obtained when the quantity supplied and demanded is q_o and the market price is P_o. Consumer's surplus is then defined as the area under the demand curve, d_j, and above the equilibrium price, P_o, or the triangle $P_o ab$. Producer's surplus or net return to factor owners is the area under the equilibrium price but above the supply curve or the triangle $OP_o b$. The sum of consumer's and producer's surpluses is given by:

$$R(\theta) = \int_o^{q_o} [F(q,\theta) - G(q,\theta)]dq \tag{3.42}$$

$$= Oabq_o - Obq_o = Oab \tag{3.43}$$

From the above equation one can compare the value of R associated with different values of θ, e.g., if we let $\theta_o = \theta(o)$ be the initial situation when there is no air pollution and θ_1 be the situation with some level of air pollution then the difference between $R(\theta_1) - R(o)$ will measure changes in consumer's and producer's surpluses due to increase in level of air pollution.

This method when applied via the mathematical concepts developed earlier in this report is analogous to Samuelson's (1952) "net social payoff" theory in which he relates Enke's formulation [Enke, 1951] to a standard problem in linear programming, the so-called Koopmans-Hitchcock (1941, 1949) minimum transport cost problem. Basically, the Samuelson's net social payoff is defined as the sum of the algebraic area under the excess demand curves of n individuals minus the total transport costs of all shipments [Takayama and Judge, 1964a, 1964b]. The objective is to artificially convert the descriptive price behavior into a maximization problem which can then be solved by using trial and error or a systematic procedure of varying shipments in the direction of increasing social payoff [Takayama and Judge, 1964b, p. 510]. However, in the formulation outlined in this section, quadratic programming can be used to approximate (see the subsequent section on analytical model) such a payoff.

3.3 An Analytical Model for Measuring Impacts of Air Pollution on Agricultural Crops

The conceptual model and mathematical concepts developed earlier in these sections can be used to construct a mathematical programming model capable of achieving some of the goals set forth in this study. This model can be explanded further by incorporating into it some additional concepts such as technical substitution possibilities, endogenous air pollution response functions and risk. The derived model will, it is hoped, present a realistic example of the agricultural sector within the constraints imposed by data limitations. Data requirements are extensive for such programming techniques and some of them, such as quadratic programming, require special computer algorithms. Nevertheless, the incorporated model should be analytically feasible and mathematically tractable. The degree of sophistication will be dependent on the availability of the required data and computer software.

In order to simplify some of the notations given in the earlier sections, matrix notation will be used in the models proposed below. However, all notations will remain as described earlier. It is assumed that air pollution in the specified area adversely affects crop production, and, consequently, may affect producers and consumers. Mathematically, the objective of the model is to maximize a "quasi-net social payoff" which is defined as the summation of consumers' and producers' surpluses and subject to certain constraints, i.e.,

$$\text{Max} \quad QNSP = C^T Q + 1/2\ Q^T DQ - E^T Q \tag{3.44}$$

subject to:

$$AQ \leq b \tag{3.45}$$

$$Q \geq 0 \tag{3.46}$$

where

QNSP = quasi-net social payoff (a scaler).
Q = jxl column vector of agricultural crop production, where production equals yield per acre times acreage planted.
C = jxl column vector of constants (intercepts in a linear demand structure).
D = jxj negative diagonal matrix (negative definite of coefficients representing slope values with the linear demand structure).
E = jxl column vector of unit cost of production.
A = gxj technology matrix relating units of inputs to one unit of output (g constraints and j variables).
b = gxl column vector of fixed inputs (land, water).
and T denotes matrix transportation.

The summation of the first two terms on the right-hand side of equation (3.44) is the total revenue for commodities Q. When integrated it represents the area under the demand curve but above the horizontal axis from the origin to the equilibrium amount demanded. The last term in the right-hand side of equation (3.44) is the total cost of production whose first-order derivative is the marginal cost. The rising portion of the marginal cost curve can then be treated as the short-run supply curve. Therefore, total cost of production can be considered as the returns to factor owners. The difference between the sum of the first two terms and the third term is the sum of producers' and consumers' surpluses over all commodities. It is equivalent to the quasi-net social payoff. Maximizing the objective function is analogous to maximizing a quadratic "quasi-net social payoff" subject to linear constraints.

The above price endogenous model can be expressed as a quadratic programming economic model. Such a model formulation will result in solution values for price and quantity of each commodity which maximize the value of QNSP.

In order to assess the impacts of air pollution upon agricultural crops, one may either introduce a variable, $Z^*_j (0 \leq Z^*_j \leq 1)$, defined as an index of crop yield reduction (% of yield reduction divided by 100) associated with crop j, into the production function (yield) or the cost function. If Z^*_j enters directly into the production function, it may affect crop yield but not necessarily total cost. Alternatively, Z^*_j may be treated through the cost function as an investment in ameliorating air pollution effects on agricultural crops by means of either increasing use of other variable inputs or relocating the site of production. The former involves the problem of technical substitution possibilities. For example, can fertilizer application rates be increased to partially offset the negative impact of air pollution? The latter can be achieved by comparing two neighboring areas, one with and the other without air pollution, using the same technique of measuring crop yield for same type(s) of crop(s). If total yield in the area with air pollution is lower than yields in adjacent areas, (keeping all other factors constant) one might suspect that such a reduction in yield is caused by air pollution. Thus, it might be possible to compare cost of relocation vs. investment in air pollution abatement.

Consider the case when Z^*_j enters directly into the production function. If one lets Z_j represent air pollution concentration, in parts per hundred million, associated with agricultural crop j, Z_j can then be calculated, by using the formulas given by Larsen and Heck (1976), Oshima (1975), Oshima, et. al. (1976, 1977) or others. Applying this method to all other crops under study will provide a vector of Z* which is a jx1 column vector for j crops. Then calculate total production of each crop by the following formula:

$$Q^* = (I - Z^*)L^TY \tag{3.47}$$

where

Q^* = jx1 column vector of total production of j crops with air pollution.
Z^* = jx1 column vector of yield reduction index.
I = jx1 vector of unity.
L = jx1 column vector of acre of land used for cultivating j crops.
Y = jx1 column vector of yield of j crops.

The model given under equations (3.44) through (3.46) will then be modified to be:

$$\text{Max} \quad QNSP = C^TQ^* + 1/2\ Q^{*T}DQ^* - E^TQ^* \tag{3.48}$$

subject to:

$$AQ \leq b \tag{3.53}$$

$$Q \geq 0 \tag{3.54}$$

As mentioned earlier, agricultural production involves various degrees of uncertainty. If farmers are assumed risk averse then their production decisions will reflect the uncertainty of climatological conditions for the coming season, and hence the total quantity supplied, and thus prices in the next season. Thus, production risks are multiplicative in nature, meaning that it is the slope of the supply curve which contains the important stochastics [Hazell and Scandizzo, 1975, p. 641]. Therefore, the traditional method of treating the risky component of supply as a constant added to the intercept term may not be appropriate. Hazell and Scandizzo (1974) use linear programming models with multiplicative supply function. Other methods frequently used in the empirical supply analysis are the econometric estimation of constant elasticity of substitution and Cobb-Douglas functions.

Another method that is widely used in farm management is the EV criterion described earlier. The analytical model may be further modified to be the following form:

$$\text{Max} \quad QNSP = C^T Q^* + 1/2\, Q^{*T} DQ^* - E^T Q^* - \lambda(Q^{*T} \Omega Q^*) \tag{3.55}$$

subject to:

$$AQ^* \leq b \tag{3.56}$$

$$Q^* \geq 0 \tag{3.57}$$

where

λ = a constant value of risk aversion coefficient.

Ω = jxj matrix of variance-covariance of income associated with each type of crop.

if Z* enters only into the yield function.

If Z* enters directly into the cost function, then the formulation becomes:

$$\text{Max} \quad QNSP = C^T Q + 1/2\, Q^T DQ - E^{*T} Q - \lambda(Q^T \Omega Q) \tag{3.58}$$

subject to:

$$AQ \leq b \tag{3.59}$$

$$Q \geq 0 \tag{3.60}$$

Thus, the quasi-net social payoff will be lower for higher values of the risk aversion coefficient given no change in income and vice versa. In the above formulations all but λ can be observed. However, the values of λ can be assigned arbitrarily or can also be estimated by using the method suggested earlier.

CHAPTER IV

AIR POLLUTION YIELD RESPONSE RELATIONSHIPS

4.1 Introduction

Effects of air pollution on agricultural crops, such as vegetables and field crops, have been well documented, as discussed in Chapter II. Although results obtained by various researchers are mixed, depending in part upon different methodologies and varieties of crops chosen for each study, the effects on some vegetable crops appear to be particularly acute. Controlled experiments performed in laboratories and greenhouse tests tend to indicate consistent adversary effects of air pollution on crop yield. However, similar results may not always be obtained in actual field tests due to the fact that various factors such as climatological conditions are either difficult or impossible to control and are capable of moderating impacts of air pollution on yield. Given the importance of selected vegetable and field crops to the agricultural sector of the study region and the significant share of the national market held by the region, the relationship between ozone and vegetable yields is a critical component of this analysis.

This chapter discusses the development of a set of yield-ozone relationships for the study area in general and the four production regions in particular. These relationships are derived from research discussed in Chapter II and some specific concepts presented in this chapter. The following subsection presents a hypothetical relationship between air pollution and yield. A quantitative relationship is obtained by using methods which will be more fully described in another subsection. The last subsection in this chapter provides estimated yield effects by crop and production region.

4.2 A Hypothetical Relationship Between Air Pollution and Yield

Most studies concerning the effects of air pollution on agricultural crops concentrate largely on physical damages such as leaf-drop and growth retardation of plants. Analyses of the specific relationship between air pollution concentration levels and yield reduction have been limited. Obviously, such a relationship is important in economic analysis of the impact of air pollution, given the need to directly estimate a market value or loss associated with air pollution.

Based on research discussed above, one may hypothesize that a negative relationship exists between ozone concentration and crop yields. A simple method for testing such a relationship is to examine the correlation coefficient between the level of air pollution and yield over a certain period of time for each crop. Again, one would hypothesize that *cet. par.* an increase in the level of air pollution concentration will lower yield. In other words the correlation coefficient between air pollution and yield should be negative. Further, the higher the coefficient the greater is the degree of relationship between air pollution and the crop, assuming the relationship is statistically significant.

To obtain correlation coefficients for the entire set of crops and regions, data on yield per acre for the 12 vegetable and 2 field crops were collected, covering the period from 1957 to 1976 for each county in the 4 major vegetable growing regions.1/ The yield per acre was then correlated against the maximum level of oxidant/ozone concentration taken from the publication "California Air Quality Data" for each county for the same period. However, due to a lack of complete data on ozone concentration and crop yields, only three counties (Orange, Riverside and Kern) and some crops were included in the correlation analysis. Orange and Riverside counties represent an area of more severe air pollution, whereas Kern County, a major agricultural county, was selected to represent an area of relatively low ozone concentration. The correlation coefficients between air pollution concentration (annual maximum level of oxidant/ozone concentration in parts per hundred million) and yield for these three counties are given in Table 4.1.

The correlation coefficients presented in Table 4.1 tend to conform to a priori expectations; that is, most of the coefficients have the expected sign although not all are statistically significant. This tends to suggest that air pollution in these areas has had some adverse effects on yield. However, correlation analysis does not imply causality, thus these results only lend support to the earlier supposition concerning yield and air pollution.

In order to further test the effects of air pollution on yield a simple production function relationship between yield per acre, the hourly maximum of oxidant/ozone concentrations and the crop acreage harvested for the three counties from 1957 to 1976 was estimated for some crops. The relationship was estimated via ordinary least squares, assuming a linear functional relationship. The production relationship was first estimated as strictly a function of ozone concentration, then acreage only and finally as a function of both variables.

Results obtained, as shown in Tables 4.2a, 4.2b, and 4.2c were generally not statistically significant, although the estimated coefficients for ozone had the expected negative sign in most equations. The coefficients of determination ($\bar{R}^2$) are very low with insignificant F-statistics. The Durbin-Watson in some equations are inconclusive. This means that variations in crop yield per acre can only be slightly explained by changes in the levels of oxidant/ozone concentration. As expected, the multiple regression had slightly higher levels of significance than the simple regressions.

4.3 Methods of Estimating Effects of Air Pollution Concentration on Yield

Earlier analysis suggests that air pollution (ozone) does indeed have a negative effect on yield. In order to estimate more precisely the effect of air pollution on yield, the Larsen and Heck and the Oshima equations as

Table 4.1

Correlation Values between Level of Oxidant and Yield

Crops	Oxidant, average of hourly maximum (pphm)		
	Orange County	Riverside County	Kern County
Beans, Lima	-0.13626	0.05014	-
Cantalopes	-	-0.23151*	-0.16470*
Carrots	-	0.42106*	-0.33044*
Cauliflower	0.62585*	-	-
Celery	-0.29654*	-	-
Lettuce	-0.19098*	0.10914	-
Onion, Green	-	0.01628	-
Potatoes	-	0.01481	-0.39337*
Tomatoes, Fresh	-0.13500	-0.28838*	-
Tomatoes, Process	-0.30188*	-	-
Cotton	-	-0.23089*	-0.05636
Sugarbeets	-	0.19790*	-0.30327*

*Denotes those coefficients significant at the 20% level.

Table 4.2a

Regression Coefficients for Selected Crops, Orange County, 1957-76

		Independent Variables				Summary Statistics		
		Oxidant (pphm)		Acreage				
Dependent Variables	Constant	Est. Coef.	T-Value	Est. Coef.	T-Value	$\bar{R}^2$	F	DW
<u>Beans, Lima</u>								
Yield (Tons/acre)	4.614	-0.0187	-0.58	-	-	0.0186	0.34	0.59
	5.018	-	-	-0.0012	-1.38	0.0954	1.90	0.72
	5.159	-0.0052	-0.15	-0.0011	-1.21	0.0966	0.91	0.71
<u>Cauliflower</u>								
Yield (CWT/acre)	144.119	2.1054	3.40	-	-	0.3917	11.59	1.51
	235.003	-	-	-0.0150	-0.77	0.0321	0.60	1.37
	155.092	2.0625	3.24	-0.0087	-0.55	0.4023	5.72	1.53
<u>Celery</u>								
Yield (CWT/acre)	589.803	-1.6592	-1.32	-	-	0.0879	1.74	1.00
	499.655	-	-	0.0189	0.03	0.0299	0.55	1.05
	557.367	-1.7191	-1.35	0.0208	0.84	0.1240	1.20	1.14
<u>Lettuce, Head</u>								
Yield (CWT/acre)	295.236	-1.2048	-0.83	-	-	0.0365	0.68	0.88
	231.671	-	-	0.0325	1.18	0.0713	1.38	0.74
	283.851	-1.5784	-1.09	0.0383	1.37	0.1317	1.29	0.99
<u>Tomato, Fresh</u>								
Yield (CWT/acre)	524.710	-1.5756	-0.58	-	-	0.0182	0.33	1.25
	740.489	-	-	-0.4807	-4.78	0.5592	22.84	1.15
	744.570	-0.1349	-0.07	-0.4794	-4.57	0.5594	10.79	1.15
<u>Tomatoe, Processing</u>								
Yield (Tons/acre)	24.838	-0.1205	-1.34	-	-	0.0911	1.80	1.26
	19.928	-	-	0.0002	0.22	0.0028	0.05	0.89
	24.085	-0.1215	-1.32	0.0003	0.28	0.0953	0.90	1.25

Table 4.2b

Regression Coefficients for Selected Crops, Riverside County, 1957-76

		Independent Variables						
		Oxidant (pphm)		Acreage				
Dependent Variables	Constant	Est. Coef.	T-Value	Est. Coef.	T-Value	$\bar{R}^2$	F	DW
Beans, Green Lima								
Yield (Tons/acre)	2.4161	0.0159	0.21	-	-	0.0025	0.0454	2.30
	5.0358	-	-	-0.0078	-1.65	0.1320	2.74	2.42
	5.6386	-0.0126	-0.17	-0.0080	-1.60	0.1335	1.31	2.49
Cantalope								
Yield (CWT/acre)	164.457	-0.5960	-1.01	-	-	0.0536	1.02	1.56
	163.975	-	-	-0.0069	-3.13	0.3529	9.82	2.03
	213.048	-1.0226	-2.25	-0.0080	-3.91	0.5016	8.55	2.53
Carrots								
Yield (CWT/acre)	122.741	3.6983	1.97	-	-	0.1773	3.88	1.62
	212.491	-	-	0.0137	1.92	0.1706	3.70	1.07
	45.298	3.7706	2.20	0.0140	2.16	0.3548	4.67	1.95
Lettuce, Head								
Yield (CWT/acre)	185.394	0.4628	0.47	-	-	0.0119	0.22	1.18
	211.929	-	-	-0.0009	-0.13	0.0009	0.02	1.16
	189.710	0.4541	0.44	-0.0006	-0.08	0.0123	0.11	1.16
Onion, Green								
Yield (CWT/acre)	251.105	0.1616	0.07	-	-	0.0003	0.01	0.56
	119.844	-	-	0.1657	7.03	0.7330	49.41	2.00
	110.930	0.2024	0.16	0.1657	6.84	0.7334	23.38	2.02
Potatoes								
Yield (CWT/acre)	270.514	0.0575	0.06	-	-	0.0002	0.01	1.06
	332.465	-	-	-0.0061	-3.27	0.3728	10.70	1.74
	366.201	-0.6614	-0.87	-0.0066	-3.36	0.3995	5.66	1.91
Tomato, Fresh								
Yield (CWT/acre)	340.654	-2.6267	-1.28	-	-	0.0832	1.63	1.10
	162.343	-	-	0.1470	4.62	0.5430	21.38	2.18
	195.421	-0.7081	-0.46	0.1424	4.19	0.5485	10.32	2.12
Cotton								
Yield (lbs/acre)	1316.92	-5.9587	-1.01	-	-	0.0533	1.01	1.65
	478.02	-	-	0.0310	3.02	0.3362	9.12	1.58
	392.62	1.3758	0.24	0.0323	2.71	0.3384	4.35	1.56
Sugarbeets								
Yield (Tons/acre)	16.1126	0.1604	0.86	-	-	0.0392	0.73	1.63
	22.3874	-	-	0.0003	0.36	0.0072	0.13	1.58
	16.1528	0.1579	0.75	0.00003	0.03	0.0392	0.35	1.64

Table 4.2c

Regression Coefficients for Selected Crops, Kern County, 1957-76

		Independent Variables						
		Oxidant (pphm)		Acreage				
Dependent Variable	Constant	Est. Coef.	T-Value	Est. Coef.	T-Value	$\bar{R}^2$	F	DW
Cantalope								
Yield (CWT/acre)	189.936	-1.2713	-0.71	-	-	0.0271	0.50	1.91
	225.148	-	-	-0.0149	-1.63	0.1290	2.67	1.97
	247.578	-1.2876	-0.75	-0.0149	-1.62	0.1568	1.58	2.14
Carrots								
Yield (CWT/acre)	415.033	-4.9290	-1.49	-	-	0.1092	2.21	1.43
	303.150	-	-	0.0067	1.45	0.1050	2.11	1.36
	370.558	-3.3722	-0.88	0.0044	0.83	0.1439	1.43	1.44
Potato								
Yield (CWT/acre)	396.505	-3.9781	-1.82	-	-	0.1547	3.30	0.73
	515.002	-	-	-0.0042	-4.44	0.5225	19.70	0.94
	518.229	-0.6357	-0.33	-0.0040	-3.65	0.5255	9.42	0.94
Cotton								
Yield (lbs/acre)	1122.86	-1.5612	-0.24	-	-	0.0032	0.06	1.02
	1146.15	-	-	-0.0002	-0.35	0.0069	0.13	1.08
	1189.35	-2.0374	-0.30	-0.0003	-0.39	0.0121	0.10	1.03
Sugarbeets								
Yield (Tons/acre)	25.827	-0.1965	-1.35	-	-	0.0920	1.82	0.82
	19.102	-	-	0.0002	2.40	0.2428	5.77	1.03
	19.823	-0.0314	-0.19	0.0002	1.85	0.2445	2.75	1.03

described in Section 4.2 are used. The Larsen and Heck relationships measure percentage leaf damage associated with different levels of air pollution concentration (ozone) and hours of exposure. They thus take into account the intuitively obvious fact that leaf damages may be more serious if a given plant is exposed to either higher levels of air pollution or a constant level for longer duration. There is one difficulty attendant to the use of the Larsen and Heck relationship, that being leaf damage may not correspond to yield reduction, especially for fruit or root crops. Thus, certain adjustments must then be made to translate leaf damage to yield reduction. Based on empirical results reported by Millecan, a general "rule-of-thumb" can be used to relate leaf damage to percentage of yield reduction. These translations are presented in Table 4.3.

An additional problem concerning the use of the Larsen and Heck methodology is that only a limited set of equations has been estimated. Of these, very few correspond to the set of crops included in the study. To circumvent this problem certain equations have been selected from the Larsen and Heck set to serve as "proxies" for general classes of crops. This assignment of equations to represent groups of included crops is based on a review of secondary information concerning degree of susceptibility of each plant or plant group to air pollution to establish some consistency of response. The representative crop equations used in this study are presented below.

Larsen and Heck equation		Study Crops
1. Pinto Beans	approximates	Green Lima Beans Celery (times 0.8)
2. Radish	"	Onion, Fresh (times 1.2) Onion, Processing (times 1.2) Sugarbeets
3. Spinach	"	Head Lettuce (times 0.6)
4. Summer Squash	"	Broccoli Cantalopes Carrots Cauliflower
5. Tomato	"	Tomato, Fresh Tomato, Processing Potato

After the selection of a specific equation to serve as a proxy for a particular study crop, a table of leaf damage (percent) associated with actual levels of air pollution concentration (ozone) as measured at representative air monitoring stations for each county and hours of exposure (8, 10, 12 hours) are calculated. For the purposes of this study, the level of air pollution concentration is classified into three categories: (1) Air pollution concentration level A represents the annual hourly maximum recorded at the county monitoring station. It is thus the highest level of oxidant/ozone concentration in each year; (2) Level B is the annual average

Table 4.3

A "Rule-of-Thumb"* Relating Leaf Damage to Yield Reduction

% of Leaf Damage						% of Yield Reduction				
1	2	3	4	5	corresponds to	0	0.1	0.4	0.8	1.0
6	7	8	9	10		1.1	1.2	1.5	1.7	2.0
11	12	13	14	15		2.3	2.7	3.0	3.5	4.0
16	17	18	19	20		4.5	5.1	6.0	7.0	8.0
21	22	23	24	25		9.0	10.1	11.2	12.5	14.0
26	27	28	29	30		15.0	16.0	17.0	18.0	19.0
31	32	33	34	35		19.9	20.9	21.7	22.5	23.0
36	37	38	39	40		23.8	24.7	25.5	26.3	27.0
41	42	43	44	45		27.6	28.2	28.8	29.4	30.0
46	47	48	49	50		30.6	31.2	31.7	32.3	33.0
51	52	53	54	55		33.6	34.2	34.8	35.4	36.0
56	57	58	59	60		36.6	37.2	37.8	38.4	39.0

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*It should be noted that Millecan's "rule-of-thumb," as cited, applies only to 20% leaf damage. For damage in excess of 20%, yield reduction was derived from secondary sources concerning general crop sensitivity as well as information relating to yield reduction at high levels of physical damage.

of the hourly maximum;2/ (3) Level C is the annual average of the average hourly maximum.3/ Table 4.4 contains the levels of oxidant/ozone concentration by station and region for the period 1972 to 1976 and the average of that period classified according to the three levels mentioned above.

The second type of equation used in the yield response analysis is that developed by Oshima, et. al. This equational structure is used to measure yield reductions in cotton, California's major field crop. The Oshima, et. al. equations, unlike those of Larsen and Heck, relate ozone doses directly to percentage of yield reduction. To date, this type of equation has been estimated for only three crops; alfalfa, cotton and tomato. In order to obtain an estimated percentage yield reduction, a cumulative ozone dose greater than 10 parts per hundred million (the required California standard) over the growing season in each year for each county is needed. Such data for 1976 were not available at the time of this study. However, the cumulative dose can be calculated for alternative levels (e.g., 8 and 20 parts per hundred million). The 8 pphm level was selected for use, with levels measured at air monitoring stations in or close to the growing regions for cotton. The stations include Indio-Oasis for Riverside and San Bernardino Counties; half the level of ozone doses observed in Indio-Oasis for Imperial County;4/ and Delano for Kern and Tulare Counties. The cumulative ozone dose is obtained by adding up total doses exceeding 8 pphm from March to September 1976 (representing the growing season) for each station, as reported in Table 1 in "California Air Quality Data, Summary of 1976 Air Quality Data Gaseous Pollutants." The average value of yield reduction across county is then used for each region producing cotton.

4.4 Estimated Results of Yield Reduction Due to Air Pollution

From the three levels of concentration in Table 4.4, concentration level C was selected for use in estimating the degree of yield reduction to be used in the study. Such a level is the most conservative level of the three, thus perhaps representing a lower bound on yield damage. In the South Coast region, the Pasadena, Anaheim, Indio-Oasis, San Bernardino, Santa Maria, San Diego, and Ventura air monitoring stations are used to calculate air pollution concentration for their respective counties. The Monterey station in the Central Coast was eliminated, as was the Bakerfield station in the Southern San Joaquin Valley on the assumption that levels at these stations are not representative of the levels in the actual growing areas.

In calculating the effect of air pollution on yield, two values of air pollution concentration (both representing level "C") are used. One is the average of 1972-1976 and the other is the 1976 level (for level C). The estimated yield reduction for a 12 hour exposure for the study crops is given in Tables 4.5 and 4.6. Table 4.7 is the average percentage of yield reduction across county in each region attributed to the presence of air pollution. Table 4.8 gives the actual yield per acre for the average of 1972-1976 and the 1976 crop year derived from Tables 1.2, 1.3 and 1.4 of Chapter I. These yield figures thus represent actual yields, i.e., yields in the presence of air pollution. Finally, Table 4.7 is used to estimate Table 4.9, the production or yield per acre in the absence of air pollution

Table 4.4

Levels of Oxidant/Ozone Concentration (pphm)

Area/Station	County	Level A						Level B						Level C					
		72	73	74	75	76	Av.	72	73	74	75	76	Av.	72	73	74	75	76	Av.
<u>Imperial Valley</u>																			
El Centro	Imperial	-	-	17	13	8	13	-	-	11	9	6	7	-	-	6	6	3	5
<u>South Coast</u>																			
Downtown	Los Angeles	25	52	25	25	34	32	18	20	17	18	22	19	7	7	8	8	8	8
Pasedena	Los Angeles	38	45	34	32	34	36	23	23	24	22	24	23	10	10	11	10	11	10
Anaheim	Orange	35	32	25	17	30	28	18	19	16	13	16	16	5	6	6	5	6	6
Riverside-Robidoux	Riverside	50	39	39	35	36	40	27	24	26	24	23	25	12	11	13	10	10	11
Indio-Oasis	Riverside	25	22	22	20	16	21	16	18	14	12	11	14	8	7	7	7	6	7
San Bernardino	San Bernardino	42	42	33	38	30	37	18	22	22	22	16	20	8	11	9	10	7	9
Santa Barbara	Santa Barbara	13	24	21	25	17	20	9	13	12	12	10	11	4	6	6	6	5	4
Santa Maria	Santa Barbara	15	13	15	6	12	12	8	7	7	5	9	7	4	4	4	3	5	4
San Diego	San Diego	17	24	18	15	16	18	12	11	12	11	13	12	4	5	6	6	6	5
Ventura-Telegraph Rd.	Ventura	-	-	20	16	19	18	-	-	14	11	13	13	-	-	7	5	5	6
<u>Central Coast</u>																			
Monterey	Monterey	11	14	14	8	7	11	7	9	7	6	5	7	3	4	4	3	3	3
Salinas	Monterey	9	15	12	8	11	11	7	9	8	5	6	7	4	4	4	3	4	4
Holliston	San Benito	-	13	14	13	15	14	-	10	10	9	9	10	-	5	5	5	5	5
San Luis Obispo	San Luis Obispo	12	11	15	11	11	12	8	8	9	7	8	8	4	4	5	4	4	4
<u>Southern San Joaquin</u>																			
Bakerfield	Kern	18	17	17	12	12	15	10	11	12	8	8	10	6	6	7	5	5	6
Delano	Kern	-	-	-	12	11	11	-	-	-	10	10	10	-	-	-	4	6	5
Visalia-Old Jail	Tulare	20	19	20	13	13	17	13	11	12	10	10	11	7	7	8	5	5	6

A = Maximum value for the year. It is the maximum of the month and also the maximum of each day. It is obtained by first obtaining the hourly maximum for each day (24 values) then pick the maximum to represent the maximum for each day and pick the maximum to represent each month (12 values). Then pick the maximum to represent each year (5 values) and the average over a 5-year period.

B = Average of the maximum of hourly max. It is obtained by the same procedure as in A but the final value for each year is obtained by averaging the monthly maximum and then the average over a 5-year period.

C = Average of the average of hourly maximum. It is obtained by averaging the average of the hourly-maximum. Then average over a 5-year period.

Table 4.5

Percentage Yield Reduction for 12 Hour Exposure, Using the Average Value of Oxidant/Ozone Concentration from 1972-1976, "C" Level

Region/Station	County	Oxidant/Ozone Concentration (pphm)	Crop											
			Green Lima Beans	Broccoli	Cantalopes	Carrot	Cauliflower	Celery	Head Lettuce	Onions	Potato	Tomato	Cotton	Sugarbeets
<u>Imperial</u>														
El Centro	Imperial	5	3.1	0	0	0	0	2.5	0	1.0	1.1	1.1	9.4	0.8
<u>South Coast</u>														
Pasadena	Los Angeles	10	49.9	0	0	0	0	39.9	1.1	23.9	34.3	34.3	-	19.9
Anaheim	Orange	6	15.8	0	0	0	0	12.6	0	1.7	2.8	2.8	-	1.4
Indio-Oasis	Riverside	7	28.2	0	0	0	0	22.6	0.1	3.4	9.4	9.4	18.7	2.6
San Bernardino	San Bernardino	9	45.0	0	0	0	0	36.0	0.7	15.8	28.2	28.2	18.7	13.2
Santa Maria	Santa Barbara	4	0.8	0	0	0	0	0.6	0	0.1	0.1	0.1	-	0.1
San Diego	San Diego	5	3.1	0	0	0	0	2.5	0	1.0	1.1	1.1	-	0.8
Ventura-Telegraph Rd.	Ventura	6	15.8	0	0	0	0	12.6	0	1.7	2.8	2.8	-	1.4
<u>Central Coast</u>														
Salinas	Monterey	4	0.8	0	0	0	0	0.6	0	0.1	0.1	0.1	-	0.1
Hollister	San Benito	5	3.1	0	0	0	0	2.5	0	1.0	1.1	1.1	-	0.8
San Luis Obispo	San Luis Obispo	4	0.8	0	0	0	0	0.6	0	0.1	0.1	0.1	-	0.1
<u>Southern San Joaquin</u>														
Delano	Kern	5	3.1	0	0	0	0	2.5	0	1.0	1.1	1.1	6.9	0.8
Visalia-Old Jail	Tulare	6	15.8	0	0	0	0	12.6	0	1.7	2.8	2.8	6.9	1.4

Table 4.6

Percentage Yield Reduction for 12 Hour Exposure, Using the "C" Level of Oxidant/Ozone Concentration for 1976

Region/Station	County	Oxidant/Ozone Concentration (pphm)	Crop											
			Green Lima Beans	Broccoli	Cantalopes	Carrots	Cauliflower	Celery	Head Lettuce	Onion	Potato	Tomato	Cotton	Sugarbeets
Imperial														
El Centro	Imperial	3	0	0	0	0	0	0	0	0	0	0	9.4	0
South Coast														
Pasadena	Los Angeles	7	28.2	0	0	0	0	22.6	0.1	3.4	9.4	9.4	-	2.8
Anaheim	Orange	6	15.8	0	0	0	0	12.6	0	1.7	2.8	2.8	-	1.4
Indio-Oasis	Riverside	6	15.8	0	0	0	0	12.6	0	1.7	2.8	2.8	18.7	1.4
San Bernardino	San Bernardino	7	28.2	0	0	0	0	22.6	0.1	3.4	9.4	9.4	18.7	2.8
Santa Maria	Santa Barbara	5	3.1	0	0	0	0	2.5	0	1.0	1.1	1.1	-	0.8
San Diego	San Diego	6	15.8	0	0	0	0	12.6	0	1.7	2.8	2.8	-	1.4
Ventura-Telegraph Rd.	Ventura	5	3.1	0	0	0	0	2.5	0	1.0	1.1	1.1	-	0.8
Central Coast														
Salinas	Monterey	4	0.8	0	0	0	0	0.6	0	0.1	0.1	0.1	-	0.1
Hollister	San Benito	5	3.1	0	0	0	0	2.5	0	1.0	1.1	1.1	-	0.8
San Luis Obispo	San Luis Obispo	4	0.8	0	0	0	0	0.6	0	0.1	0.1	0.1	-	0.1
Southern San Joaquin														
Delano	Kern	6	15.8	0	0	0	0	12.6	0	1.7	2.8	2.8	6.9	1.4
Visalia-Old Jail	Tulare	5	3.1	0	0	0	0	2.5	0	1.0	1.1	1.1	6.9	0.8

Note: The Salinas Station is also used for Santa Cruz County.

Table 4.7

Percentage Yield Reduction Averaged Over County, for each Region, by Time Period

Crop	Southern Desert		South Coast		Central Coast		Southern San Joaquin		Total	
	1972-76 Average	1976	1972-76 Average	1976	1972-76 Average	1976	1972-76 Average	1976	1972-76 Average	1976
Vegetable Crop										
Beans	-	-	22.66	15.71	1.57	1.57	9.45	9.45	11.23	8.91
Broccoli	-	-	0	0	0	0	-	-	0	0
Cantalopes	0	0	0	0	-	-	0	0	0	0
Carrots	0	0	0	0	0	0	0	0	0	0
Cauliflower	-	-	0	0	0	0	-	-	0	0
Celery	-	-	18.11	12.57	1.23	1.23	-	-	9.67	6.90
Lettuce	0	0	0.27	0.03	0	0	0	0	0.068	0.01
Onion, Fresh	1.00	0	6.80	1.99	0.40	0.40	-	-	3.60	0.60
Onion, Process	1.00	0	6.80	1.99	0.40	0.40	1.35	1.35	2.387	0.94
Potato	-	-	11.24	4.20	0.43	0.43	1.95	1.95	4.54	2.19
Tomato, Fresh	1.10	0	11.24	4.20	0.43	0.43	1.95	1.95	3.68	1.65
Tomato, Process	1.10	0	11.24	4.20	0.43	0.43	1.95	1.95	3.68	1.65
Field Crop										
Cotton	9.40	9.40	18.70	18.70	-	-	6.90	6.90	11.67	11.67
Sugarbeets	0.80	0	5.66	1.63	0.33	0.33	1.10	1.10	1.97	0.77

Table 4.8

Actual Yield Per Acre (in the Presence of Air Pollution)

Crop	Unit	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	Tons	-	-	2.16	2.04	2.23	2.52	2.96	3.00	2.29	2.35
Broccoli	CWT	-	-	81.62	83.72	54.09	60.67	-	-	57.81	64.12
Cantalopes	CWT	128.57	127.46	139.85	150.42	-	-	188.12	180.00	145.12	141.72
Carrots	CWT	333.87	402.00	312.12	257.30	292.03	303.12	341.10	350.00	321.86	318.87
Cauliflower	CWT	-	-	127.68	114.02	99.28	97.68	-	-	108.66	103.43
Celery	CWT	-	-	568.65	546.58	561.88	549.73	-	-	565.94	547.87
Lettuce, Head	CWT	250.65	266.97	253.57	261.37	265.14	279.14	259.95	292.16	258.73	273.46
Onion, Green	CWT	274.37	208.94	322.54	291.31	302.55	285.45	-	-	300.05	258.26
Onion, Dehydrated	CWT	273.04	324.32	318.66	350.00	335.05	314.61	340.03	396.92	323.70	368.70
Potatoes	CWT	-	-	319.47	315.77	327.12	326.46	275.34	295.11	288.50	301.78
Tomato, Fresh	CWT	217.72	217.44	469.96	505.89	307.67	201.29	288.12	199.45	372.81	370.18
Tomato, Process	Tons	21.66	25.17	24.83	20.34	25.52	19.89	20.29	24.53	22.71	21.64
Field Crops											
Cotton	Lbs	1,144.98	996.48	1,019.12	1,084.84	-	-	1,026.16	1,088.10	1,039.19	1,075.95
Sugarbeets	Tons	25.53	25.45	27.86	28.47	32.87	35.55	26.50	28.42	27.08	28.44

Table 4.9

Potential Yield Per Acre (without Air Pollution Effects)

Crop	Unit	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	Tons	-	-	2.65	2.36	2.26	2.56	3.24	3.28	2.55	2.56
Broccoli	CWT	-	-	81.62	83.72	54.09	60.67	-	-	57.81	64.12
Cantalopes	CWT	128.57	127.46	139.85	150.42	-	-	188.12	180.00	145.12	141.72
Carrots	CWT	333.87	402.00	312.12	257.30	292.03	303.12	341.10	350.00	321.86	318.87
Cauliflower	CWT	-	-	127.68	114.02	99.28	97.68	-	-	108.66	103.43
Celery	CWT	-	-	671.63	615.28	568.79	556.49	-	-	620.67	585.67
Lettuce, Head	CWT	250.65	266.97	254.25	261.45	265.14	279.14	259.95	292.16	258.91	273.49
Onion, Green	CWT	277.11	208.94	344.47	297.11	303.76	286.59	-	-	310.85	259.81
Onion, Dehydrated	CWT	275.77	324.32	340.33	356.96	336.39	315.87	344.62	402.28	331.43	370.91
Potatoes	CWT	-	-	355.38	329.03	328.53	327.86	280.71	300.86	301.60	308.39
Tomato, Fresh	CWT	220.11	217.44	522.78	527.14	308.99	202.16	293.74	203.34	386.53	376.29
Tomato, Process	Tons	21.90	25.17	27.62	21.19	25.63	19.98	20.69	25.01	23.55	22.00
Field Crops											
Cotton	Lbs	1,252.55	1,090.15	1,209.70	1,287.70	-	-	1,096.97	1,163.18	1,160.46	1,201.51
Sugarbeets	Tons	25.73	25.45	29.44	28.93	32.98	35.67	26.79	28.73	27.61	28.66

Southern Desert includes Imperial County
Southern Coast includes Los Angeles, Orange, Riverside, San Bernardino, Santa Barbara, San Diego, and Ventura Counties
Central Coast includes Monterey, San Benito, San Luis Obispo, and Santa Cruz Counties
Southern San Joaquin includes Kern and Tulare Counties

Sources: County Agricultural Commissioner Annual Crop Reports effects in the study area. Table 4.9 thus represents the potential or hypothetical yield that could be realized if the negative effects of air pollution were removed from the crop environment.

FOOTNOTES: CHAPTER IV

[1/] The counties in each region as well as included crops in this study are discussed in Chapter I.

[2/] See the explanation on these levels at the bottom of Table 4.4.

[3/] *Ibid*.

[4/] El Centro, the monitoring station for Imperial County, typically has approximately one-half the ozone level observed at Indio-Oasis. Hence, the one-half value for cumulative doses.

CHAPTER V

PRICE-FORECASTING EQUATION ESTIMATION[1/]

As discussed in Chapter I, price fluctuations observed in most agricultural crops depend on a wide range of economic and physical factors, such as climatological conditions, which may affect per-unit and aggregate yield of a crop in a particular year and thus translate into subsequent changes in crop price. For most agricultural crops supply is inelastic in the short run. In other words, changes in crop price cannot affect the quantity supplied in the short run, since supply cannot respond immediately to such changes in price. Furthermore, some agricultural crops (e.g., vegetables) are highly perishable; thus, the quantity produced must be sold immediately after harvest. These characteristics of agricultural production imply that quantity produced, perhaps more than other factors, determines the overall level and variation in prices.[2/]

Due to these characteristics, price cannot reasonably be assumed to be predetermined for many crops; consequently, a price endogenous structure of demand is needed to correctly capture the structure of the market. There are, however, some exceptions; e.g., prices of some vegetable or field crops are predetermined, as in the case of "contractual" crops or crops affected by institutional arrangements such as payments, subsidies and quotas on production. Processing tomatoes and market (dehydrated) onions are examples in the first case (contracts) and sugarbeets the second case (government support and quota program).

The mathematical model developed in Chapter III features linear demand functions incorporated into a quadratic objective function, with the intent of determining prices endogenously. The objective of such a model is to capture the price effect of air pollution. The purpose of this chapter is to discuss the estimation procedure and present the statistical results associated with the derivation of price forecasting equations for the 12 vegetable and 2 field crops included in the study, on a seasonal basis. As pointed out by Adams (1975) and as discussed earlier, seasonality of production for vegetables is particularly important. Given the regional production patterns observed in California, correct analysis of comparative advantage, on a regional basis, requires a suitable set of seasonal demand function estimates.

The following subsection describes the procedure for estimating general price forecasting equations. The actual results of price forecasting equations for the 12 vegetable and 2 field crops are then presented. A brief summary of the overall estimation will then be given in the concluding subsection.

5.1 Price Forecasting Equation Estimation Procedure

The concept of a price forecasting equation was discussed in Chapter III with respect to a general formulation. In this section, the actual procedure used in estimating such equations will be described briefly. The linear demand functions included in the model have the following form:

$$p = c + dQ \tag{5.1}$$

where p is a vector (j x 1) of commodity prices, c is a vector (j x 1) of constants, d is a negative diagonal matrix (j x j) of price-quantity slope coefficients and Q is a vector (j x 1) of agricultural crop production. The above equational form assumes that price of a particular crop is affected only by its quantity supplied, i.e., a diagonal "d" matrix implies zero cross-effects for competing commodities.

Consider the following functional specification of a price endogenous demand equation:

$$P_j^c = f(Q_j^c, Q_j^r, S_j, Y) \tag{5.2}$$

where P_j^c = annual seasonal average price received by farmers in California for commodity j.

Q_j^c = seasonal production of commodity j in California.

Q_j^r = seasonal production of commodity j, the rest of the United States.

S_j = existing stocks for commodity j for the United States.

Y = U.S. personal aggregate disposable income.

A priori one would expect that quantity produced and existing stocks would have a negative sign whereas income would be positively correlated with changes in price. That is, an increase in quantity produced of crop j has a negative effect on its own price regardless of where it is sold, assuming the crop is homogeneous. An increase in stock tends to indicate a reduction in price since stocks tend to be positively correlated with production and producers tend to increase the level of stocks (for sale in a later period when price is higher) during periods of lower price. An increase in income enables one to consume more (if a good is assumed to be normal) and thus affects the price. To keep the assessment problem tractable, it is assumed that the price of commodity j is not affected by price or quantity of other commodities, i.e., cross-price effects are zero.

The above formulation was used for all seasonal demand relationships for all crops included in the study, except processing tomatoes, cotton and sugarbeets which cannot be estimated by the same procedure due to suspected simultaneity. As a result, a single equation estimation would not be valid; thus, some secondary estimates were used. Ordinary least squares was used in estimating the coefficients for all the variables in the above equation, for all the study crops on a seasonal basis. Once coefficients are obtained for the variables in the price equation, coefficients of all independent variables (except quantity produced in California) are then used to calculate an "adjusted intercept." This, then, results in a price forecasting equation featuring an adjusted intercept and the slope coefficient with respect to California quantity. Results of the estimations, including price-flexibility coefficients, are given in the next section.

5.2 Price Forecasting Equations for Vegetable and Field Crops[3/]

Vegetables

The seasonal patterns and magnitudes of production for the 12 vegetable crops included in this study are described in Adams (1975) and King, et. al. (1978). The period covered in estimating the price forecasting equations for the 12 vegetable crops in this study is from 1955 to 1976, using data from Adams (1975) for the period 1955 to 1972. There is a problem attendant to quantifying seasonal production for these 12 crops in California after 1972 due to changes in seasonal patterns as reported by the U.S. Department of Agriculture, i.e., the twelve reporting seasons used in the earlier period were collapsed into four. As a result, this required disaggregating some seasonal estimates for the period 1973 to 1976 into the more numerous seasonal classification employed in the earlier time period. Such adjustments were made for the period 1973 to 1976 to ensure consistency with data from 1955 to 1972. The adjustments, by season, are given in Appendix Table A. The net result is the estimation of 28 equations for the 12 vegetable crops. These estimated equations will be presented below in order of importance, as measured by gross income received in 1976.

1. Lettuce. Lettuce contributes the second highest gross income to California growers (behind tomatoes--fresh and processing), with a total gross value of $327.7 million in 1976. This value is almost 70% of the total revenue from U.S. lettuce production. The leading counties are Monterey, San Benito, San Luis Obispo and Santa Cruz in the Central Coast, and Santa Barbara in the South Coast for summer lettuce, spring and fall lettuce. Winter lettuce is produced mostly in Imperial and Riverside counties. Imperial County also dominates production of fall lettuce. The nature and marketing patterns of this and other crops are more completely described in Adams (1975).

Following Adams (1975), the four seasonal price forecasting equations for lettuce were estimated and presented in Table 5.1. Results of the estimation were not totally satisfactory, even though the signs of all variables except that of "other production" in the winter lettuce were as expected. The estimated coefficients of all variables in the winter lettuce are statistically insignificant (5%) and test of autocorrelation among error terms is inconclusive at 5% levels of significance in all but one equation. Comparing the results obtained with those in Adams (1975) shows that the coefficients of determination ($\bar{R}^2$) and the price flexibility coefficient with respect to California production are higher in all equations of the same seasons. However, as is true in Adams (1975), the estimated California production slope coefficient in this study is higher than that associated with "other production" in the same season except for fall lettuce. This result tends to suggest that lettuce sold in California vis-a-vis "other" U.S. production is not homogeneous. Evidence from other researchers (Johnston and

Table 5.1

Price-Forecasting Equations for Lettuce and Fresh Tomato, By Season[a]

Crop/ Season	Constant[b]	Estimated Coefficient with Respect To:				Summary Statistics		Average California Production 1972-76 (Actual)	Price Flexibility With Respect to California Production 1972-76
		California Production	"Other" Production	Stock	Personal Aggregated Disposable Income	$\bar{R}^2$	D.W.		
		(1000 cwt.)	(1000 cwt.)		($ billion)			(1000 cwt.)	
Lettuce									
Winter	2.12	-0.59E-3 (0.48)	0.20E-3 (0.63)	-	2.78E-3 (0.67)	0.54	2.86[e]	11903	c
Early Spring	5.67	-1.27E-3 (-2.27)	-0.47E-3 (-1.19)	-	10.00E-3 (3.22)	0.52	2.55[e]	6953	-1.50
Summer	6.60	-0.84E-3 (-2.59)	-0.31E-3 (-0.95)	-	10.11E-3 (5.24)	0.75	2.02[d]	10580	-1.30
Fall	2.71	-0.50E-3 (-1.54)	-0.82E-3 (-2.99)	-	11.90E-3 (4.71)	0.79	1.50[e]	7617	-0.55
Tomato, Fresh									
Early Spring	0.30	-5.49E-3 (-0.82)	0.47E-3 (0.30)	-	19.89E-3 (4.83)	0.70	2.45[e]	378	c
Early Summer	-3.29	-1.07E-3 (-1.01)	2.34E-3 (2.95)	-	18.76E-3 (6.44)	0.93	1.89[d]	3887	-0.19
Early Fall	7.10	-1.27E-3 (-1.23)	-	-	14.09E-3 (7.65)	0.93	2.46[e]	2529	-0.18

[a] Data cover period for 1955 to 1976 crop year with quantity produced expressed in units of 1000 hundredweight (cwt.) and price on actual dollars per cwt. Personal aggregate disposable income (in billion dollars) is for the fiscal year. Numbers in parentheses are estimated *t*-statistics.

[b] Dollar per cwt.

[c] Not available due to statistically insignificant and/or wrong expected sign for the estimated coefficient.

[d] No autocorrelation among error terms at 5% levels of significance.

[e] Test of autocorrelation among error terms is inconclusive at 5% levels of significance.

Dean, 1969; Zusman, 1962) indicates that fresh vegetables produced in California have somewhat higher quality compared to that produced elsewhere; hence, it may not be unreasonable to expect a divergence across such coefficients.

2. Processing tomatoes. Processing tomatoes in California have a gross value of $284.7 million in 1976. This value is about 75% of the national total. The processing tomatoes industry is one of the most rapidly growing subsectors in California agriculture over the last two decades. Several factors such as a favorable climate, advances in production technology, harvesting systems and a progressive canning industry attribute to such growth. Major production areas are Solano, Sutter and Yolo counties in the Sacramento Valley; and Fresno and San Joaquin counties in the San Joaquin Valley. Total state production in 1976 exceeded 230,000 acres, down from almost 300,000 acres in 1975. This reduction in production is partially attributable to drought conditions in 1976.

It is more difficult to estimate a reasonable price forecasting equation for processing tomatoes, given that processing tomatoes are generally grown under contract between growers and processors. Prices are usually determined prior to planting based on several factors, most important being the carryover of tomato products and the existing market situation, characteristics which suggest simultaneity. Moreover, the estimation of a price forecasting equation for such a crop is further complicated by the fact that processing tomatoes are marketed in various forms such as catsup, juice, canned whole tomatoes, paste and puree, and other concentrated products. Each form does not have the same price flexibility coefficient, as is evidence from the secondary information presented in Table 5.2.

Given these problems, it was decided that the values given in Adams (1975), derived via a weighting procedure of flexibilities presented in Table 5.2, will be used for the price-forecasting equation for processing tomatoes in this study.

3. Fresh market tomatoes. Gross income for California fresh tomatoes in 1976 exceeded $137 million, 32.4% of the national total. Early spring fresh tomatoes are produced mostly in Imperial and San Diego counties. Early summer tomatoes come almost exclusively from the Central Coast (Monterey County), San Joaquin Valley (Fresno, Merced, San Joaquin, Stanislaus and Tulare Counties) and the South Coast (San Diego County). San Diego and Ventura Counties in the South Coast are the main suppliers of early fall fresh tomatoes in California. California fresh tomato production has to compete with other major production regions such as Florida, Texas, New York, Michigan and Mexico.

The estimated price forecasting equations for fresh tomatoes are given in Table 5.1. The sign attached to the coefficient on early spring California production was not consistent with expectations, i.e., it had a positive sign. In such a case, the coefficient had to be reestimated by using a weighting procedure, utilizing the price flexibilities for other seasons weighted by the volume of production from 1972 to 1976. The estimated coefficients of "other production" have positive signs, perhaps due to the confounding effects of California production. From the table, it is evident

Table 5.2

Estimated Price Flexibility for California Processing Tomatoes, 1948-1971[a]

Product	Price Flexibility Coefficient	California total Shipments[1] of the Processing Tomatoes, 1975[b], (Thousand Tons)
Canned whole	-0.33	566
Juice	-0.23	290
Catsup and Chile	-0.33	369
Puree	-0.10	333
Paste and other	-0.28	1,979
Total	-	3,537
Weighted average	-0.277	-

[1] Total shipments = beginning stocks plus pack minus ending stocks.

[a] Source: King, Jesse and French (1973), and Adams (1975).

[b] Brandt, French and Jesse (1978).

that income was the most significant explanatory variable. The price flexibility with respect to California production obtained in this study is of the same magnitude of that obtained by Shuffett (1954) and Adams (1975).

4. Potatoes. Although California's current potato production is only about 9% of the national total, it contributed more than $110 million to totoal state gross income in 1976. Kern County supplies most of the California winter and spring potatoes, whereas Riverside County is the major producer of summer potatoes. Fall potatoes are produced mostly in the Central Coast and Siskiyou and Modoc Counties in extreme northern California.

Potatoes are marketed in either fresh and/or processed forms; thus, in estimating the price forecasting equations stock is also included as an explanatory variable. Results obtained are presented in Table 5.3.

From Table 5.3 it is evident that most of the estimated equations are somewhat disappointing with respect to statistical robustness although the estimated coefficients attached to the California production have the expected signs. A divergence of sign is noticed on the disposable income variable for winter and early summer potatoes. One would expect that an increase in personal income will tend to reduce potato consumption and thus depress price since potatoes are usually assumed to be an inferior good.

The estimated price flexibility coefficients are somewhat lower than those estimated by Adams (1975). However, the coefficients of determination in all equations are higher than those of Adams'.

5. Celery. California celery production in 1976 constituted about 66% of the total U.S. production. The gross income in that year is $78.9 million which is about 60% of the U.S. value of celery production. Of the four marketing periods, Ventura County supplies most of the winter and spring celery. Monterey County, on the other hand, produces most of the early summer and late fall celery. Nationally, California celery faces some competition from other states such as Florida (for winter celery) and Michigan and New York (for early summer celery).

Celery is highly perishable and is marketed only in its fresh form. Thus, in estimating the price forecasting equation only three explanatory variables were used. These variables are California production, "other production," and personal aggregate disposable income. The estimated results are presented in Table 5.4.

As is evident from the table, all the estimated coefficients have the right expected signs and most are statistically significant. Income is the most important variable in explaining the variation of price. Only one equation has an inconclusive test of autocorrelation whereas the rest indicate no autocorrelation among error terms. In terms of competition from other states, the magnitude of the estimated coefficient of production from other areas is higher than that of California for spring celery and vice versa for winter celery. This tends to suggest that cet. par. production outside California has an influence on the price of celery sold in California in the spring season but not in the winter market. The magnitude of the

Table 5.3

Price-Forecasting Equations for Potatoes, By Season[a]

		Estimated Coefficient with Respect to:				Summary Statistics			
Crop/Season	Constant[b]	California Production	"Other" Production	Stock As at Dec. 1	Personal Aggregated Disposable Income	$\bar{R}^2$	D.W.	Actual Average California Production 1972-76	Price Flexibility with Respect to California Production for 1972-76
		(1000 cwt.)	(1000 cwt.)	(1000 cwt.)	($ billion)			(1000 cwt.)	
Potatoes									
Winter	-0.49	-0.85E-3	0.31E-3	0.06E-3	-4.62E-3	0.71	1.49[c]	1082	-0.18
		(-1.99)	(0.82)	(3.06)	(-1.61)				
Late Spring	2.79	-0.30E-3	0.26E-3	0.02E-3	0.22E-3	0.62	1.72[3]	12066	-0.69
		(-1.89)	(1.60)	(0.71)	(0.07)				
Early Summer	8.56	-1.29E-3	-0.34E-3	0.02E-3	-4.38E-3	0.65	2.48[d]	894	-0.23
		(-1.68)	(-2.65)	(1.01)	(-1.09)				
Late Summer	7.27	-0.15E-3	-0.15E-3	-	0.06E-3	0.66	1.69[d]	1761	-0.05
		(-0.35)	(-2.26)		(0.03)				
Fall	4.14	-0.04E-3	-0.03E-3	-	7.38E-3	0.77	1.30[e]	6574	-0.05
		(-0.33)	(-1.90)		(4.09)				

(continued)

Table 5.3
(continued)

[a] Data cover period from 1955 to 1976 crop year with quantity produced expressed in units of 1000 hundredweight (cwt.) and price in actual dollars per cwt. Stock is in units of 1000 pounds. Personal aggregate disposable income (in billion dollars) is for the fiscal year. Numbers in parentheses are estimated t-statistics.

[b] Dollars per cwt.

[c] No autocorrelation among error terms at 5% levels of significance.

[d] Test of autocorrelation among error terms is inconclusive at 5% levels of significance.

Table 5.4

Price-Forecasting Equations for Celery, Cantalopes and Broccoli, By Season[a]

		Estimated Coefficient with Respect to:				Summary Statistics			
Crop/Season	Constant[b]	California Production	"Other" Production	Frozen Stock As at Dec. 31	Personal Aggregated Disposable Income	$\bar{R}^2$	D.W.	Average California Production 1972-76 (Actual)	Price Flexibility With Respect to California Production for 1972-76
		(1000 cwt.)	(1000 cwt.)	(1000 lbs.)	($ billion)			(1000 cwt.)	
Celery:									
Winter	6.19	-1.35E-3 (-2.22)	-0.35E-3 (-0.57)	-	4.53E-3 (5.24)	0.68	2.61[e]	2459	-0.48
Spring	10.70	-1.76E-3 (-2.49)	-2.89E-3 (-3.41)	-	4.18E-3 (5.35)	0.67	1.83[d]	2421	-0.69
Early Summer	3.29	-0.62E-3 (-0.71)	-	-	4.05E-3 (3.81)	0.65	2.11[d]	1961	-0.20
Late Fall	6.35	-1.62E-3 (-1.88)	-	-	6.42E-3 (6.15)	0.69	1.96[d]	3667	-0.88
Cantaloupes:									
Spring	6.58	-1.63E-3 (-2.49)	-0.77E-3 (-1.61)	-	7.83E-3 (7.82)	0.89	2.20[d]	1197	-0.18
Summer	6.53	-0.54E-3 (-2.69)	-0.52E-3 (-1.27)	-	5.73E-3 (5.78)	0.90	2.56[e]	5870	-0.40
Broccoli:									
Early Spring	5.32	-0.72E-3 (-0.76)	-	-0.02E-3 (-1.92)	12.28E-3 (6.80)	0.93	1.20[e]	2000	-0.11
Fall	4.68	-2.97E-3 (-1.73)	1.76E-3 (0.60)	-0.02E-3 (-1.65)	17.03E-3 (9.13)	0.96	2.14[d]	1615	-0.34

(continued)

Table 5.4
(continued)

[a] Data cover period from 1955 to 1976 crop year with quantity produced expressed in units of 1000 hundredweight (cwt) and price in actual dollars per cwt. Stock is in units of 1000 lbs. Personal aggregate disposable income (in billion dollars) is for the fiscal year. Numbers in parentheses are estimated t-statistics.

[b] Dollars per cwt.

[c] No autocorrelation among error terms at 5% levels of significance.

[d] Test of autocorrelation among error terms in inconclusive at 5% levels of significance.

price flexibility coefficients obtained in this study are similar to those obtained by Adams (1975).

6. Cantaloupes. California produces about two-thirds of the total cantaloupes produced in the United States. In 1976, gross income from cantaloupes in California amounted to about $70.4 million (65.2% of the U.S.). Prior to 1972, cantaloupes were marketed in two seasons: spring and summer. After 1972, three seasons were recognized with the third season being fall. Imperial County is the leading production area for spring and fall cantaloupes, whereas Fresno and Kern Counties supply most of the California summer cantaloupes. Of the three seasons in the present system, summer season accounts for more than 75% of annual production. California cantaloupes face strong competition from other areas such as Texas and Mexico, especially for the summer market. Disease and labor problems and a decline in the price of cantaloupes relative to other less labor-intensive commodities caused a sharp reduction in the spring crop over the past decade [Adams, 1975, p. 88].

Since cantaloupes are highly perishable and are marketed only in fresh form, the formulated price forecasting equations for this crop consist only of three explanatory variables. The estimated results are presented in Table 5.4.

The estimated coefficients for the explanatory variables in all equations have the right expected signs and are statistically significant at not less than 10% levels of significance (except the coefficient for "other production" in summer cantaloupes). Income is significant and the coefficients of determination are quite high. The price flexibility coefficient is consistent with that obtained by Adams (1975).

7. Broccoli. California produces about 97% of total U.S. broccoli production. Gross income from broccoli production in 1976 was $65.6 million (99% of the U.S.). Broccoli is marketed in two forms: fresh and frozen. Fresh market broccoli was previously reported for two market seasons, early spring and fall. After 1972, however, the market had been broadened to four seasons: winter, spring, summer, and fall. Monterey and Santa Barbara Counties are the main production areas for broccoli in California.

The estimated price forecasting equations for broccoli are given in Table 5.4. All but one variable had the expected signs, the exception being the estimated coefficient for "other production," which is also statistically insignificant. Once again, income is the most important explanatory variable in explaining the variations in price of broccoli. The price flexibility coefficients obtained in this study again are similar to those obtained by Adams (1975).

8. Carrots. The average production of carrots in California over the last 5 years represents about 50% of the national total. In 1976, California's market share of carrots was 50.3% with a gross income of $58.3 million (49.6% of the U.S.). Winter carrots are produced mostly in Riverside and Kern Counties, whereas Monterey, Kern and Imperial Counties supply most of the early summer carrots. Monterey, Kern and Riverside Counties are also important producers of late fall carrots.

Since carrots are marketed in both fresh and frozen forms, the frozen pack is included in the price forecasting equation estimations. The estimated results are presented in Table 5.5.

Of the three estimated equations, winter carrots have the wrong expected sign on the stock variable. The magnitude of the price flexibility coefficient obtained in this study displays a wider range of values than those obtained by Adams (1975).

9. Cauliflower. California is a major producer of cauliflower, supplying about 80% of the national total in 1976. The gross income from cauliflower production in that year exceeded $50 million (76.8% of the U.S.). Cauliflower is marketed in fresh and frozen forms. Frozen pack accounts for about 36.5% of the total production and 19% of the gross income from California cauliflower production in 1976. Early spring cauliflower is produced mostly in Alameda and Monterey Counties. Kern, Monterey and Santa Barbara Counties are main producers of late fall cauliflower.

The fact that California cauliflower production faces little significant competition in any season from other sources resulted in only three variables being included in the equation; California production, frozen pack and aggregate income. The estimated equations are given in Table 5.5.

The estimated equations obtained do not have the expected signs for all variables. Most significantly, the estimated coefficient attached to the California production of late fall cauliflower has the wrong expected sign. The slope coefficient for this variable was reestimated by using the price flexibility coefficient for early spring production, adjusted to fall quantities and prices.

10. Processing onions. California produces the bulk of the supply of processing (dehydrated) onions in the U.S., due to the state's long growing season. Processing onions in California are marketed in summer (late). Total production in 1976 was 7.2 million hundredweight, with a gross income of $27.5 million. Kern, Fresno, Riverside and Monterey Counties are the main producers of processing onions.

Processing onions are grown mostly under contract to specific processors. These institutional arrangements influence the fluctuations in price and thus the causality of price-quantity relationship; hence, a single equation estimation may not be appropriate. In estimating the price forecasting equation for processing onions, four explanatory variables are included in the model. Results obtained, shown in Table 5.5, are not entirely satisfactory, given that the estimated coefficients are either statistically insignificant (10%) or do not have the right expected signs. This tends to confirm the hypothesis stated above. Lack of alternative estimates from more detailed econometric analysts mandated the use of this equation, as estimated.

11. Fresh market onions. California fresh onion production contributed only about 23.0% in volume and 17.6% in value to the national totals in 1976. The other states that produce late spring (or spring) onions are

Table 5.5

Price-Forecasting Equations for Carrots, Cauliflower, Onions and Beans, by Season[a]

Crop/Season	Constant[b]	Estimated Coefficient with Respect to:				Summary Statistics		Average California Production 1972-76 (Actual)	Price Flexibility with Respect to California Production for 1972-76
		California Production (1000 cwt.)	"Other" Production (1000 cwt.)	Frozen Stock As at Dec. 1 (1000 lbs)	Personal Aggregated Disposable Income ($ billion)	$\bar{R}^2$	D.W.	(1000 cwt.)	
Carrots:									
Winter	7.71	-1.48E-3 (-2.13)	-0.54E-3 (-1.91)	0.01E-3 (0.77)	2.02E-3 (1.12)	0.56	2.01[d]	3438	-0.83
Early Summer	3.10	-0.15E-3 (-0.21)	-	-0.01E-3 (-1.39)	5.54E-3 (2.27)	0.47	2.28[e]	4072	-0.10
Late Fall	2.63	-0.18E-3 (-0.39)	-	-0.02E-3 (-2.42)	7.85E-3 (5.00)	0.68	1.59[e]	3501	-0.10
Cauliflower:									
Early Spring	5.64	-6.40E-3 (-2.43)	-	-0.03E-3 (-1.19)	18.47E-3 (9.75)	0.93	1.22[e]	792	-0.30
Late Fall	3.38	-2.40E-3 (1.69)	-	-0.07E-3 (-4.28)	10.91E-3 (9.31)	0.96	1.21[e]	1594	c
Onions:									
Late Spring	3.84	-0.60E-3 (-0.29)	-0.14E-3 (-0.21)	-0.33E-3 (-0.29)	6.23E-3 (1.46)	0.36	2.63[e]	1788	-0.14
Late Summer	-1.04	-0.01E-3 (-0.03)	0.13E-3 (1.40)	0.12E-3 (0.49)	1.77E-3 (1.21)	0.71	1.44[e]	7555	-0.01
Processing Green Lima Beans	69.61	-0.15E-3 (-0.08)	-1.40E-3 (-1.20)	13.61E-3 (0.79)	218.35E-3 (10.42)	0.91	1.52[e]	42930	-0.02

(continued)

Table 5.5
(continued)

[a] Data cover period from 1955 to 1976 crop year with quantity produced expressed in units of 1000 hundredweight (cwt.) except for processing green lima beans which is in tons. Prices are in actual dollars per cwt. except for processing green lima beans which are in dollars per ton. Frozen stock is in 1000 lbs. except processing green lima beans which is in tons. Stock for onion is expressed as stock in storage, January 1, in 1000 cwt. Personal aggregate disposable income (in billion dollars) is for the fiscal year. Numbers in parentheses are estimated t-statistics.

[b] Dollars per cwt. except for processing green lima beans which is in dollars per ton.

[c] Not applicable due to either insignificant and/or wrong expected sign of the estimated coefficient.

[d] No autocorrelation among error terms at 5% levels of significance.

[e] Test of autocorrelation during error terms is inconclusive at 5% levels of significance.

Texas (66.8%) and Arizona (10.2%). Gross income from California fresh onion production in 1976 amounted to $7.8 million. San Joaquin and Imperial Counties are the leading counties for spring onion production, with Kern and Fresno Counties supplying the remainder of the production.

The variables estimated in the price forecasting equation for late spring onions, shown in Table 5.5, are not statistically significant at the 10% level of significance except for personal aggregate disposable income, although the estimated coefficients of all variables have the right expected signs. The test of autocorrelation among error terms is inconclusive at the 5% level of significance.

12. Processing Green Lima Beans. Processing green lima bean production in California currently is about 45% of the national total. In 1976, California produced 25,750 tons at a gross income of $8.3 million (52% of the U.S. value). Processing green lima beans in California includes two varieties, Fordhooks and baby limas. Leading producing counties for processing green lima beans are Ventura and Stanislaus.

In estimating the price forecasting equation for processing green lima beans, four explanatory variables were used. They were production in California, production elsewhere, frozen pack and personal aggregate disposable income. Results of the estimation are given in Table 5.5.

It is somewhat surprising that although California's share of processing green lima beans represents about 45% of the national total, the estimated coefficient for California production is significantly smaller than that of "other production." This might be due to the fact that about 50% of annual production of processing green lima beans in California are used as dry edible beans, implying a somewhat different demand structure. Only the estimated coefficient for personal aggregate disposable income is statistically significant at the 10% level. The test of autocorrelation among error term is inconclusive at the 5% level of significance.

Field Crops

As mentioned in the introductory subsection of this chapter, the market structure of some agricultural crops may not be adequately represented by a single equation model due to institutional arrangements and other factors. Thus, the estimation of price forecasting equations for these crops is more unwieldly than vegetable crops, requiring a multiple equation econometric model. The two field crops included in this study are examples of these types of crops. Cotton prices were usually muted by government intervention, whereas sugarbeet prices were affected by a combination of processor capacity scheduling, government quotas, payments and subsidies [Adams, 1975]. Therefore, the specified price forecasting equation estimation for vegetables discussed above was deemed inappropriate for these two crops. Consequently, estimates obtained from more detailed econometric sources will be used in this study.

1. Cotton. Total acreage harvested of cotton in California in 1976 exceeded 1.1 million acres, yielding about 2.3 million 500-lb. bales. Gross

income for that year exceeded $835 million, which is about 25.6% of the total U.S. value. San Joaquin (Fresno, Kern, King and Tulare Counties) and Imperial Valley are two major cotton producing areas in California. The average yield per acre for California cotton production currently is about 1,000 pounds of cotton lint. This yield is higher than the U.S. average (almost twice the U.S. average in 1976). Over the period 1972-1976, California cotton production averaged about 18.6% of U.S. total production. California's share in 1976 increased to 23%, due primarily to the higher yields obtainable under irrigation, the high quality of cotton planted, and the adaptability of mechanical harvesting systems [Adams, 1975, p. 101].

The price forecasting equation chosen for this study is taken from Adams (1975) and is given in Table 5.6.

2. Sugarbeets. The production and marketing mechanism for sugar in the U.S. are discussed in Adams (1975) and elsewhere. Sugarbeet production in California has increased each year since 1967 with the exception of 1973 and 1974. Total production in 1975 was 8.9 million tons. Gross income received (including government payments and subsidies) in 1975 exceeded $267 million which is about 46% of the U.S. value (1976 figures were not available at the time of this study). Annual yield per acre of sugarbeets in California is higher than the U.S. average (about 40% higher, 1972-1976). *Sugarbeets are grown in 31 counties in California. The leading producing* counties are Imperial, Fresno, Kern and San Joaquin, and Monterey.

The estimated slope coefficient for sugarbeets used in this study is also taken from Adams (1975) and is given in Table 5.6.

Summary of Price Forecasting Equations

The estimated price forecasting equations for the 12 vegetable and 2 field crops discussed above are needed to obtain the linear price structure discussed earlier (see equation 5.1). The slope coefficient for California production was obtained directly from the equations, except where the signs were deemed inappropriate. Two procedures for the calculation of the intercept term were employed. The first, identified as "calculated" intercept in Table 5.6, was derived by adding a value to the constant term which would ensure that the "actual" price for 1976 would be predicted when 1976 quantities were used in the price forecasting equation. The second procedure resulted in the obtaining of an "adjusted" intercept. The "adjusted" intercept term reported in Table 5.6 is derived by adding to the estimated constant term all explanatory variables (at mean and 1976 levels) except California production. Additionally, price flexibility coefficients were estimated with respect to California production as a means of establishing general credibility of the slope coefficients and as a point of comparison with *other studies. A summary of the various intercept calculations and the* price flexibility coefficients for each crop and season are presented in Table 5.6. For the purposes of calculating "price effects" of air pollution, those equations employing the "adjusted" intercept were used.

Table 5.6

Summary of Price Forecasting Equations

Crop/Season	Intercept Term[a] Calculated (1976)	Intercept Term[a] Adjusted (1976)	Intercept Term[a] Adjusted (1955-76) Mean	Slope Coefficient With Respect to California Production	Mean Value for Quantity Divided by Mean Value for Price $\bar{Q}/\bar{P}$ 1955-76	Mean Value for Quantity Divided by Mean Value for Price $\bar{Q}/\bar{P}$ 1972-76	Price Flexibility Coefficients With Respect to Calif. Production Mean Value 1955-76	Price Flexibility Coefficients With Respect to Calif. Production Mean Value 1972-76	$\bar{R}^2$
Vegetable Crops									
Processing Green Lima Beans	326.97	333.29	215.20	-0.1543	207.32	139.66	-0.03	-0.02	0.91
Broccoli:									
Early Spring	16.57	15.85	9.30	-0.7247	138.56	151.51	-0.10	-0.11	0.93
Fall	22.64	20.85	11.39	-2.9696	100.51	115.69	-0.30	-0.34	0.96
Cantaloupes:									
Spring	14.40	14.62	9.16	-1.6286	160.88	110.22	-0.26	-0.18	0.89
Summer	12.62	12.40	8.46	-0.5355	1048.61	708.08	-0.56	-0.40	0.90
Carrots:									
Winter	9.05	9.22	7.20	-1.4781	418.40	561.76	-0.62	-0.83	0.56
Early Summer	6.25	7.94	5.11	-0.1467	563.38	684.37	-0.08	-0.10	0.47
Late Fall	9.48	8.32	4.80	-0.1808	596.55	534.50	-0.11	-0.10	0.68
Cauliflower:									
Early Spring	25.91	25.51	14.56	-6.3986	69.59	47.17	-0.45	-0.30	0.93
Late Fall	12.04	11.57	5.72	-2.4036[c]	124.81	134.46	d	d	0.96
Celery:									
Winter	10.53	10.83	7.86	-1.3500	476.57	355.86	-0.64	-0.48	0.68
Spring	10.88	11.43	8.59	-1.7608	400.40	389.85	-0.71	-0.69	0.68
Early Summer	7.56	8.09	5.61	-0.6228	319.02	322.53	-0.20	-0.20	0.65
Late Fall	14.00	13.97	10.04	-1.6232	708.35	544.07	-1.15	-0.88	0.69
Lettuce:									
Winter	5.98	6.36	4.57	-0.5857[c]	1877.87	1845.43	d	d	0.53
Early Spring	16.55	16.72	9.75	-1.2690	1003.26	1184.50	-1.27	-1.50	0.52
Summer	19.68	17.75	11.60	-0.8376	1846.05	1555.88	-1.55	-1.30	0.75
Fall	14.01	12.57	8.00	-0.5047	1137.20	1081.96	-0.57	-0.55	0.79
Onions:									
Late Spring	5.71	8.97	5.61	-0.5951	308.02	239.04	-0.18	-0.14	0.36
Late Summer	4.00	4.27	2.55	-0.0053	1958.13	2098.61	-0.01	-0.01	0.71
Potatoes:									
Winter	6.86	6.50	5.04	-0.8493	691.72	210.51	-0.59	-0.18	0.71
Late Spring	8.64	9.95	7.69	-0.2997	4712.18	2315.93	-1.41	-0.69	0.62
Early Summer	5.23	5.32	5.34	-1.2868	700.33	173.80	-0.90	-0.23	0.65
Late Summer	4.13	5.27	3.49	-0.1512	870.57	352.20	-0.13	-0.05	0.66
Fall	4.79	4.00	2.07	-0.0377	2173.06	1386.92	-0.08	-0.05	0.77
Tomato, Fresh:									
Early Spring	20.29	26.04	13.21	-5.4866[c]	33.62	15.87	d	d	0.70
Early Summer	29.60	29.41	14.72	-1.0698	218.76	181.30	-0.23	-0.19	0.93
Early Fall	26.34	23.81	15.18	-1.2692	293.04	142.88	-0.37	-0.18	0.93
Tomato, Processing:	68.00	-	-	-2.4800	-	-	-	-	-
Field Crops:									
Cotton	70.17	-	-	-0.0296	-	-	-	-	-
Sugar beets	32.46	-	-	-0.2655	-	-	-	-	-

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[a] Units in the intercept terms are dollars per hundredweights for all vegetables except processing tomatoes and sugar beets and beans, which are dollars per ton. The unit for cotton is cents per pound.

[b] Units in the slope of coefficients are million hundredweights for all vegetables except processing tomatoes, sugar beets which are in million tons, beans in thousand tons and cotton in million 500-lb. bales.

[c] Due to statistical insignificance and wrong expected signs of the estimated slope coefficient, the incorporated slope coefficient is derived from other season price-flexibilities, for the same crop, at relevant price and quantity levels.

[d] Not applicable due to reasons given under Footnote c.

Appendix Table A
Seasonal Patterns of Production for Selected Vegetable Crops in California

	Period To 1972	Period After 1972	
Crop	Season	Actual Season	Adjustments
Broccoli:	Early Spring	Winter	Winter + Spring
	Fall	Spring	Summer + Fall
		Summer	
		Fall	
Cantaloupes:	Spring	Spring	Spring
	Summer	Summer	Summer + Fall
		Fall	
Carrots:	Winter	Winter	Winter (Desert) + Winter (Other)
	Early Summer	Spring	Spring + 1/2 (Summer)
	Late Fall	Summer	1/2 (Summer) + Fall
		Fall	
Cauliflower:	Early Spring	Winter	Winter + Spring
	Late Fall	Spring	Summer + Fall
		Summer	
		Fall	
Celery:	Winter	Winter	Winter (South Coast) + Spring (Central Coast)
	Spring	Spring	Spring (South Coast)
	Early Summer	Summer	Summer (Central Coast)
	Late Fall	Fall	Fall (South Coast) + Fall (Central Coast)
Lettuce:	Winter	Winter	Winter + 1/3 (Spring)
	Early Spring	Spring	2/3 (Spring)
	Summer	Summer	Summer
	Fall	Fall	Fall
Onions:	Late Spring	Spring	Spring
	Late Summer	Summer	Summer
Potatoes:	Winter	Winter	Winter
	Late Spring	Spring	Spring
	Early Summer	Summer	0.3 (Summer)
	Late Summer		0.7 (Summer)
	Fall	Fall	Fall
Tomatoes, Fresh:	Early Spring	Spring	Spring (Desert)
	Early Summer	Summer	Spring (Others) + Summer (Others)
	Early Fall	Fall	Fall

FOOTNOTES: CHAPTER V

[1] The material presented in this chapter, including the estimation procedure, is borrowed from Adams (1975) and King, *et. al*. (1978). The interested reader is referred to these references for a more complete discussion.

[2] As an example, consider the events of spring lettuce of 1978. During that period, the retail price of head lettuce throughout the country increased sharply over prices in the preceding period. This sharp increase was attributed to the reduction of supply caused by heavy rains in the Central Coast region of California, the major source of lettuce supply during spring. However, within a few months, supply conditions improved, reflected in a gradual drop in the price of lettuce.

[3] It should be emphasized that these estimated equations are for California, but the regions included in this study only encompass a part of California. Nevertheless, the included regions together constitute a major share of production of the study crops in the state.

CHAPTER VI

AN ECONOMIC ASSESSMENT OF CROP LOSSES DUE TO AIR POLLUTION: THE CONSUMING SECTOR

As mentioned earlier, past economic assessments of crop losses due to air pollution were obtained simply by multiplying the estimated reduction in yield by the respective prices associated with each crop. Such an approach is not appropriate for most vegetable and specialty crops where prices may be affected by the reduction in supplies, whether due to air pollution or other factors. Thus, variations in quantity produced due to the presence of air pollution may subsequently alter the existing price of that crop.

This chapter describes a simple procedure used in arriving at an economic assessment of crop losses due to air pollution in the study area for some selected vegetable and field crops. The procedure takes into account variations in prices due to yield depression and thus the effect on consumers' well-being. Several steps were involved in the procedure yielding the estimated results presented at the end of this chapter. It should be emphasized that this procedure is only a "first-step" approach; a more elegant and detailed analysis of both the consuming and producing sectors is planned for "Phase 2" as discussed in Chapter VII.

Two levels of production, the annual average from 1972 to 1976 and that for 1976, were determined by region for each of the included annual vegetable and field crops. These are presented in Table 1.2 and 1.3 of Chapter I. These levels of production should reflect the effects of air pollution (oxidant/ozone concentrations) in those regions observed during the production periods, given that the values represent actual production. In the absence of such air pollution, one might expect to observe higher production yields, at least for the more sensitive crops. This "potential" level of production can be calculated after determining the percentage of yield reduction due to air pollution for each crop in each region. Such a degree of yield reduction has been calculated and discussed in Chapter IV and is presented in Table 4.7 of that chapter. The "potential" levels of production in the absence of air pollution were then calculated as shown in Table 6.1 of this chapter.

The next step involved is to calculate the changes in production due to air pollution. Such changes, by region and by crop, are derived by

Table 6.1

Production without Air Pollution

Crop	Unit	Southern Desert		South Coast		Central Coast		Southern San Joaquin	
		1972-76 (Average)	1976	1972-76 (Average)	1976	1972-76 (Average)	1976	1972-76 (Average)	1976
Vegetable									
Pro. Lima Beans	Tons			28,562	16,310	6,434	2,547	7,390	9,840
Broccoli	Cwt.			238,178	292,770	1,012,180	1,207,400	-	-
Cantaloupes	Cwt.	1,199,600	1,128,000	320,823	461,332	-	-	728,400	468,000
Carrots	Cwt.	1,703,400	2,215,000	3,193,959	2,908,021	1,402,620	1,416,800	3,220,000	3,500,000
Cauliflower	Cwt.	-	-	546,599	617,877	861,370	975,850	-	-
Celery	Cwt.	-	-	7,324,125	7,292,298	4,136,810	4,585,478	-	-
Lettuce	Cwt.	11,124,800	11,720,000	4,503,785	4,951,602	18,349,364	20,535,170	1,151,600	1,490,000
Onion, Fresh	Cwt.	464,990	374,000	610,745	282,849	388,509	598,973	-	-
Onion, Process	Cwt.	553,470	300,000	1,291,212	1,427,840	565,806	394,833	2,146,983	2,614,820
Potato	Cwt.	-	-	3,141,204	3,105,385	1,577,930	1,434,715	9,798,744	10,837,879
Tomato, Fresh	Cwt.	388,494	384,000	4,643,332	5,231,337	1,203,516	875,757	687,939	411,357
Tomato, Process	Tons	24,309	36,000	262,500	185,963	258,709	189,810	170,196	198,830
Field Crop									
Cotton	Bales	136,277	154,801	44,171	60,682	-	-	906,799	1,039,883
Sugarbeet	Tons	1,610,698	1,476,000	288,836	260,804	602,149	869,991	747,334	858,768

NOTE: Dash indicates no production of that crop in that region.

taking the differences between production with and without air pollution and are given in Table 6.2. These changes in production were then used to calculate changes in price. Such changes in price were obtained by using the price forecasting equations discussed and presented in Chapter V. Seasonal as well as annual price forecasting equations were required, due to the fact that each region, because of distinct climatic conditions, produces vegetable crops for different market periods. Appropriate seasonal price forecasting equations were assigned to each region based on actual marketing patterns1/ and are given in Table 6.3.

Table 6.4 contains changes in prices due to air pollution by crop and by region for two periods of time -- the average for the period 1972 to 1976 and the 1976 periods. These are the increases in price per unit due to the reduction of production caused by the adversary effect of air pollution in that area. Table 6.4 is thus a measure of the overall price effect due to air pollution. Such price effects were then used to calculate a measure of consumers' surplus (or compensating variation).2/ Due to the absence of regional consumption data on the study crops, it is assumed that production in each year is totally consumed. Such an assumption does not appear to be unrealistic for most vegetable crops which are highly perishable and thus have to be consumed in a relatively short period of time. However, some vegetable crops are consumed in processing forms and thus have some carryover stock. Nevertheless, total consumption and total production for those crops in each year should be somewhat consistent. Total production for each crop in each region was then used to calculate the compensating variations as given in Table 6.5 (for the mean of 1972-1976) and Table 6.6 (for 1976).

Results obtained in Table 6.5 show that the most severe economic damage is associated with celery (65.6% of the total crop loss), fresh tomatoes (16.9%) and potatoes (11.4%). On a regional basis, as expected, the South Coast region suffers the heaviest crop loss among the study regions, almost 90% of total crop loss. Most of the damage in the Southern San Joaquin Valley is on cotton and potatoes, whereas celery contributes almost all crop losses in the Central Coast region. The Southern Desert (includes only Imperial County in this study) shows very minimal crop loss. The total crop loss per year during 1972 to 1976 is $14.8 million. This loss is about 1.48% of the total value of production for the included crops in the four regions and 0.82% of the value of these crops produced in the entire state.

Table 6.6 shows the total crop loss due to air pollution by crop and county in 1976. As is true in the case of Table 6.5, celery, fresh tomatoes and potatoes contribute most of the losses and are followed by cotton lint. The South Coast and the Southern San Joaquin Valley suffer the most severe crop losses. Total crop loss in 1976 is $11.1 million (0.9% of the value of production in the study regions and 0.48% on the state basis). Note that this total crop loss for 1976 is lower than the crop loss observed for the average of the past five years. This might be due partly to improvement in the air quality in the study regions, especially in the Southern Desert region.

Table 6.2

Changes in Production Due to Air Pollution

Crop	Unit	Southern Desert		South Coast		Central Coast		Southern San Joaquin	
		1972-76	1976	1972-76	1976	1972-76	1976	1972-76	1976
<u>Vegetable</u>									
Pro. Gr. Lima Beans	1000 Tons	-	-	5.306	2.223	.088	.042	.626	.840
Broccoli	1000 Cwt.	-	-	0	0	0	0	-	-
Cantaloupes	1000 Cwt.	0	0	0	0	-	-	0	0
Carrots	1000 Cwt.	0	0	0	0	00	0	0	0
Cauliflower	1000 Cwt.	-	-	0	0	0	0	-	-
Celery	1000 Cwt.	-	-	1122.973	814.198	50.230	55.678	-	-
Lettuce	1000 Cwt.	0	0	11.968	1.472	0	0	0	0
Onion, Fresh	1000 Cwt.	4.590	0	38.883	5.521	1.549	2.373	-	-
Onion, Process	1000 Cwt.	5.470	0	82.212	27.840	2.256	1.578	28.583	34.820
Potato	1000 Cwt.	-	-	317.430	125.185	6.770	6.115	187.292	206.979
Tomato, Fresh	1000 Cwt.	4.094	0	469.137	210.921	5.136	3.757	13.171	7.877
Tomato, Process	1000 Tons	.249	0	26.530	7.425	1.120	.830	3.256	3.830
<u>Field Crop</u>									
Cotton	1000 Bales	11.709	13.301	6.959	9.560	-	-	58.531	67.123
Sugarbeet	1000 Tons	12.298	0	15.531	4.170	2.047	2.971	8.060	9.130

NOTE: Dash indicates no production of that crop in that region.
Zero indicates no change in production (due to insignificant effect of air pollution on that crop).

Table 6.3

Seasonal Vegetable Crop Production by Region in California

Crop	Region			
	Southern Desert	South Coast	Central Coast	Southern San Joaquin
Broccoli	--	Early Spring	Fall	--
Cantaloupes	Spring	Spring	--	Summer
Carrots	Winter	Late Fall	Early Summer	Early Summer
Cauliflower	--	Late Fall	Early Spring	--
Celery	--	Winter	Late Fall	--
Lettuce, head	Winter	Early Spring	Summer	Early Spring
Onion, fresh	Late Spring	Late Spring	Late Spring	--
Onion, process.	Late Summer	Late Summer	Late Summer	Late Summer
Potatoes	--	Early Summer	Late Summer	Late Spring
Tomatoes, fresh	Early Spring	Early Fall	Early Summer	Early Summer

NOTE: Dash indicates no production in that region.

Table 6.4

Changes in Crop Price Due to Air Pollution, 1972-76 and 1976

Crop	Unit	Southern Desert		South Coast		Central Coast		Southern San Joaquin	
		1972-76	1976	1972-76	1976	1972-76	1976	1972-76	1976
Vegetable									
Pr. Cr. Lima Beans	$/Ton	-	-	.8187158	.3430089	.0135784	.0064806	.0965918	.129612
Broccoli	$/Cwt.	-	-	0	0	0	0	-	-
Cantaloupes	$/Cwt.	0	0	0	0	-	-	0	0
Carrots	$/Cwt.	0	0	0	0	0	0	0	0
Cauliflower	$/Cwt.	-	-	0	0	0	0	-	-
Celery	$/Cwt.	-	-	1.5160135	1.0991673	.0813726	.0901983	-	-
Lettuce	$/Cwt.	0	0	.0151993	.0018694	0	0	0	0
Onion, Fresh	$/Cwt.	.002754	0	.0233298	.0033126	.0009294	.0014238	-	-
Onion, Proc.	$/Cwt.	.0000547	0	.0008221	.0002784	.0000225	.0000157	.0002858	.0003482
Potato	$/Cwt.	-	-	.4094847	.1614886	.0010155	.0009172	.0561876	.0620937
Tomato, Fresh	$/Cwt.	.022476	0	.5958039	.2678696	.0054955	.0040199	.0140929	.0084283
Tomato, Proc.	$/Ton	.0006175	0	.0657944	.018414	.0027776	.0020584	.0080748	.0094984
Field Crop									
Cotton	$/Lb.	.0003512	.000399	.0002087	.0002868	-	-	.0017559	.0020136
Sugarbeet	$/Ton	.0033204	0	.0041933	.0011259	.0005526	.0008021	.0021762	.0024651

NOTE: Dash indicates no production of that crop in that region.
Zero indicates no changes in price due to no effect from air pollution on that crop in that region.

Table 6.5

Consumers' Surplus at Mean (1972-1976) Consumption
Using the Mean Value (1972-1976) Level of Oxidant Concentration

Crop	Southern Desert	South Coast	Central Coast	Southern San Joaquin Valley	Total	Percent of Total Consumer Surplus
			$			
Vegetable Crops						
Beans, Pro. Gr. Lima	-	19,040	86	653	19,779	0.13
Broccoli	-	0	0	-	0	0
Cantaloupes	0	0	-	0	0	0
Carrots	0	0	0	0	0	0
Cauliflower	-	0	0	-	0	0
Celery	-	9,401,030	332,536	-	9,733,566	65.57
Lettuce, Head	0	68,272	0	0	68,272	.46
Onion, Fresh	1,268	13,341	360	-	14,969	0.10
Onion, Processing	30	994	13	605	1,642	0.01
Potato	-	1,156,292	1,596	540,044	1,697,932	11.44
Tomato, Fresh	8,640	2,487,002	6,586	9,509	2,511,737	16.92
Tomato, Processing	15	15,526	715	1,348	17,604	0.12
Field Crops						
Cotton, Lint	22,000	4,000	-	744,500	770,500	5.19
Sugarbeets	5,307	1,146	332	1,609	8,394	0.06
Total	37,260	13;166,643	342,224	1,298,268	14,844,395	
Percent of Total	0.25	88.70	2.30	8.75		100.00

Table 6.6

Consumers' Surplus at 1976 Consumption Levels, Using the 1976 Level of Oxidant Concentration

	Region					
Crop	Southern Desert	South Coast	Central Coast	Southern San Joaquin Valley	Total	Percent of Total
			$			
<u>Vegetable Crops</u>						
Beans, Pro. Gr. Lima	-	4,832	16	1,167	6,015	0.05
Broccoli	-	0	0	-	0	0
Cantaloupes	0	0	-	0	0	0
Carrots	0	0	0	0	0	0
Cauliflower	-	0	0	-	0	0
Celery	-	7,120,516	408,580	-	7,529,096	68.04
Lettuce, Head	0	9,254	0	0	9,254	0.08
Onion, Fresh	0	919	849	-	1,768	0.02
Onion, Process	0	390	6	898	1,294	0.01
Potato	-	481,268	1,310	660,112	1,142,690	10.33
Tomato, Fresh	0	1,344,817	3,505	3,401	1,351,723	12.22
Tomato, Process	0	3,288	389	1,852	5,529	0.05
<u>Field Crops</u>						
Cotton, Lint	28,000	7,500	-	979,500	1,015,000	9.17
Sugarbeets	0	289	695	2,094	3,078	0.03
Total	28,000	8,973,073	415,350	1,649,024	11,065,447	
Percent of Total	0.25	81.09	3.76	14.90		100.00

As a benchmark on the magnitude of these results, the results obtained can be compared with those obtained by Millecan (1976)3/ although the methodologies used are quite different. In the Millecan study, the total crop loss (obtained by multiplying the reduction in yield with prices (for vegetables4/ due to air pollution in the South Coast region (includes Los Angeles, Orange, Riverside, San Bernardino and Ventura Counties) has an average value of $1,400,308 per annum from 1970 to 1974. Total loss for field crops5/ in that region for the same period is $964,047 per year. For Los Angeles and Orange Counties, the Millecan study did not specify the types of vegetable and field crops included, thus it is not possible to compare results on an individual crop basis. Nevertheless, one common finding is that celery suffers the heaviest loss among included vegetable crops in Ventura County. It should be noted that the Millecan study did not include some counties selected for this study, e.g., Kern, Tulare, Imperial and the Central Coast. The magnitude of the difference in total damages realized under the two approaches suggests that damages (in terms of "costs" to consumers) may be underestimated in earlier research.

It should also be noted that the results of this study, as presented in this section, do not include effects of air pollution on producers (growers). Such effects may be reflected in higher cost of production and/or lower revenue, depending upon the price elasticity for each crop. These effects will be addressed in the second phase of the analysis via the mathematical model presented earlier. In addition, this study includes only selected types of vegetable and field crops; thus, the value of crop losses derived above represents only a portion of total crop losses in these regions. One would expect to have a much higher value of crop losses if other types of agricultural crops, such as citrus and horticultural crops, were also included in the analysis.

FOOTNOTES: CHAPTER VI

[1] For details see Johnston and Dean (1969).

[2] The concept of compensating variation (or price compensating) popularized by R. Hicks, is the amount of money the consumer of a commodity would have to gain (lose) in order to offset the loss (gain) in utility due to the rise (fall) in price of that commodity (caused by, say, reduction in quantity supplied due to yield depression in the presence of air pollution) in order to be as well off as before. It differs from "equivalent variation" (or price equivalent) in that the level of utility, after being compensated, in the case of compensating variation is unchanged whereas in the case of equivalent variation, it is the amount of money paid to (or received from) the consumer in order to make him as well off as before after the changes in utility level caused by the rise (or fall) in price of that commodity.

[3] Details of that study had already been discussed in Chapter II of this analysis.

[4],[5] The mix of vegetable and field crops included in the Millecan study do not coincide with those in this study. Also, Millecan includes more crops in the analysis.

CHAPTER VII

IMPLEMENTATION OF THE COMPLETE MODEL: AN ASSESSMENT

The preceding six chapters have dealt with numerous conceptual and empirical issues relevant to the assessment of air pollution damages to crops. As is evident, the analysis to date has not integrated and empiricized the complete set of components. Specifically, the economic costs at the producer's level have not been measured. Included under this general area of producer's impacts are such issues as changes in cropping mix and location in response to air pollution, substitution effects on the input side and other mitagative strategies. Also, impacts of air pollution on non-included crops (e.g., perennials and horticultural crops) are not addressed. This concluding chapter will deal with these areas, with an emphasis on detailing the approaches to be used in their assessment in the second phase of the agricultural impact study.

7.1 Production Adjustments

Agricultural producers are capable of modifying their production decisions and/or plans in the face of change. California agriculture has demonstrated a high degree of resiliency in dealing with such adjustments as energy shortages, labor disruptions or natural phenomena such as drought. Typical response patterns have been reflected in adjustments in cropping patterns and input use to minimize the effects of the "shock" to the agricultural system. Similar mitagative procedures would be expected in the presence of air quality degradation. While increasing levels of oxidants may not be viewed as a "shock," the response pattern should be similar, if somewhat more gradual. As an indication of such adjustments, it appears that producers of vegetable crops are planting crop varieties with greater resistance to certain air pollutants.

The range of mitagative procedures open to producers within southern California includes the following set of responses:

1. in situ adjustments in cropping mix, substituting more resistant crops into current cropping systems;

2. in situ increase in input use rates to offset adverse effects of air pollution (reflected in an increase in firm's cost structure); and

3. locational adjustments in production whereby production is shifted from areas of high oxidant levels to areas of relatively low levels (timing of such adjustments will obviously be determined by land market considerations).

In addition to such mitagative procedures, which entail either increased costs or reduced returns for total produce sold, producers also face the possibility of revenue losses due to quality degradation, even in the absence of yield reductions. As a result of quality degradation, prices received for selected commodities may be discounted. A further decision-affecting phenomenon associated with air pollution is the effect on producer risk-bearing. If ambient air quality experiences a continuous or abrupt degradation over time, crop yield variation (a major source of farm risk) may be increased. Thus, the inherent riskiness of crop production decisions may be exacerbated.

It should be noted that the potential exists for net increases in the revenue of producers in the face of yield reductions, given the price elasticity of demand for some agricultural crops. Such an outcome would be dependent upon the price elasticity of each crop in the crop mix and the magnitude of changes in the firm's cost structure due to mitagation.. Given the price endogenous nature of the proposed mathematical model, this potential outcome would be tested directly within the analysis.

The mathematical model formulated in Chapter III of this report is intended to deal with the production decision variables outlined above. The data for such an analysis has been obtained and risk measures have been calculated. The overall integration effort will be discussed below.

7.2 Consumer Impacts

Chapter VI of this report presented a somewhat simplistic assessment of consumer effects of air pollution. The economic cost of air pollution (compensating variation) was captured via the use of price forecasting equations for each included crop. However, given that production adjustments in the form of cropping mix changes or relocation will also affect quantities supplied, an integration of producer and consumer sectors is desired and needed to capture future economic effects of air pollution. This can be accomplished through the price endogenous model outlined in Chapter III.

Indirect impacts on a third group, input suppliers, could also be substantial, if the derived demand for inputs were altered as a result of such mitagative procedures as changes in cropping mix or input use. Major crop adjustments could also portend significant disruptions to agricultural land markets as well as the demand for irrigation water, given a differential in production coefficients across crops. While input suppliers are not included within the scope of this analysis, the resource usage and shadow price values generated by the model should suggest potential input supply disruptions.

7.3 The Integrated Model

As discussed in Chapter III, the complete model will assess a wide range of possible outcomes associated with actual and projected levels of air pollution, with emphasis on approximating current damages (under actual air quality parameters) as well as potential damages under a range of possible air quality changes.

The model output will feature the surplus maximizing (producer's and consumer's) levels of commodity production (for the included crops) in the face of alternative levels of oxidant concentration. The programming algorithm employed will optimize, based on the relationship between commodity prices, yield sensitivity and resource availabilities. Additional output from the model should be regional production, equilibrium prices, resource usage and resource shadow prices as well as the relevant surpluses.

While most data necessary for the construction of the model has been collected, additional programming assistance is needed to develop subroutines for existing software. This programming is needed to:

1. allow for multiple regions in the analysis (test of locational adjustments in production between the South Coast and the three contiguous regions);

2. introduce risk directly into the objective function; and

3. include cost vectors directly in the objective function.

While current economic damages can be approximated in the absence of the programming effort, the full general equilibrium flavor of the analysis will be lacking without such an effort.

7.4 Related Research Needs

The yield-oxidant relationships used in this analysis have been outlined in Chapter IV. The correlation analysis and production function estimation serve to establish a possible negative relationship between oxidants and selected crops, over the last 20 years. The significance and signs attached to oxidants suggest a range of sensitivities across crops. However, to further test the relationship and to establish consistency with results obtained under controlled conditions, a more complete production function is required. A more complete specification of the production function would serve to further define the nature and magnitude of the oxidant-yield interface under actual production conditions.

The included crops in this study have been limited to annual vegetables and field crops. Some measure of damages experienced by perennials such as fruits and nuts, as well as horticultural crops, is needed to complete the analysis. While their complex time horizons make assessment more difficult (in a dynamic sense), damages can be approximated via more pedestrian approaches such as survey techniques. These results would be needed for a complete agricultural assessment.

7.5 Concluding Comment

The primary purpose of the agricultural assessment component of the EPA Benefits project is to address some conceptual and empirical limitations of earlier studies concerning agricultural damages. The first specific objective of the agricultural study is to define a methodology capable of dealing with some of the weaknesses inherent in previous research. Thus, this study should not be viewed as a definitive empirical assessment of agricultural damages within southern California, but rather an initial inquiry into crop damage assessment methodologies.

The analytical framework, conceptual issues and preliminary results reported in this report offer support to the use of more complete models in the measurement of air pollution damages/benefits. While this report and results obtained in the next phase of the project will not resolve all relevant issues in assessment methodologies, it is hoped that the study output will be suggestive of more fertile areas for investigation.

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16. ABSTRACT

This volume of a five volume study of the economic benefits of air pollution control 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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