APPENDIX A2

EFFECTS OF OZONE AND SULFUR DIOXIDE ON CROP PRODUCTIVITY

A2.1 OBJECTIVES

This chapter reviews current knowledge concerning the effects of ozone (O_3) and sulfur dioxide (SO_2) on crop productivity. The objectives of this review are to provide insight to the selection of appropriate air pollution variables; to suggest the expected magnitude, both relative and absolute, of air pollution-yield relationships for the selected crops; to develop testable hypotheses concerning O_3 and SO_2 effects upon crop production, separately and in combination with each other and other environmental attributes; and to provide laboratory evidence which can be used to validate the field data regressions or provide alternative damage functions.

Previous literature reviews demonstrate air pollutants have long been known to affect plant health and crop production (Katz et al., 1939; Halliday, 1961; Treshow, 1970; Naegele, 1973). This chapter will not repeat this documentation, but will summarize the most recent and relevant research pertaining to the effects of O_3 and SO_2 on crop yields, specifically for the principal study crops. Documentation is limited to research which provides air pollutant concentrations, exposure times, and yield or injury data. The chapter summarizes the reviews with a grouping of the study crops into sensitivity categories, and an assigning of damage functions or categories for other crops grown in the San Joaquin Valley and analyzed in the California Agricultural Resources Economic Model (see Chapters 5 and 6).

A2.2 BACKGROUND

How Pollutants Affect Plants

Sulfur dioxide emanating from smelting and home heating has damaged plants since before the turn of the century (Halliday, 1961). Concentrations then were far higher than today, and the resultant damage far more severe. Plant mortality was not unknown. Extensive timber losses surrounding such locations as Trail, British Columbia, and Ducktown, Tennessee, provided classic examples (Sheffer and Hedgecock, 1955). Though it was suggested as early as 1923 (Stoklasa, 1923) that yields could be adversely affected even in the absence of visible leaf injury, it was many years before this was documented. For many years it was generally accepted that losses were proportional to leaf injury. Only during the past decade has it become increasingly accepted that SO_2 may impair productivity even in the absence of the characteristic leaf yellowing or browning.

Only recently have we begun to understand the way ozone affects plants. Beginning in the late 1950s and into the 1960s, increasing numbers of plants were found to be sensitive to ozone (Hill et al., 1961). Production losses were again thought to be proportional to the extent of visible symptoms. Gradually, it became recognized that plant health was impaired before the appearance of chlorotic flecking (Unsworth and Ormrad, 1982).

Up to a certain pollution level, commonly called a "threshold," plants can generally detoxify pollutants. Beyond that point, pollutant entry into the plant results in yield reductions, followed by visible symptoms and finally death. The visible symptoms of plant injury caused by air pollutants are infrequently seen today because pollutant concentrations are generally not high enough. Diagnosis of symptoms, where they occur, still remains very difficult because similar symptoms can be caused by many other environmental stresses and biotic pathogens. Of primary concern here are the adverse effects of sublethal concentrations of a pollutant, especially ozone, which is widespread in harmful concentrations. A significant historical aspect common to both ozone and sulfur dioxide is that more sophisticated methods of study and more sensitive monitoring methods employed in recent years have continually revealed adverse effects at lower concentrations than formerly believed.

Demonstrating that ozone and SO_2 are known to be harmful to plants provides only the first step. The second is to explain how or why such effects occur, and the concentration at which such effects might be expected. Biochemical studies over the past few years have provided some explanations of the process through which O_3 and SO_2 damage plants. These processes were reviewed in the greatest depth in a recent symposium at Oxford, England (Kozial, 1983).

The initial receptors of any gaseous atmospheric pollutant are the leaf cuticle and stoma. The effects of SO_2 on the cuticular waxes are well documented (Fowler et al., 1980), but these involve mostly conifers and other perennial species. Effects on the stomatal mechanism are more critical to annuals and agricultural crops. Sulfur dioxide has a notable effect in stimulating stomatal opening (Majernik and Mansfield, 1970). When ambient humidity is high, low SO_2 concentrations may stimulate this opening within 15 - minutes. Naturally, the wider stoma enhance the rate of pollutant intake. It is important to understand that pollutant concentration within the leaf is most critical, not the concentration in the ambient air.

Once through the stoma, the pollutants enter the substomatal, intercellular spaces where they dissolve in the water on the moist cellular surfaces. This reaction forms sulfite and bisulfite. The hydrogen ion concentration also may increase, which can cause leakage of potassium and chlorine ions (Smith and Raven, 1979). Ozone may cause the formation of free radicals, which can oxidize various cellular metabolites and affect membrane constituents such as SH groups, amino acids, proteins, and unsaturated fatty acids (Heath, 1975).

Both SO_2 and O_3 next come into contact with the cell membranes. Each appears to interact most critically with the protein component of the membrane; O_3, for instance, alters a number of amino acids found in proteins of the membrane. This disrupts membrane permeability and alters the normal flow of ions through the cell. Once in a cell, the pollutants encounter more membranes as well as the various organelles. The chloroplast membrane may be especially sensitive to both SO_2 and O_3. Chloroplasts change shape from ellipsoidal to round, following exposure to SO_2, and become more irregular in shape following exposure to O_3.

Hampp and Ziegler (1977) have suggested that both SO_3^{2-} and SO_4^{2-} ions are transported to the inner chloroplast membranes by phosphate translocators. It has been suggested (Kozial and Whatley, 1984) that sulfur is taken up at binding sites in the thylakoids, which alters the form of certain enzymes that are critical in the electron transport necessary for the conversion of light to chemical energy.

It has also been speculated (Thomson et al., 1966) that ozone affects SH groups in photosynthetic enzymes. Exposure to increasing concentrations of O_3 inhibits electron transport in the photosynthesis process.

Wellburn (in Kozial and Whatley, 1984) has suggested ways in which pollutants disrupt energy flow. Sulfur dioxide especially depresses the formation of the energy-carrier, adenosine triphosphate (ATP), which alone could reduce growth and production potential.

Laboratory Methods for Measuring Crop Damages from Air Pollution

The above explanations of physiological mechanisms have been generated largely from research conducted in laboratories or from plants fumigated in chambers. While such studies help us understand the mechanisms of pollutant action, they are not designed or intended to reveal concentration thresholds or measure rates of production losses.

Greenhouse studies have been used to determine the pollutant concentrations required to cause effects, such as on crop production; but great caution must be exercised in translating results from greenhouse studies to field responses (Heagle, Philbeck and Knot, 1979). Conditions in the greenhouse and in the field are never identical; not only may the concentrations required to produce an effect be different, but the responses may not be the same. This is stressed by Drummond and Pearson (1978) who point out that plants in chambers or greenhouses are exposed to pollutants under artificial conditions, which may alter responses even though the conditions may appear to be "natural." The main limitations of greenhouse studies are the quantity and quality of light, confinement of roots, unnatural air-movement conditions, and often the low number of plants used. Information generated under long-term exposures to artificial conditions has limited predictive value when extrapolated to field conditions.

In order to learn actual field effects, innovative methods have been applied. In the "reverse fumigation" method (currently referred to as "exclusion" studies), ambient air is passed through one greenhouse, and plant growth is compared with that in another greenhouse through which filtered air is passed (Hill et al., 1959).

A second approach is the use of open-top chambers (Heagle et al., 1973). In this system, plants are grown in small greenhouses or chambers which have no tops. Filtered air with controlled pollutant concentrations is passed into these chambers, and flows over the plants under pressure, excluding the ambient air. These chambers simulate field conditions reasonably well, although not completely, because the chamber walls still restrict natural air flow and alter moisture and light conditions.

This basic plan was later refined and utilized in the National Crop Loss Assessment Network (NCLAN) studies. Because several NCLAN results are used in subsequent analyses, additional description of their approach is useful.

The NCLAN consists of a group of government and nongovernment organizations cooperating in field work, crop production modeling, and economic studies, to assess the immediate and long-term economic consequences of the effects of air pollution on crop production. The program is working to define the relationships between major agricultural crop yields and doses of O_3, SO_2, NO_2, and their mixtures. These relationships will be used to assess the primary economic consequences of the exposure of agricultural crops to these pollutants, and advance the understanding of cause-effect relationships with the intent of developing simulation models.

The NCLAN field studies are designed to provide crop dose-response data that are as free of artifact as is currently possible using open-top chambers. The chambers permit control of gases around the plant canopy, allowing specific pollution regimes to be imposed on experimental plants. The chambers ordinarily have little effect on the crops growing within them.

The NCLAN program uses open-top field chambers at four regional sites. All sites use a series of five O_3 concentrations (related daily by a fixed increment to the ambient pollutant level to retain the same variance in exposure) replicated four times with a different crop at each site.

A third laboratory approach, that of field exposure, allows plants to grow in the field while either filtered air or filtered air plus a pollutant is introduced around them through pipes or ducts lying either along the ground or elevated. Variations on this concept have been utilized since the mid-1970s.

A detailed review of these methods appears in Unsworth and Ormrad, 1982.

A2.3 ENVIRONMENTAL FACTORS INFLUENCING CROP SENSITIVITY TO O_3 AND SO_2

The fumigation approaches to studying air pollutant effects have provided considerable information on the influence of both genetics and environmental factors on the sensitivity and response of plants to air pollution, and therefore to the establishment of thresholds and crop damage rates. Nevertheless, environmental parameters such as the level of soil moisture can produce a tenfold difference in the amount of SO_2 required to cause injury. This influence of environmental variables creates problems in establishing the threshold at which injury first occurs and damage rates thereafter. These factors should be considered when attempting to establish air pollution-yield relationships. This section reviews a few of the many research results in the literature, to highlight the potential or probable influences of environmental factors upon the relationships between O_3 and SO_2 pollution and crop yields in the San Joaquin Valley. During this review it is important to understand that each environmental factor continually interacts with other factors as well as air pollution, so individual effects may be difficult to sort out in an uncontrolled experiment such as that used in this study.

Overriding all other factors is the genetic nature of the individual plant. Differences in sensitivity among species are almost self-evident (and are specifically addressed for several crops below), but differences among varieties or even individuals within a variety are less obvious. Although such differences are often overlooked in many research papers, they are being increasingly recognized and must be treated in establishing production effects and economic losses.

Soil moisture and relative humidity have a considerable, but not always predictable, influence on plant response to pollution. Taylor (1982) provides a striking example of cotton plant yields. Plants subjected to normal irrigation yielded 50 percent less when grown in non-filtered air as opposed to filtered air. When water was withheld so that wilting began at 10 a.m. rather than 2 p.m., plants in non-filtered air produced more than those in filtered air. The influence of moisture stress appeared to override that of the ambient ozone. Others have shown that plants experiencing strong growth are more susceptible to oxidant injury than plants experiencing water stress (U.S. EPA, 1978; Setterstrom and Zimmerman, 1939; NAS, 1978).

Relative humidity can scarcely be separated from soil moisture since both are intimately associated with the stomatal mechanism. Generally, the higher the relative humidity, the greater the likelihood that the stomatas will be open, and the greater the opportunity for pollutants to enter the leaf (Rich and Turner, 1972; Salisburg and Ross, 1969). Hallgren (Kozial and Whatley, 1984) reports that as relative humidity increased from 30 to 70 percent, SO_2 intake increased threefold. The combined timing of acute pollution episodes and low soil moisture and relative humidity may save a crop from serious loss (Oshima, 1979).

Temperature determines the metabolic rate of the plant. This is significant because the ambient temperature affects the guard cells that control stomatal opening and the resulting pollutant intake. Temperatures which increase the physiological activity of the plant also tend to increase the plant's response to pollution (Heck and Dunning, 1978). It is generally believed that plant sensitivity to O_3 and SO_2 increases with temperature over a wide range from about 4^o to 35^oC, but is species-specific (Guderian, 1977; U.S. EPA, 1978).

Light also controls stomatal opening and consequently pollutant intake. Generally, plants are more tolerant when fumigated in darkness. It is difficult during the day, however, to isolate light from temperature and moisture conditions, which also interact to regulate stomatal resistance. Plants are generally more sensitive to O_3 in low light (Stern, 1968), while the relationship is the reverse for SO_2 (Zimmerman and Crocker, 1954).

Soil fertility, in terms of mineral nutrition, has a significant influence on plant response to pollutants. Unfortunately research on the effects of soil fertility on pollution sensitivity often conflicts, and is not conclusive. Cowling and Kozial, in a recent review (in Kozial and Whatley, 1984), conclude generally that plants given an adequate supply of nutrients are less sensitive to injury from O_3 and SO_2 than plants with a deficient supply, although there are exceptions. Plants also appeared to be most sensitive to O_3 when the nutrient supply is adverse, but again there are numerous conflicting reports (U.S. EPA, 1978).

In summary, environmental factors (1) independently influence the growth of crops, (2) interact to determine the amount of pollutant taken by the plant, and (3) influence the sensitivity of plants once the pollutant is in them. Since these variables are not constant, it is impossible to prescribe the status of every parameter. Thus it is impossible to establish a precise, definitive threshold dose at which a plant first responds, or to determine the one rate of response to air pollution. Unfortunately, it is not only impractical but essentially impossible to incorporate all of the variables into a damage function. Therefore any damage function or threshold estimate must be regarded broadly as a range of concentrations which varies with environmental conditions.

A2.4 MEASURES FOR O_3 AND SO_2

The selection of an air pollution measure can be important in defining the levels at which plants will respond, even though there may be a high correlation across measures. Several measures can be considered, including average concentrations, dose, maximum concentration, and number of hours exceeding some level. Each of these could be defined over different time periods, and for exposures at or above some threshold value.

If a concentration could be established below which no effects have been reported under any circumstances, it would seem most appropriate to consider only the periods when concentrations exceed this value. This would eliminate measuring variations in low concentrations which have no impact. In recent years, the weakness of incorporating low values in some measures has been recognized, and a preference has been developed for using data which reflect only those concentrations that exceed a known harmful level.

The most reasonable measure of air pollution impacts upon plant physiology is the total pollutant dose above the threshold where the plant can no longer detoxify the pollutant, and less than the level where the plant is lethally affected (a level seldom, if ever, experienced in the San Joaquin Valley). Dose is defined as the concentration of a pollutant times its duration of exposure. It would be convenient if the yield effects of long-term, low-level exposure were the same as an equal dose from a short-term, high-level exposure, but this is rarely the case. It should be apparent that a one-hour exposure to 1 ppm O_3 will not have the same effect as a 100-hour exposure to .01 ppm O_3, although the dose is equal. Therefore, comparisons of different doses are generally only valid when a narrow range of pollution levels is considered. The range of interest should consider the plant sensitivity and local prevailing ambient conditions: Are pollution episodes short-term high concentration, or long-term low concentrations? Alternative measures, such as the number of hours above a threshold, sometimes set equal to an existing or potential regulatory threshold, are not likely to be as accurate, but can be useful approximations of the dose concept for the evaluation of these alternative regulatory thresholds.

A2.5 YIELD SENSITIVITIES TO O_3 AND SO_2 FOR THE PRIMARY STUDY CROPS

Two important related questions remain: What is the critical threshold which should be used in the air pollution measures? and; What is the yield sensitivity of the selected study crops to O_3 and SO_2? Although specific findings for the selected crops are somewhat limited, they do suggest that different crops have different thresholds and damage rates. The significance of environmental variables dictates that these factors be considered wherever such data are available and, where they are not available, reported findings are given less consideration. These findings from chamber studies are reviewed below. Emphasis is placed on studies where pollution impacts are in the realm of realistic exposures experienced in the field, so studies on the effects of much higher concentrations are largely omitted. Another useful review of the effects of air pollution upon major crops in the San Joaquin Valley is found in Brewer (1979).

Alfalfa

In a study undertaken during the 1979-1981 summers in southern Fresno County, California, Brewer and Ashcroft (1982) compared the growth of the Moapa 69 variety, which was grown in the San Joaquin Valley during the early and mid 1970s, to the WL-512 variety of alfalfa, which is now extensively grown in the San Joaquin Valley. Studies were conducted under conditions of ambient air, ambient air with added O_3 and SO_2, and filtered air. Moapa yields in filtered air averaged 8.2 percent higher than under ambient conditions (average O_3 seasonal dose was approximately 75-100 pphm-hours over threshold of 10 pphm). When 1-1/2 times the ambient ozone concentration was given, yields were reduced to 81 percent of ambient-air yields, or 25 percent of filtered air yields. The ambient air plus 10 pphm SO_2 for six hours, four times per week reduced yields by nine percent.

In the same study, yields of the WL-512 variety showed little change when subjected to filtered or ambient air, but raising ambient ozone by 50 percent reduced yields by 10 percent. Similarly, the introduction of a SO_2 dose to both filtered and ambient air reduced yields by eight to ten percent. In all comparisons, the authors suggest the O_3 and SO_2 effects were additive, not synergistic. Using the Brewer and Ashcroft data, the following yield per acre equations were estimated:

$$Y = 19.2 - .00149\,(O_3) - .000298\,(SO_2) + 2.17\,YR \qquad \text{(MOAPA)} \quad \text{(A2-1)}$$

$$Y = 18.656 - .000594\,(O_3) - .000224\,(SO_2) + 2.37\,YR \qquad \text{(WL512)} \quad \text{(A2-2)}$$

$$\%\,\Delta\,Y = 11.5 - .00677\,(O_3) - .00133\,(SO_2) - 9.7\,YR \qquad \text{(MOAPA)} \quad \text{(A2-3)}$$

$$\%\,\Delta\,Y = 11.2 - .0028\,(O_3) - .0010\,(SO_2) - 11.2\,YR \qquad \text{(WL512)} \quad \text{(A2-4)}$$

where:

- Y = yield per acre
- O_3 = pphm-hours for hours greater than 10 pphm
- SO_2 = pphm-hours for hours greater than 1 pphm
- YR = dummy variable for first or second year of the study (either 1980 or 1981)
- $\%\Delta Y$ = percent loss in yield from the base level in the study

Less tangible, but still significant, the stand life of both the Moapa and WL-512 varieties was reduced in ambient air, and mortality was further increased when SO_2 was present. The quality of the crop, however, was largely unaffected.

Oshima et al. (1976), working in the California South Coast Air Basin calculated yield loss functions for Moapa 69 using O_3 dose measured as pphm-hours greater than 10 pphm. The dose ranged from 200-5600 pphm-hours for this study area. A linear regression was performed with the dose-response relationship illustrated in Table A2-1. These results are quite similar to those of Brewer and Ashcroft (1982).

Table A2-1

Oshima's Alfalfa (Moapa) Ozone Dose Response Relationship

Ozone dose	**Predicted percent reduction**	**Range of reduction at 95 percent confidence**
0	0.0	0 - 15
250	2.3	0 - 16
500	4.6	0 - 17.7
1000	9.3	0 - 20.6
2000	18.6	9.1 - 28.0
3000	27.8	17.3 - 38.3
4000	37.3	23.2 - 50.8
5000	46.3	28.1 - 64.5

In other chamber studies, Tingey and Reinert (1975) fumigated alfalfa at five pphm SO_2 for eight hours per day for the growing season, and found no injury symptoms on foliage, but the foliage dry weight was reduced 26 percent and the root weight was reduced 49 percent. Tingey (1973) was among the first to demonstrate the synergistic action of SO_2 in combination with O_3. Although neither concentration alone was harmful, when 9 pphm O_3 was combined with 10 pphm SO_2, adverse effects were reported.

Neely et al. (1977) exposed mesa sirsa alfalfa plants to 10 pphm O_3 for six hours per day for 70 days. Production was reduced 4 percent at the first harvest, 20 percent in the second and 50 percent in the third, showing a strong cumulative effect of exposure upon yield. The presence of SO_2 was also found to increase the yield losses more than additively for O_3 and SO_2 alone. The cumulative effect of SO_2 exposure on alfalfa yields was also noted in Stevens and Hazelton (1976) who noted that "yield loss was estimated to increase at an increasing rate with the occurrence of each successive exposure of sulfur dioxide" (p. 10).

In conclusion, it appears that ambient O_3 concentration in parts of southern California can cause significant yield reductions for alfalfa. The work by Neely et al. (noted above) showed that concentrations of 10 pphm O_3 are critical if sustained for six hours per day for 70 days, causing a 50 percent reduction in the third harvest. Effects of lower concentrations are not known, but based on this study, it is possible that lower levels would have some adverse effect. In order to be inclusive of concentrations most likely to adversely affect alfalfa, O_3 measures should be based on ozone concentrations equal to or less than 10 pphm. Sulfur dioxide concentrations above approximately 10 pphm, in combination with ozone, could conceivably be adverse if sustained, but this is not adequately documented.

Almonds

No published data could be found regarding the sensitivity of almonds to ozone. Art Millican (plant pathologist, air pollution specialist), who for many years was responsible for field studies of air pollutants in California for the California Department of Food and Agriculture, has never observed injury to this species. He suspects (personal communication, 1983) that almond crops would be affected only at rather high O_3 concentrations. Chamber studies on almonds and other fruit and nut crops appear warranted due to their economic importance in California.

Cotton

Among recent cotton studies, Heggestad et al. (1977) grew several varieties of cotton in greenhouses in Beltsville, Maryland, and exposed them to carbon-filtered and non-filtered air. According to these studies, newly developed varieties from California were most tolerant. Yields of an older variety, Paymaster 220 from Texas, however, were 44 percent lower when grown in non-filtered air. Varieties studied in an expanded study included Pima 54, Gregg 45, Paymaster 202 and Delta Pine Smooth Leaf. When grown in ambient air (for which the O_3 concentrations were not reported), they produced yields that were 75, 71, 70 and 60 percent, respectively, of those in carbon-filtered air. Yields of Stoneville 213 and Acala SJ-1, while most tolerant, were still 88 percent and 86 percent of those grown in the filtered air. Data indicated that flower numbers were about the same, but boll set was poorer in the non-filtered air. The number of bolls and seeds per plant, and seed and lint yield per boll and plant, was reduced.

Brewer (1979) exposed cotton plants (Acala SJ-2 and SJ-5) to ozone at Parlier, California, using open-top chambers. The results of the treatments are summarized in Table A2-2.

Table A2-2

Brewer's (1979) Ozone - Cotton Results

	Boll Set (percent of filtered)		Yield (percent of filtered)	
Variety	SJ-2	SJ-5	SJ-2	SJ-5
Carbon filtered air (CF)	100	100	100	100
1/3 CF air	100	105	92	99
Non-filtered (NF) air	88	107	86	106
Air with O_3 added at 2 times NF	82	85	70	89
Plots with no chambers (Field Plots)	78	98	70	89

Heggestad and Christianson (1982) cited NCLAN work conducted by Taylor in Shafter, California, which showed yields in non-filtered air to be about 80 to 83 percent of these for plants grown in filtered air. Yields of plants grown in chambers in which half of the air was filtered was intermediate between filtered and non-filtered. The 1982 seven-hour ambient concentration was on the order of 4.5 pphm. Addition of 3, 6 and 10 pphm O_3 for seven hours each day caused further yield reductions, reaching 50 percent at 10 pphm. A negative correlation between yield and O_3 dose was highly significant. Again, the yield reduction resulted mostly from the reduced boll set.

The critical importance of soil moisture was noted. When irrigation was withheld and plants allowed to wilt by 10 a.m. or 11 a.m., rather than the normal mid-afternoon, plots with ambient air (NF) yielded more than those with filtered air. Taylor concluded that plants in filtered air required more water than plants affected by O_3. These tests were conducted on the newer and more ozone tolerant Acala SJ-2 variety, which comprises about 75-80 percent of the San Joaquin Valley production; although an even more tolerant Acala SJ-5 variety is now being introduced in the valley.

Oshima et al. (1979) exposed Acala SJ-2 for six hours twice per week to 25 pphm O_3 over a 19-week period. Fiber and seed yields were reduced by at least 60 percent. Fewer leaves were produced and abscission was enhanced, thus stimulating leaf production and taking energy from normal fruit production. The ozone concentration used was higher than experienced in the field.

Brewer and Ferry (1974) reported on the differences between yield of cotton grown in filtered air versus ambient air in several California locations. Varying but often significant differences occurred depending on the location. At all four locations, plants grown in filtered air were noticeably more vigorous, and foliage retained better color than that in ambient air.

The importance of cotton variety must be stressed. Hill et al. (1961) were unable to impair plants of the Upland 1517 variety at concentrations of up to 41 pphm, and thus ranked cotton as "resistant", a conclusion not supported in later work.

Sulfur dioxide can also adversely affect cotton production, but only after the appearance of leaf injury (Brisley et al., 1959). There was a 0.75 percent increase in crop loss for each 1 percent increase in leaf area destroyed. On the other hand, crops (including cotton) grown in sulfur-deficient soils may increase yield when exposed to SO_2 in the air (Noggle and Jones, 1979).

Cotton is generally considered to be rather tolerant of SO_2 and the effects of interactions with those in the San Joaquin Valley at the current SO_2 concentrations are considered negligible (Oshima, 1978).

The above studies do not definitively establish thresholds, because the ambient concentration which adversely affects yields was often not reported. However, based on recorded effects from as low as 6 pphm ozone, ozone measures should probably be based on concentrations at or below 8 pphm. This is subject to differences among varieties and environmental conditions, but due to the empirical use of the 8 pphm concentration, it would be unrealistic to attempt to further refine this value.

Dry Beans

An NCLAN study conducted in 1980 at the Boyce Thompson Institute (Kohout et al., 1982) exposed red kidney beans (California Light Red cultivar) to ozone in open-top chambers during pod filling from August 20 to September 10. Relative to a base level of yield at a seven-hour average concentration of .25 pphm O_3, yields were reduced by 2 percent at 5.3 pphm, 6 percent at 8.6 pphm, 24 percent at 12.8 pphm and 27 percent at 16.2 pphm ozone concentrations. A 1980 Zonal Air Pollution Study (ZAPS) also assessed (Kohout et al., 1982) California Light Red and Red Klond cultivars of red kidney beans exposed to SO_2. Three-hour concentrations of SO_2 ranged up to 30 pphm at nearby monitoring sites. No yield losses were detected across the alternative sites.

Many varieties of dry beans have been shown to be highly sensitive to 0_3 and SO_2. Brewer et al. (1982), in a study for the California Air Resources Board found that black-eyed pea yields in ambient air were 96 percent of those yields in filtered air. This is equivalent to yields in chambers with one-third filtered air and two-thirds ambient air. Yields were reduced 18 and 8.6 percent, respectively, when 10 pphm SO_2 was introduced for six hours, four days per week to filtered air and ambient air. Interestingly, yields increased slightly when 5 pphm SO_2 was introduced to ambient air.

Other authors have indicated that ozone and sulfur dioxide have nonadditive effects on dry beans (Jacobson and Colavito, 1976; and Hofstra and Ormrod, 1977). Hofstra and Ormrod fumigated Sanalac beans with 15 pphm ozone and sulfur dioxide ranging from 7.5 to 60 pphm for five to ten days in experimental facilities. The combined gases resulted in injury symptoms appearing several days later than did symptoms from ozone alone. SO_2 did not result in visible injury except for plants exposed to 60 pphm.

Heggestad and Bennett (1981) subjected field grown dry beans to SO_2 exposures ranging from 6 to 30 pphm for six hours per day, five days per week for 31 days. During that time, the ambient monthly average ozone concentration ranged from 3.8 to 4.5 pphm with monthly average hourly peaks ranging from 10 to 13 pphm. In this study, SO_2 reduced bean yields more in the presence of ambient ozone than in ozone free chambers. The combined effects were more than the addition of the individual effects.

Oshima (1978) examined red kidney bean yields at alternative ozone dose levels varying between filtered air and ambient air near Riverside, California, alone and in combination with 10 pphm SO_2. Ambient ozone alone produced yield reductions in excess of 65 percent, compared to the yields in filtered air, but only at doses exceeding 5144 pphm-hours for concentrations greater than 10 pphm (50 percent of ambient conditions). Sulfur dioxide did not affect yields except in 50 percent ambient air where yield losses were increased. Oshima suggests the SO_2 simply lowered the O_3 threshold.

Brennan and Rhodes (1976) report ozone damage to dry beans following a single six- to seven-hour exposure to 4 pphm. Hill et al. (1961) showed Mexican Pinto and Black Valentine beans to be injured following a two-hour ozone exposure of 25 pphm, an impact the author rated as "sensitive." Treshow (unpublished) has found premature senescense to occur with exposures as low as 5 pphm.

The California Department of Food and Agriculture (CDFA, 1982) provides estimated dose-response rates, illustrated in Table A2-3, based upon a number of studies, and rates beans as highly sensitive.

Table A2-3

Ozone - Dry Bean Dose-Response Function

Ozone Dose*	Predicted Percent Reduction	Range of Reduction
50	0	0
250	43.3	38.8-48.3
500	55.7	54.7-62.9
750	67.7	63.4-72.1
1,000	74.1	69.5-78.7

* pphm-hours above 10 pphm, May-August 1977.
Source: (CDFA 1982)

Butler and Tibbits (1979) examined 33 varieties of dry beans and found several major categories of dry white and red bean varieties to be among the most ozone sensitive agricultural crops.

Bennett, now with the Air Quality Division of the U.S. National Park Service, who collaborated with Oshima on many previous zonal studies involving vegetable crops, also considered dry beans to be among the most ozone-sensitive of the crops studied, and in the same sensitivity range as cotton (personal communication, 1983).

Grapes

Although grapes were among the earlier species for which crop losses were recognized (Richards et al., 1958), there has been little quantitative work treating their response to O_3 and SO_2.

In an early study, Thompson et al. (1969) compared the yield and quality of Zinfandel grapes in "smoggy" and clean air over a three-year period. Thompson and Kats (1970) reported that grape yields in 1968 were 12 percent greater in carbon-filtered air than in ambient air. Zinfandel grapes dusted twice during the 1967 season with DPPD (an anti-oxidant) showed an average yield increase of 20 percent, but the variance was too great for the difference to show statistic significance. In a 1971 study, Thompson (et al. 1972) examined the susceptibility of several grape varieties to smoggy air in Riverside, California, in terms of growth and leaf drop. The relative sensitivities are reported in Table A2-4.

Table A2-4

Grape Varieties in Order of Sensitivity to Smoggy Air at Riverside, CA (based on average percent leaf drop)

Variety	Smoggy Air (average percent leaf drop)	Clean Air (average percent leaf drop)
Mission	4	7
Ribier	14	14
Carignane	16	4
Thompson Seedless*	20	14
Emperor	17	7
Palomino	24	5
Grenache	26	17
Cabernet Sauvignon	30	8
Pedro Ximenes	33	17
French Colombard	34	11
Cardinal	36	6
Rubired	38	16
Zinfandel	41	5
White Riesling	51	15

Source: Thompson et al. (1972)

* Thompson Seedless Grapes were also used in the work by Brewer (See discussion)

Brewer (personal communications, 1982, 1983 and California Arizona Farm Press, 1983) has compared yields of 10-year-old Thompson seedless grape vines grown in ambient and filtered air at the Kearney, California field station. Ozone exposure was measured by pphm-hours greater than 5 and 10 pphm. The average ambient dose over the three-year study period ranged from 78 to 183 pphm-hours greater than 10 (and 1910 to 3333 pphm-hours greater than 5). Concentrations on "outside" ambient plots were over 100 percent higher than the "inside chamber" ambient levels, because ozone is lost in the air circulation process. Yields in ambient conditions were 27 and 17 percent lower than in filtered air over the first and second control periods. Brewer noted it may be important to consider lagged pollution effects, because grapes are produced from buds developed in the previous season. Brewer indicates these preliminary results suggest Thompson seedless grapes may have sensitivities similar to cotton, and are at least as sensitive as alfalfa.

The Thompson seedless grape is the most prominent variety in the San Joaquin Valley, particularly for non-wine grapes. Preliminary evidence suggests relative yield losses across grape varieties are similar to the relative leaf drop reported by Thompson (Table A2-4). Consequently, it is likely on average that wine grapes may be more affected by ozone than non-wine grapes.

At this time, no data were found that provided a basis for establishing an ozone dose threshold. However, based on a comparison of the general sensitivity of such dominant varieties as Thompson Seedless or Zinfandel, with alfalfa and cotton, it seems that these are at least as sensitive. Therefore, ozone measures should again consider concentrations below 10 pphm.

Lettuce

Data regarding the response of lettuce to ozone are limited. A 1982 California Air Resources Board report titled, "The Effect of Smog on California Plants," reports smaller, lighter heads when lettuce plants are exposed to ozone concentrations below 10 pphm for one hour. Bennett (personal communication, 1983) explained the loose bib variety which he studied is more intermediate in sensitivity, being impaired only at ozone concentrations above 10 pphm.

A NCLAN study by Taylor concerning ozone effects on lettuce was conducted in Riverside, California in 1980 (Taylor et al., 1982, and reported in Kohout et al., 1982) with Empire lettuce subjected to seven-hour O_3 concentrations ranging from 4.3 pphm to 14.9 pphm. Yield reduction, in terms of head weight, was on the order of 22 percent over the interval 4.3 to 6.8 pphm, 50 percent over the interval 4.3 to 10.2 pphm, and 70 percent over the interval 4.3 to 14.9 pphm. These rates of damage were nearly as large as those found for cotton (Taylor, 1982).

The earlier work by Hill et al. (1961) placed endive (Green Curled cultivar) in the intermediate sensitivity category, with leaves first being injured by a two-hour exposure to 35 pphm. Romaine lettuce was considered resistant, not being injured at 41 pphm. Reinert et al. (1972) also found lettuce to be relatively tolerant of ozone. They subjected several varieties to 35 pphm for 1-½ hours, and recorded the percent injury on the three most severely affected leaves. From most to least sensitive, the varieties and amount of injury were: Crimson Giant, 33.9 percent; Comet, 32.4 percent; Champion, 30.7 percent; Red Boy, 24.7 percent; Calvalrondo, 23.7 percent; Early Scarlet Globe, 23.6 percent; French Breakfast, 23.4 percent; and Icicle, 17.1 percent.

Oranges

Some of the earliest yet most sophisticated research to determine the effects of ozone and ambient air on citrus was conducted in the 1960s (Thompson et al., 1972). In one phase of their study, mature navel orange trees were enclosed in plastic-covered greenhouses from blooming to picking time. The trees were exposed to ambient air, carbon-filtered air, and carbon-filtered air with either ambient or one-half ambient air levels of ozone for eight months. One-half the ambient level of ozone had no statistical effect on either the number or weight of mature fruit, but a significant reduction occurred at ambient levels of ozone. Ambient air that included PAN and nitrogen oxides caused further yield reductions. Ambient peak levels of total oxidant varied from 0 to 69 pphm per hour. The average of maximum hourly concentrations ranged from 1 to 37 pphm. Total dose could not be derived from the data. The total yield of navel oranges in the carbon-filtered air was 81.1 kg, compared with 52.6 kg in the filtered air plus ambient ozone, and 28.5 kg in ambient air. These represent reductions of 35 percent and 65 percent, respectively. Valencia oranges are thought to be slightly more tolerant of ozone than navels, but this has not been quantitatively documented.

Thompson (personal communication, 1983) indicated that the effects found in these early studies may be much larger than would now be found in the San Joaquin Valley. This is because the ozone levels in the studies were perhaps twice those now experienced in the Valley, and the methods in use at the time may have inadvertantly increased the yield losses from ozone exposure by up to a factor of two. Thompson further indicated he was unaware of any reported or proven incidences of ozone induced losses to peaches or oranges in the valley, although he had heard reports of ozone damage to lemons.

Thompson and associates in 1983, initiated a new multi-year orange study near Riverside, California, but results will not be available for several years.

The only other evidence of ozone sensitivity for oranges is from a regression analysis of actual orange yields versus air pollution levels in the South and Central Coast Air Basins, where Leung et al. (1981) estimated ozone-induced yield reductions ranging from 0 to 60.6 percent from ambient ozone levels (as reported in Table A1-2), however, these results indicate oranges are much more ozone sensitive than alfalfa, but less sensitive than tomatoes, while other evidence suggests tomatoes and alfalfa have similar sensitivities, and are much more sensitive than oranges.

Peaches

Little information could be found in the literature regarding the sensitivity of peaches to ozone. One reference appears in the EPA manual, "Diagnosing Vegetation Injury Caused by Air Pollution," edited by LaCasse and Treshow (1976). The authors listed peaches as tolerant which meant no injury was expected below 25 pphm to 35 pphm O_3 for one hour.

In a 1961 study (Hill et al., 1961), peaches (Elberta variety) were place in an "intermediate" category of sensitivity. The lowest O_3 concentration at which injury appeared was 28 pphm for a two-hour exposure.

Millican (personal communication, 1983) observed leaf flecking injury attributed to ozone on peach leaves in San Bernadino County and at Little Rock (just north of Los Angeles). In both cases, concentrations were well over 30 pphm. He has never observed such symptoms in the San Joaquin Valley.

Based on the above, damages might not be observed for ozone concentrations below 20 pphm. However, lower thresholds would be empirically acceptable, realizing that a high dose would be required before any production loss would be likely.

Potatoes

The response of potatoes to ozone has been reviewed by Foster (1979, 1980), who carried out environment exclusion studies in Riverside, California in 1978. The Centennial cultivar, a russet-skinned type important in the San Joaquin Valley, was exposed to ambient air and to alternative levels of filtered air using activated carbon filters in separate chambers. Sulfur dioxide was injected into half of the chambers at each ozone dose. Speckle-leaf symptoms characteristic of ozone toxicity occurred at all exposures and were reflected in substantial yield reductions. Sulfur dioxide foliage damage was also substantial when it was introduced. Tuber yield was reduced by 45 percent at a seasonal oxidant dose of 3850 pphm-hours. A seasonal SO_2 dose of 2555 pphm-hours reduced yields a statistically significant six percent (the thresholds over which the pphm-hours were measured were not reported).

Pell et al. (1980) grew Norland and Kennebec potato varieties in greenhouses with ozone exposures of 20 pphm for six hours every second week through the 1977 and 1978 growing seasons. This amounted to an exposure dose of about 720 pphm-hours greater than zero. Significant reductions in yields relative to unpolluted air were found as reported in Table A2-5. Tuber and weight yields were reduced on the order of 37 to 44 percent for Norland, and 52 to 72 percent for Kennebec varieties.

Table A2-5

Pell's (1980) Potato Yield Reduction Due to Ozone

	Percent Reduction In Tuber Weight		Percent Reduction In Tuber Number	
Variety	1977	1978	1977	1978
Norland	30	20	19	21
Kennebec	54	30	40	32

Research using anti-oxidants has further confirmed the sensitivity of several potato varieties to ozone, but failed to develop any threshold dose response. Anti-oxidant use did, however, reveal an average tuber increase of 18 percent in the Centennial variety. Significant yield losses occurred in areas where the daily O_3 means exceeded 2 to 4 pphm, and daily maximums reached 8 pphm. The California Department of Food and Agriculture report (1982) showed over a 40 percent loss in total potato number and yield.

Based on the above data and the well-established sensitivity of potatoes to ozone, the minimum ozone concentration on which to base a dose measure should be no less than 8 pphm and is likely to be much less for the most sensitive cultivars (i.e., Centennial).

Tomatoes

An early effort by Oshima et al. (1977) found, in general, fruit size and weight decreased as pollution increased, but such yield losses did not correlate well with visible injury symptoms under ambient air conditions. He later found (1979) that 10 or 20 pphm SO_2 reduced tomato yields by 16 and 20 percent respectively. The ambient 0_3 dose in Riverside, California of 11,671 pphm-hours greater than 10 caused a 66 percent reduction in commercial yields relative to yields in filtered air.

A recent NCLAN experiment in Beltsville, Maryland (reported in Kohut et al.), examined tomato (Jet Star cultivated variety) yields in ambient and filtered air into which 0, 6, 12, 24 and 48 pphm SO_2 were added five hours per day, five days per week (except on days of high winds or rain for 57 days in July through September). Ambient ozone reduced yields about 17 percent over filtered air, as did the addition of 48 pphm SO_2 in the filtered air. Average seven-hour ambient O_3 concentrations were about 5.6 pphm. The combination of SO_2 to ambient ozone reduced yields 31.5 percent when compared to yields in filtered air. The effects of SO_2 were found to be additive. This work suggests that the sensitivity of tomatoes to ozone is quite similar to that of alfalfa.

Polepack F_2 VF 6718 VF, Pole Ace and Earlypak 7 tomatoes have been rated as the most sensitive cultivars (CDFA, 1982). Yield reductions are predicted above a dose of 250 pphm-hours. The ozone dose function for processing tomato yields (cultivar VF-145-B7879) was also given. A dose of 25 pphm-hours was predicted to reduce yields 5.7 percent with a confidence range of 0 to 22.1 percent. The NCLAN work suggests that processing tomatoes are affected by repeated ozone concentrations at or below 10 pphm (Heck et al, 1983).

A2.6 SUMMARY FOR THE PRIMARY STUDY CROPS

A major goal of this review was to determine yield reduction results (either relative or absolute) which can be expected from the regression-based damage-function estimates undertaken in this study. This review highlights the difficulty in predicting exact air pollution-yield functions due to the limited research, which is often undertaken under many different procedures, environmental conditions, and with the use of different cultivars of the same species. It is clear that due to the ambient concentrations and the durations experienced in the San Joaquin Valley, ozone induced damages are likely to be substantially greater than those from sulfur dioxide. With this in mind, more attention has, and will, be placed on examining O_3 impacts.

The responsiveness of plants to O_3 and SO_2 are dependent on the concentration of the pollutant and the duration of exposure; together they comprise the exposure dose. The dose at which yields are affected is dependent on the genetic nature of the plant, and the growing conditions before, during and after exposure, as well as many other environmental parameters. Therefore the detrimental exposure dose cannot be a single value, but a range of concentrations. Integrating environmental variables and the dose in order to calculate a threshold value is at best a difficult task. The environment changes from one day to the next, and conditions which enhance sensitivity one day may be just the opposite later and mitigate sensitivity another day. The stage of plant growth also can be important, but this varies from field to field and would be impractical to consider in calculating a threshold dose value.

Ozone

Despite the above complexities, the chamber study research can be used to establish a likely relative ranking of ozone impacts on the primary study crops. The relative sensitivities are determined by first comparing results from the various NCLAN study efforts, which have entailed the most consistency in methodology across studies. Next, the damage-function results from other studies are considered. Finally, evidence on the threshold at which damage first occurs, and observations by "crop experts" are used to rank crops where the damage function information is insufficient. Assuming typical moisture, temperature and growing conditions for each crop, "sensitivity categories" have been defined; the definitions of which remain an arbitrary judgment of the authors. Figure A2-1 depicts the relative sensitivities of the study crops to ozone exposures. Because there is limited consistency between the studies used to evaluate the alternative crops, this comparison entails somewhat arbitrary assignments and ranking.

Plants which are affected by ozone concentrations below 10 pphm are placed in the "sensitive" category, and can be expected to show yield losses in excess of 10 percent from existing levels in the San Joaquin Valley. Plants in this category might be physiologically affected when exposures exceed 10 pphm for a two- to four-hour period. Plants subjected to more hours of lower concentrations also may be adversely affected. Measurable yield responses under field conditions would be anticipated if the dose over a growing season exceeded about 250 pphm-hours when the dose is calculated from the number of hours ozone concentrations exceed 10 pphm. Under this categorization, five species we are examining are considered to be sensitive to ozone. These are, roughly in order of decreasing sensitivity, varieties of dry beans, potatoes, cotton, lettuce and grapes.

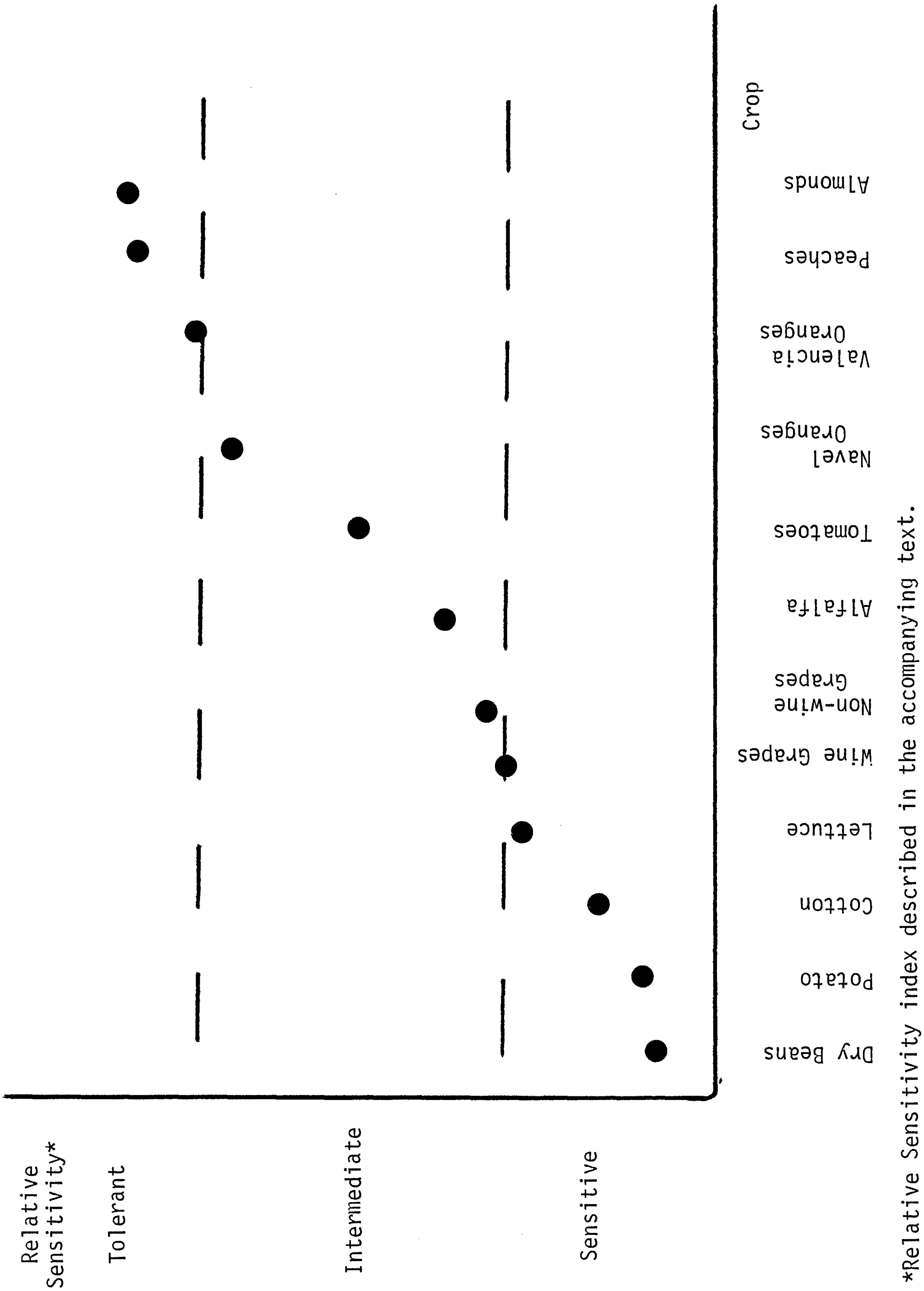
An "intermediate" category is defined as those crops first responding adversely to ozone concentrations in the 10-20 pphm range for a two- to four-hour period, or to a seasonal dose of 250 to 2000 pphm-hours, calculated as noted above. These crops can be expected to show yield losses between 2 and 10 percent at the San Joaquin valley ozone levels. This category includes alfalfa, tomatoes, and navel and valencia oranges.

A "tolerant" category consists of plants affected only by ozone concentrations in excess of 20 pphm, or a seasonal dose in excess of 2000 pphm-hours, and would therefore probably not experience ozone damage at current San Joaquin Valley levels. Of the crops being considered, peaches and almonds would likely fall into this category.

The ozone exposure dose has often been calculated by adding together all hours in which ozone concentrations exceeded zero. This is known as a zero base. Others have utilized only those values above arbitrary concentrations such as 5, 8, 10 or 15 pphm (Bennett, personal communication, 1983). The CARB has based the dose mostly on the number of hours in which ozone concentrations were above 10 pphm. This number does not take

Figure A2-1

Relative Sensitivity of the Primary Study Crops to Ozone



into consideration the many hours below 10 pphm that may have adversely affected the crop in question. Data suggest that, at least with some crops (e.g. dry beans and potatoes), virtually any exposure above background (i.e., 3 to 4 pphm) could have some adverse impact, and a threshold lower than 10 pphm should be used. However, the hours above 10 pphm should be representative of the larger number of hours for which concentrations might exceed some lower concentrations. To examine these considerations the study considers alternative threshold measures of 6 and 10 pphm.

Sulfur Dioxide

Among the objectives of this effort was to examine whether existing sulfur dioxide levels in the San Joaquin Valley affected crop yields, either individually or in combination with ozone. It is important to note, based upon past evidence, that it is unlikely for most crops that SO_2 yield effects will be detected. Table A2-6 summarizes some of the SO_2 findings, as well as the actual levels experienced in the San Joaquin Valley for 1978, a year with high SO_2 levels in the Valley. It is readily apparent that Kern County is the only county with SO_2 levels high enough to be compared with the levels used in the experimental studies. For example, with alfalfa, Tingey and Reinert applied 5 pphm SO_2 for 8 hours per day every day over the entire growing season to obtain a 29 percent yield reduction, while Fresno County only experienced 5 pphm a few times during the year with those occurrences typically occurring in the non-growing season. In fact, even in Kern County the average daily maximum value was less than 5 pphm with the most occurrences of high SO_2 levels during the winter months. Consequently, for all crops not grown during the winter months, one would not expect an SO_2-yield relationship to exist.

For potatoes grown during the winter in Kern County, Foster found that 2555 pphm-hours over 10 pphm SO_2 only reduced yields by 6 percent. Even this dose exceeds the levels that winter potatoes in Kern County experienced in any year during the study period.

The above analysis suggests that only those crops grown in Kern County during the winter have the potential to reflect an SO_2-yield relationship, even under chamber study conditions which eliminate extraneous influences and have a high degree of measurement precision. These crops are lettuce and potatoes. Irving and Ballon (1980) have rated potatoes "sensitive" to SO_2, with a three-hour damage threshold at about 60 pphm. They also categorize vegetables with damage thresholds of about 50 pphm as sensitive to SO_2. Lettuce could conceivably fit into this category.

Table A2-6

SO_2 Effects on Crops and SO_2 Levels in the San Joaquin Valley

I. SO_2 Effects on Crops[1]

Crop	SO_2 Exposure	Yield Production (percent)	Study
Alfalfa	10 pphm SO_2 6 hours/ day 4 days/week over the growing season	8-10	Brewer & Ashcroft
	5 pphm SO_2 8 hours/day over the growing season	29	Tingey and Reinert
Tomatoes	10 to 20 pphm/hour over the growing season	16-20	Oshima
	48 pphm SO_2 5 hours/ day 5 days/week	17	NCLAN
Potatoes	2555 pphm/hours greater than 10 pphm	6	Foster
Dry Beans	Up to 30 pphm 3 hour average	0	NCLAN
	10 pphm SO_2 + O_3 reduced ozone threshold		Oshima
Cotton Grapes Peaches, Oranges, Almonds Lettuce	Considered resistant, or no known sensitivities research available		

II. SO_2 levels in the San Joaquin Valley (pphm), 1978[2]

County	Annual Mean-All Hours	Average Daily Max	Annual 1st High	Annual 2nd High
Fresno	0.4 pphm	0.9 pphm	5 pphm	5 pphm
Kern	1.6 pphm	4.8 pphm	34 pphm	29 pphm
San Joaquin	0.1 pphm	0.1 pphm	2 pphm	2 pphm
Modesto	0.6 pphm	1.2 pphm	4 pphm	4 pphm

Sources: 1. Appendix A2 of this report
2. California Air Resources Board "Air Quality Data for 1978"

When considering ozone and SO_2 in combination, estimation of dose threshold responses becomes especially complex because the ratio of the pollutants is as important as their individual concentrations. Thus, the possible ozone-SO_2 dose combinations become infinite. At certain ratios, SO_2 concentrations as low as 10 pphm may enhance ozone effects. It is questionable if concentrations in the 10- to 30-pphm range should be considered, but certainly SO_2 concentrations below 10 pphm need not be considered as having any adverse effect on production. Consequently, except for winter crops, such a relationship is unlikely to be found on the San Joaquin Valley.

A2.7 OZONE SENSITIVITIES FOR OTHER CROPS IN THE SAN JOAQUIN VALLEY

The application of the California Agricultural Resources model (CAR), described in Chapter 5, requires the consideration of over 20 crops other than those given detailed attention in this chapter and for which field data regressions will be estimated. To appropriately implement the CAR model, yield sensitivities must be assigned to all crops in the San Joaquin Valley. Including all crops allows a better estimate of the total economic damage of ozone to crops in the Valley. Further, if these crops were ignored, or it was assumed that they were unaffected by ozone, the model would incorrectly substitute acreage into these crops as air pollution increases (because they would be insensitive to the change) and would substitute acreage out of these crops as air pollution decreases. This section presents and documents the yield-ozone assumptions used for the other crops in the CAR model.

Table A2-7 lists the yield-ozone assumptions used for other crops in the San Joaquin Valley. It should be noted that the study crops comprise about 80 percent of the economic value of the crops considered in the CAR model. Consequently, measurement error in estimating ozone damages for these other crops is less serious than for the study crops. Damage estimates were, if possible, obtained from NCLAN studies by regressing yields versus ozone concentrations used in the studies (see Section 6.4). Next, other available chamber study results were used to either establish damage functions or damage categories for crops. These categories of "sensitive," "intermediate" or "resistant" are relative to the O_3 levels experienced in the San Joaquin Valley. Crops in these categories in the CAR analyses were assigned the yield losses for similar primary study crops classified similar.

Table A2-7

Assumptions Regarding Ozone Sensitivity and Acreage Substitutions for "Other" Crops in the San Joaquin Valley

Crop	1980 Amount ($ millions)	No Air[1,4] Pollution Effect Assumed	Sensitivity Category[2] and Source of Results Used	References[5]
Alfalfa Seed	$ 34		Intermediate Use Alfalfa	Hill et al. 1961
Apples	4	X	Crab is sensitive Delicious is tolerant	Treshow 1970 and unpublished
Asparagus	24	X		
Avocados	2	X		
Barley	79		Sensitive at Intermediate-Use NCLAN Wheat	Hill et al. 1961 NCLAN 1982 Adams et al. 1979
Cantaloupes	66	X[3]		
Carrots	31		Intermediate-Use tomatoes	Hill et al. 1961 NCLAN 1982
Cauliflower	31	X[3]	Tolerant	Bennett and Oshima 1976 Adams et al.
Corn	65		Intermediate-Use NCLAN Corn	Hill et al. 1961 NCLAN 1982
Grain Hay	16		Sensitive-Use NCLAN Wheat	Price, 1973
Grain Sorghum	16		Tolerant-Use NCLAN Sorghum	NAS, 1977
Lemons	22	X	Tolerant	Thompson, 1983
Nectarines	90	X	Tolerant-Similar to Peaches	
Onions, Dry	31	X	Tolerant	Bennett, 1978 Hill, et al. 1961
Pasture, Irrigated	31		Intermediate-Use NCLAN Wheat	Price 1973

Table A2-7

(continued)

Assumptions Regarding Ozone Sensitivity and Acreage Substitutions for "Other" Crops in the San Joaquin Valley

Crop	1980 Amount ($ millions)	No Air[1,4] Pollution Effect Assumed	Sensitivity Category[2] and Source of Results Used	References[5]
Pears	$ 4	X	Tolerant	Treshow, 1970
Plums	132	X		
Prunes	12	X		
Rice	30		Tolerant- Set Equal to Zero	Thompson et al. 1983
Safflower	16		Sensitive	Howell and Thomas 1972
Silage	72		Intermediate-Use NCLAN Corn	
Sugar Beets	132		Tolerant- Set Equal to Zero	Brewer (1978)
Walnuts	111	X		
Wheat, Dry, Irrigated	150		Sensitive-Use NCLAN Wheat	NCLAN 1982 Treshow, 1970; NAS, 1977
	$1,178	for all "other crops."		
	$ 3,960	for the "primary study crops."		
	$ 5,138	Total - All CAR crops in San Joaquin Valley.		

Notes:

1. Acreage also assumed not to change as a result of changes in ozone.
2. NCLAN results and damage equations are reported in Chapter 8.
3. Adams et al. was the only group to examine canteloupes and cauliflower. They found no statistical relationship between yields and ambient ozone levels in California using field data or Heck's rule of thumb relating leaf damage to yield loss.
4. Statistically significant reductions in yields were not observed at O_3 averages well above those experienced in the San Joaquin Valley.
5. NCLAN refers to National Crop Loss Assesment Network studies reported in Heck et. al. (1983).

In some cases, crops were assumed not to be sensitive to ozone at the levels experienced in the San Joaquin Valley, and acreage was assumed not to change with changes in ozone conditions. This assumption was applied where either the economic value of the crop is very small, such that any estimation error would be negligible, or where no estimate of the crop's sensitivity exists. The assumption of no ozone induced changes in yields results in conservative estimates of the economic value of changes in ambient ozone conditions (see Section 6.4).

APPENDIX A3

DISTRIBUTIONAL EFFECTS OF ALTERNATIVE AIR POLLUTION STANDARDS: AN ANALYSIS OF SAN JOAQUIN VALLEY AGRICULTURE

A3.1 INTRODUCTION

Economic impacts due to air pollution are not isolated in one subsector of agriculture but rather tend to have effects throughout the entire agricultural system. Further, these air pollution effects may have differential impacts both across and within various groups, such as consumers, producers, and resource owners. The overall purpose of this Appendix is to extend the discussion concerning the distribution of air pollution control benefits beyond the aggregate groups of producers and consumers identified in the main report. Specific issues addressed here include: (1) estimation of the effect (or benefit) of these air pollution control alternatives on producer well-being, by farm size and commodity; (2) measurment of the impact of alternative air pollution controls on consumers of California-produced commodities as measured by consumers' surplus changes for each commodity; and (3) evaluation of these effects across consumer income and other socioeconomic and demographic classifications. Each distributional issue is addressed within the context of changes in crop production due to reductions in ambient air pollution levels, which in turn may affect the welfare of various groups differently. While sometimes conditional on a sparse set of data, these distributional effects and implications can serve to identify in more detail the potential gainers and losers associated with alternative levels of air pollution control in the San Joaquin Valley (SJV).

The main report provided summary tables on CAR model output limited to major crops. Additional detailed summaries of the output for all crops are provided in Tables A7 through A21 at the end of this appendix and provide further data on distributional impacts of changes in air pollution in the SJV.

A3.2 AGGREGATE ECONOMIC EFFECTS

The economic analysis in the main body of this report relies upon the results of the CAR model based upon estimated changes in crop yields associated with changes (reductions) in ambient air pollution levels in the SJV in 1978. The point estimates of the statewide total net economic benefits of three progressively more stringent air pollution control options in the SJV are $43, $106, and $117 million; respectively. Producers' and consumers' shares (surpluses) of these net benefits suggest general distributional effects. For the first case ($43 million) the shares are $13.4 million (consumers) and $29.2 million (producers); for the second option ($106 million), $27.7 million (consumers) and $78.2 million (producers); and for the most stringent case ($117 million), $30.3 million (consumers) and $87.1 million (producers).

These aggregate distributional effects are of interest in that they can answer general equity questions concerning alternative air pollution control policies. However, both "consumers" and "producers" are made up of a large numbers of individuals, each with potentially different economic and demographic characteristics. Such characteristics can influence how individual welfare is affected by changes in agricultural production and prices associated with alternative air pollution controls. While economic surplus is generally viewed as the appropriate welfare measure for policy analysis (e.g. see Just et al., 1982), other welfare or distributional measures may be of interest to policy makers.

A3.3 PRODUCER DISTRIBUTIONAL EFFECTS

The distribution of air pollution damages to producers can be related to the crops produced, location and ownership category. Chapter 6 of the main report identified the aggregate producer losses by major crops and location. That data can, however, be somewhat misleading. For example, because of the great number of grape farms the aggregate losses to grape producers in the SJV is second only to cotton, yet losses per farm acre are fourth behind lettuce, cotton, and potatoes.

Fourteen crops were selected to examine distributed effects on producers in more detail. These fourteen crops represent those with the largest percent change in producers' surplus from a change in ambient air pollution conditions. CAR model results were used to calculate changes in producers' surplus for Scenario 3 on a total and on a per acre basis. ERC also commissioned the Bureau of the Census to perform a special analysis of the 1982 Census of Agriculture to determine ownership characteristics of selected crops in the SJV. This data is used to determine which types of farmers are experiencing the most economic impacts of air pollution. The summary data on producer distribution effects is listed in Table A3-1.

SJV cotton, grapes, lettuce, tomatoes, drybeans, and potato producers experience the greatest dollar loss per acre due to air pollution. These crops are produced, on average, more heavily on non-corporation owned farms. However, for lettuce, cotton, and tomatoes, the percent of corporation owned farms are substantially higher than the all crop average in the SJV. Due to the relative magnitude of economic damage of air pollution on cotton, compared to other crops, and the much larger size of corporation owned cotton farms, the percent of total economic losses incurred by corporation owned farms slightly exceeds the percent of total harvested acreage in the SJV held by corporation owned farms (41 percent of losses are on corporation owned acreage for nine crops for which census data was obtained versus 37 percent of SJV acreage being corporation owned).

Due to the distribution of ozone concentration and ozone sensitive crops, the economic impacts of air pollution are most heavily felt in the southern and central portions of the SJV. However, for several crops the SJV production provides a substantial market share of California or national markets. These crops include such as lettuce, corn, drybeans, tomatoes, pasture and grapes. As a result, increased production in the SJV reduces prices and causes California producers outside of the SJV to realize reduced profits (See Tables 6-15 and A3-14).

A3.4 CONSUMER DISTRIBUTIONAL EFFECTS

As noted in the main report, air pollution affects many crops and, therefore, the consumers of these crops. However, the diversity of yield and price impacts across crop groups may affect income classes differently, if food consumption patterns differ across income groups. This then implies another set of distributional consequences within the broad "consumer" classification. However, an assessment of these specific air pollution impacts by income classes, and other demographic characteristics for consumers, is much more tenuous than for the aggregative consumer measures derived by the solution of the

Table A3-1

Differential Impacts of Air Pollution upon Agricultural Producers in the San Joaquin Valley for Selected Crops

	All Farms[2]			
Crop	Total $ Change in Producers' Surplus (Total)	Avg $ Change in Producers' Surplus Per Acre	Corporation[3] Owned Farms	Other[3] Farms
Lettuce	$1.0 million	$55.5		
# farms (% of total)			26 (26%)	74 (74%)
Avg. Acreage/Farm			526	60
% of Total Acreage			75%	25%
Primary Location of Impacts			Western Fresno, Kings and San Joaquin Counties	
Potatoes (All) (Irish)	$1.1 million	$44.0		
# farms (% of total)			23 (21%)	84 (79%)
Avg. Acreage/Farm			376	208
% of Total Acreage			33%	67%
Primary Location of Impacts			Kern County and San Joaquin County	
Cotton	$57.8 million	$41.0		
# farms (% of total)			412 (15%)	2333 (85%)
Avg. Acreage/Farm			1273	300
% of Total Acreage			43%	57%
Primary Location of Impacts			Central and Southern San Joaquin Valley	
Grapes	$9.2 million	$19.0		
# farms (% of total)			564 (8%)	6493 (92%)
Avg. Acreage/Farm			300	64
% of Total Acreage			29%	71%
Primary Location of Impacts			Central and South Central San Joaquin Valley	
Tomatoes	$2.1 million	$16.5		
# farms (% of total)			132 (26%)	300 (74%)
Avg. Acreage/Farm			433	128
% of Total Acreage			54%	46%
Primary Location of Impacts			San Joaquin and Fresno Counties	

Table A3-1
(continued)
Differential Impacts of Air Pollution upon Agricultural Producers in the San Joaquin Valley for Selected Crops

	All Farms[2]			
Crop	Total $ Change in Producers' Surplus (Total)	Avg $ Change in Producers' Surplus Per Acre	Corporation[3] Owned Farms	Other[3] Farms
Dry Beans (All)	$1.7 million	$16.0		
Dry and Lima				
# farms (% of total)			121 (16%)	642 (84%)
Avg. Acreage/Farm			269	111
% of Total Acreage			32%	68%
Primary Location of Impacts			Central San Joaquin Valley	
Corn	$3.2 million	$14.0	Census data not obtained	
Alfalfa	$6.3 million	$12.0		
# farms (% of total)			341	2445
Avg. Acreage/Farm			448	127
% of Total Acreage			33%	67%
Primary Location of Impacts			Central and Southern San Joaquin Valley	
Pasture	$4.2 million	$9.5	Census data not obtained	
Wheat	$6.3 million	$12.0		
# farms (% of total)			303 (19%)	1331 (81%)
Avg. Acreage/Farm			627	207
% of Total Acreage			41%	59%
Primary Location of Impacts			South and Central San Joaquin Valley	
Barley	$3.9 milion	$7.0		
# farms (% of total)			192 (19%)	826 (81%)
Avg. Acreage/Farm			498	191
% of Total Acreage			38%	62%
Primary Location of Impacts			Central and South Central San Joaquin Valley	

Table A3-1
(continued)
Differential Impacts of Air Pollution upon Agricultural Producers in the San Joaquin Valley for Selected Crops

	All Farms[2]			
Crop	Total $ Change in Producers' Surplus (Total)	Avg $ Change in Producers' Surplus Per Acre	Corporation[3] Owned Farms	Other[3] Farms
Silage	$.7 million	$6.0	Census data not obtained	
Grain Hay	$.3 million	$5.0	Census data not obtained	
Grain Sorghum	$.2 million	$3.0	Census data not obtained	

1 Crops selected and ordered according to importance of producer losses per acre.

2 Data compiled from CAR model runs based upon 1978 conditions in the San Joaquin Valley. Values relate to existing 1978 condition relative to most likely conditions with ozone at background levels (or peak hourly values not to exceed 8 pphm), or Scenario 3. See Tables A-15 and A3-16.

3 Results based upon a special run on the 1982 Census of Agriculture by the Bureau of the Census for Energy and Resource Consultants Inc. In some cases crop definitions do not exactly match those used in the CAR model.

economic model. The diversity of the crop groups included in the model and the general lack of data concerning price-quantity and income-quantity relationships by income class, contribute to the difficulties of performing such a detailed distributional assessment. Further, any evaluation of effects across income groups must consider the impacts of government transfer payments (e.g. food stamps). Such programs may dampen the normal consumption responses for the recipient class. For example, Davis et al. (1983) observe that food stamps reduce expenditures for food with respect to money income. Therefore, for the purpose of this discussion, a rather general set of implications will be drawn concerning these distributional effects, based primarily on the relationship between specific commodity price adjustments portrayed by the model and income class consumption patterns and demographic characteristics reported elsewhere.

Under a certeris paribus situation, falling commodity prices may be viewed as having a beneficial effect on consumer welfare. Reduced prices result in increased consumer surplus, as indicated in the benefits reported earlier in this report. Further, economic theory suggests that as average income rises, the percentage of total income spent on food declines. This implies that general reductions in food prices may be relatively more important for low income households. The degree to which consumption of a commodity is affected by price changes depends on a complex set of relationships including the substitution and income effects, within and across commodity groups. The extent to which a particular income class is affected can be inferred from the consumption pattens of that group, as defined by the Engel conditions, i.e., per capita consumption of various commodities and the associated relative expenditure weights. In addition to income, other socioeconomic and demographic variables, such as household size and composition, may affect food consumption patterns (Salathe and Buse, 1979; Davis et al., 1983). The interaction of all these variables will influence the impact that air pollution may have on individual household well-being.

To assess the plausible effects of crop production and price changes due to alternative air pollution controls, several types of information are needed. To start the distributional analysis, the magnitude of production and price changes associated with the control options are obviously needed. Since these control options are hypothetical (have not actually been implemented), such effects must be simulated. This was the role of the CAR model used in this analysis. These changes, as predicted by the model for each analysis, are presented in Table A3-2. In addition, the breakdown of total consumers' surplus by commodity is also reported. This quantitative information, when coupled with information on consumption patterns by income or demographic group, can provide some suggestion of the net gainers (among consumers) from reductions in air pollution.

A number of important observations can be gleaned from Table A3-2. First, the general pattern of price response is a reduction in price associated with reductions in pollution levels, with greatest price reductions occurring at the most stringent control option (No. 3). These price reductions stem from the increase in crop production due to reduced air pollution. Second, the magnitude of the price changes is generally small. However, small price changes can translate into large consumer welfare gains, if the quantities consumed are large. For example, the associated consumer surplus changes for each of these commodities display much larger percentage changes than for prices with the largest changes in consumer surplus associated with major commodities, such as cotton. Third, note that not all crops display price changes. Specifically, only 16 of the 34 crops in the CAR model experience price reductions. This is due to the differential sensitivity across crops to air pollutants as well as substitution effects in production arising from that difference in pollution sensitivity.

Overall, the changes in consumer surplus indicate that consumers of these specific 16 crops are made better off than before the change in air pollution. However, the different rates of changes for prices and consumers surplus is the result of changes (increases) in the amount consumed as prices change (decrease). Therefore, one cannot simply make inferences concerning consumer well-being based upon price changes, but must consider also the elasticity of demand with respect to price changes as well as the income elasticity of demand to determine which consumers are affected. This information suggests, in very general terms, how consumers' welfare may be affected by price changes. It also indicates that the consumption patterns of individual commodities display a wide range of responses to prices and income changes, implying that individual consumers' welfare effects will depend on the relative proportions of total food budget spent on each commodity.

The general quantity responsiveness of such California commodities, for proportionate changes in both price and income, are presented in Table A3-3. These elasticity measures, while nearly all inelastic (frozen vegetables are the exception), show a rather broad range, from almost no responsiveness to approximately unitary elasticity. Such estimates provide an indication of those commodities for which consumption will be more or less resistant to proportional changes in the causal factors. This implies that in

Table A3-2

Commodity Price Changes and Associated Changes in Consumer Surplus, by Pollution Control Scenario[a]

Commodity[b]	Price Changes (%)			Consumer Surplus Changes (%)		
	1 (12 pphm)	2 (10 pphm)	3 (8 pphm)	1 (12 pphm)	2 (10 pphm)	3 (8 pphm)
Alfalfa	-.004	-.009	-.009	2.0	3.9	3.9
Barley	-0.33	-0.33	-0.33	4.8	9.7	11.4
Beans	-0.55	-1.01	-1.26	1.2	2.3	2.8
Corn	-0.05	-0.08	-0.10	2.9	5.5	6.7
Carrots	0	0	-0.12	0	0	.3
Cotton	-0.14	-0.43	-0.50	7.3	23.8	26.8
Hay	-0.31	-0.58	-0.68	1.4	2.7	3.3
Grapes	-0.70	-1.33	-1.36	2.2	4.2	4.3
Lettuce	-0.12	-0.23	-0.34	0.1	0.5	0.5
Pasture	-0.94	-1.81	-2.15	4.4	8.6	10.3
Potatoes	-0.14	-0.43	-0.43	0.8	1.4	1.4
Safflower	-0.38	-0.91	-1.08	0.6	1.4	1.7
Silage	0.68	-1.30	-1.60	3.2	6.5	7.7
Tomatoes (fresh)	-0.16	-0.20	-0.32	0.0	0.0	0.0
Tomatoes (processed)	-0.08	-0.18	-0.19	0.5	1.2	1.4
Wheat	-0.03	-0.05	-0.10	1.6	3.1	3.7

[a] See text for scenario definition. See Table A3-7 for price data and Table A3-8 for consumer surplus data.

[b] Twenty-one additional crops in the economic model showed no price changes under any of the control options.

Table A3-3
Retail Level [a] Elasticities for Selected Commodities

Crop	Elasticity with Respect to: Price	Income
Field Crops		
Beans (dry)	-.26	-.80[b]
Rice	-.32	.06
Sugar	-.24	.03
Wheat Flour	-.30	.08
Vegetables		
Broccoli	N.A.	.94[c]
Cantaloupes	N.A.	.54[d]
Carrots	-.90[e]	.32
Lettuce	-.54	.45
Onions	-.59[h]	.55[d]
Potatoes	-.31	.12
Tomatoes (fresh)	-1.20[i]	1.80[i]
Tomatoes (processed)	-.65[j]	.45[j]
"Other" Vegetables	-.32	.15
Canned Vegetables	-.40	.20
Frozen Vegetables	-1.04	.62
Grapes		
Wine	-.232[k]	1.76[l]
Raisins	-.481[k]	1.81[m]
Table	-.529[k]	0.24[k]

FOOTNOTES

SOURCE: George and King, unless otherwise noted.

a Elasticity for celery determined at the farm level.
b Source: Vandeborre (as reviewed in Nuckton).
c Source: French (Western Extension Marketing Committee Report).
d Source: Purcell (as reviewed in Western Extension Marketing Committee Report).
e Source: Shafer (as reviewed in Nuckton).
f Source: Brandow (as reviewed in Nuckton).
g Source: Blaich (as reviewed in Nuckton).
h Source: Chen (as reviewed in Western Extension Marketing Committee Report).
i Source: Adams et al. (as reviewed in Nuckton).
j Source: King et al. (as reviewed in Nuckton).
k Source: Renaud (as reviewed in Nuckton).
l Source: Hutchinson an Graves (as reviewed in Nuckton).
m Source: McKusick (as reviewed in Nuckton). Reported originally as an income flexibility; converted to elasticity for this table.

general consumers will be better off with lower food prices (due to both the direct price effect and an indirect income effect). This is confirmed by the consumers' surplus changes provided in Table A3-2. However, since these are aggregative measures (estimated across income classes), no specific inferences concerning distributional effects of price adjustments can be drawn.

To draw specific distributional inferences, one can use additional data on household food consumption patterns, by income and other stratification measures, available from periodic USDA household food consumption surveys. Data from these most recent surveys have been analyzed by numerous researchers and their findings can be useful in drawing general inferences in this analysis. For example, within the 1965-66 data, three income groupings (low, medium, and high) are delineated by George and King (1971). In addition, Salathe and Buse (1979) describe consumption patterns by demographic characteristics for that same survey. Smallwood and Blaylock (1981) assess the impact of household size and income on food spending patterns. Davis et al. (1983) use similar data from Florida consumers to examine such relationships. A general ranking of several included commodities, in order of their respective consumption by each income grouping, is presented in Table A3-4. As is evident from the table, these commodities assume variable importance across the three income classes. For example, rice, dry beans, and wheat flour are consumed at higher levels by individuals in the low income group while the high income group displays higher per capita consumption of carrots, lettuce, tomatoes and frozen vegetables than the lower groupings.

An additional bit of information concerning food consumption patterns is the wide range of total expenditures on "all food" items across income classes. For example, the 1965-66 data reveal that weekly food expenditures by the highest income group (over $15,000) is over four times that of the lowest grouping. However, while absolute amounts expended (by income class) on specific food items may increase with income, the relative importance of that item in terms of total expenditures may be quite different as reflected in the Engel conditions. This is indicated in recent research by Salathe and Buse (1979) on the effects of income and household composition on food consumption. Specifically, low income households not only spent a larger share of their total budget on food, they have a propensity to consume a different mix of food items than higher income groups. Using the most recent USDA date (1977-78) data, Smallwood and Blaylock similarly observe that households with higher incomes spend more on beef, bakery products and vegetables than lower income households.

Table A3-4

Relative Ranking[a] of Per Capita Consumption Across Income Classes, for Some Commodities in the CAR Model

Crop	Income Class		
	Low	Medium	High
Beans	1	2	3
Canned Vegetables	3	1	2
Carrots	3	2	1
Frozen Vegetables	3	2	1
Lettuce	3	2	1
Onions	2	1	3
Potatoes	3	1	2
Rice	1	2	3
Sugar	2	1	3
Tomatoes (fresh)	2	3	1
Tomatoes (processed)	3	2	1
Wheat Flour	1	2	3

SOURCE: George and King

[a] A ranking of 1 corresponds to highest per capita consumption (across the three income classes). Conversely, a ranking of 3 implies lowest per capita consumption.

The Salathe and Buse analysis of the effect of household composition (using 1965-66 USDA data) are highlighted in Table A3-5. As indicated, consumption of various commodity groups is a function of such characteristics as race, household size, sex and education. Thus, highly educated white males spend less of their disposable income on food than poorly educated whites, or than blacks. Further, their propensities to spend marginal dollars on food varies. In addition to income, the affect of these demographic characteristics has a statistically significant influence on consumption patterns. Such quantitative information can serve to verify the distributional consequences suggested by general economy theory; i.e., an air pollution policy that increases crop production and reduces prices of specific food items will generally benefit lower income groups more than higher incomes. Household size was also shown by Smallwood and Blaylock to have a greater effect on the consumption of most categories of food items than income (e.g., dairy products, fats and oils, cereals, bakery products, juices, and sugar and sweets). These findings are summarized in Table A3-6. To the extent that family size is negatively correlated with income in California, a plausible implication is that the relative benefits of reduced air pollution again benefits lower income groups.

The inclusion of intermediate products within the study makes consumer welfare comparisons even more complex. This is particularly pronounced due to the presence of feed grains, which have implications in terms of livestock prices. Given that livestock products constitute the most important component of food budgets for all income classes, any livestock price reduction due to falling feed grain prices, may be potentially more significant than price changes for vegetables or other field crops. However, given California's small relative market share of feed grains, inferences concerning such livestock price effects are beyond the scope of this study.

In the absence of price and income elasticity information for specific income classes, the exact magnitude of effects by consumer income class is impossible to discern. However, the relative consumption rankings (as presented in Table A3-5 and discussed in Salathe and Buse and Smallwood and Blaylock) suggest the general nature of the production and price effects for each air pollution alternative across income and household groupings. With the appropriate caveats the effect of price reductions (from increased production) for those commodities such as beans, rice and cereal products (wheat, barley, corn) may be viewed as more beneficial in terms of low income groups and large households. Similarly, the effects of price reductions for items such as lettuce, tomatoes and other fresh fruits and vegetables as well as beef products may be more beneficial to higher

Table A3-5

Proportion of Income Spent on Foods for Various Partitions of Households

Characteristic	Proportion of Income Spent On: Total Food	Grain Products	Vegetables	Beef & Pork	Dairy Products	Fruits
Sample	0.244	0.029	0.030	0.054	0.031	0.020
Region:						
Northeast	.247	.029	.028	.055	.032	.021
North Central	.237	.027	.029	.055	.030	.020
South	.257	.031	.033	.055	.032	.019
West	.226	.026	.027	.049	.029	.021
Urbanization:						
Urban	.228	.027	.027	.052	.028	.019
Rural nonfarm	.271	.033	.034	.056	.036	.022
Rural farm	.338	.040	.046	.077	.046	.029
Race:						
White	.234	.027	.029	.052	.030	.020
Black	.336	.042	.038	.076	.035	.024
Other	.304	.038	.037	.059	.039	.029
Education:						
0-7 years	.314	.040	.039	.065	.038	.022
8-11 years	.298	.036	.038	.065	.037	.024
12-15	.245	.029	.029	.056	.031	.020
16 or more years	.182	.020	.022	.041	.023	.017
Female Head:						
Employed	.221	.026	.027	.050	.027	.018
Not employed	.254	.030	.031	.056	.033	.021

SOURCE: Adopted from Salathe and Buse (1979)

Table A3-6

Response of Commodity Group Consumption to Changes in Income and Household Size

Commodity Group	Response of Consumption to Changes in	
	Income	Household Size
Milk	Slight	Substantial
Fats and Oils	None	Substantial
Cereal Products	Negative	Substantial
Bakery Products	Slight	Substantial
Fruits and Vegetables	Substantial	None
Sugar	Negative	Slight

SOURCE: Smallwood and Blaylock (1981).

income groups or particular demographic groupings, given their consumption pattern. However, the overall expenditure weight for food in general and fresh and frozen vegetables in particular, is still less for high income groups, suggesting that consumption response for these groups, in terms of price adjustments, may be lower than the low income groups. Thus, low income groups will also benefit by being able to consume more of these products.

The results presented here can only suggest that there may indeed be differential effects associated with specific air pollution control options, though all classes of consumers appear to benefit. While the results are drawn from a set of conditions representing yield changes only in the SJV, the results for many of the included commodities have broader implications, given that the markets for these commodities are national in scope. These implications/results should not necessarily be viewed as alternative welfare measures to the economic surplus changes reported earlier. However, decision-makers evaluating alternative environmental policies pertaining to agriculture may wish to consider the direction and magnitude of these other welfare effects. If such effects are deemed relevant to policy research, then consideration should be given to collection of data bases to better perform similar analyses in the future.

The extensive list of caveats attached to the results indicates that substantial improvement is needed in this area of agricultural policy analysis. While adequate analytical tools exist, data sets required to facilitate the analysis appear to be lacking, particularly on the producer side. This is also the case concerning the measurement of consumption and expenditure patterns by income classes, in the estimation of regional an seasonal price-forecasting equations, and in the differentiation of producers according to income classes.

Table A3-7
Statewide Price Changes by Crop By Scenario*

Crop	Price				Percent Change		
	Base ($/Ton)	Scenario 1 ($/Ton)	Scenario 2 ($/Ton)	Scenario 3 ($/Ton)	Scenario 1	Scenario 2	Scenario 3
Alfalfa	77.44	77.13	76.84	76.84	-0.004	-0.009	-0.009
Almonds	1955.5	1955.5	1955.5	1955.5	0.0	0.0	0.0
Apples	144.96	144.96	144.96	144.96	0.0	0.0	0.0
Asparagus (cwt)	38.66	38.66	38.66	38.66	0.0	0.0	0.0
Avocados	918.28	918.28	918.28	918.28	0.0	0.0	0.0
Barley (bushel)	3.05	3.04	3.04	3.04	-0.328	-0.328	-0.328
Beans (cwt)	32.61	32.43	32.27	32.20	-0.552	-1.043	-1.257
Cantaloupe (cwt)	13.21	13.21	13.21	13.21	0.0	0.0	0.0
Carrots (cwt)	8.04	8.04	8.04	8.03	0.0	0.0	-0.124
Cauliflower (cwt)	20.52	20.52	20.52	20.52	0.0	0.0	0.0
Corn (bushel)	3.83	3.83	3.83	3.83	0.0	0.0	0.0
Cotton (bushel)	0.70	0.70	0.70	0.70	0.0	0.0	0.0
Grain (Hay)	55.68	55.51	55.36	55.30	-0.305	-0.575	-0.682
Grain (Sorghum) (bushel)	3.54	3.54	3.54	3.54	0.0	0.0	0.0
Grapes	184.35	183.08	181.90	181.85	-0.689	-1.327	-1.355
Lemons	202.82	202.82	202.82	282.82	0.0	0.0	0.0
Lettuce	8.75	8.74	8.73	8.72	-0.114	-0.229	-0.343
Nectarines	282.34	282.34	282.34	282.34	0.0	0.0	0.0
Onions	6.78	6.78	6.78	6.78	0.0	0.0	0.0
Oranges	130.98	130.98	130.98	130.98	0.0	0.0	0.0
Pasture	29.79	29.51	29.25	29.15	-0.940	-1.813	-2.148
Peaches	14.75	14.75	14.75	14.75	0.0	0.0	0.0
Pears	159.31	159.31	159.31	159.31	0.0	0.0	0.0
Plums	365.40	365.40	365.40	365.40	0.0	0.0	0.0
Potatoes (cwt)	6.79	6.96	6.94	6.94	-0.143	-0.430	-0.430
Prunes	533.11	533.11	533.11	533.11	0.0	0.0	0.0
Rice (cwt)	11.76	11.76	11.76	11.76	0.0	0.0	0.0
Safflower	310.40	306.23	307.57	307.06	-0.377	-0.912	-1.076
Silage	17.79	17.67	17.56	17.51	-0.675	-1.293	-1.574
Sugar Beets	38.82	38.82	38.82	38.82	0.0	0.0	0.0
Tomatoes (Fresh) (cwt)	24.95	24.91	24.90	24.87	-0.160	-0.200	-0.321
Tomatoes (Packaging)	61.75	61.7	61.64	61.63	-0.081	-0.178	-0.194
Walnuts	766.34	766.34	766.34	766.34	0.0	0.0	0.0
Wheat (bushel)	4.15	4.15	4.15	4.15	0.0	0.0	0.0

*Prices per ton unless otherwise noted.

Table A3-8
Statewide Consumer's Surplus Charges by Crop By Scenario

Crop	Consumers' Surplus				Percent Change		
	Base ($ thous.)	Scenario 1 ($ thous.)	Scenario 2 ($ thous.)	Scenario 3 ($ thous.)	Scenario 1	Scenario 2	Scenario 3
Alfalfa	107186	109350	111406	111415	2.0	3.9	3.9
Almonds	84969	84969	84969	84969	0.0	0.0	0.0
Apples	5954	5964	5963	5963	0.2	0.2	0.2
Asparagus	2959	2959	2959	2959	0.0	0.0	0.0
Avocados	49163	49163	49162	49162	0.0	0.0	0.0
Barley	6043	5333	6628	6730	4.8	9.7	11.4
Beans	57834	58547	59154	59444	1.2	2.3	2.8
Cantaloupe	26089	26089	26088	26088	0.0	0.0	0.0
Carrots	31229	31265	31302	31326	0.1	0.2	0.3
Cauliflower	9034	9034	9032	9032	0.0	0.0	0.0
Corn	2057	2116	2171	2194	2.9	5.5	6.7
Cotton	19615	21048	24285	24877	7.3	23.8	26.8
Grain (Hay)	5101	51704	5241	5268	1.4	2.7	3.3
Grain (Sorghum)	468	473	477	480078	0.9	1.9	2.6
Grapes	244936	250264	255203	255407	2.2	4.2	4.3
Lemons	95735	95735	95734	95734	0.0	0.0	0.0
Lettuce	82986	830314	830644	830897	0.1	0.5	0.5
Nectarines	16888	16888	16887	16887	0.0	0.0	0.0
Onions	18111	18111	18110	18110	0.0	0.0	0.0
Oranges	229250	229250	229249	229249	0.0	0.0	0.0
Pasture	31357	32729	34066	34601	4.4	8.6	10.3
Peaches	28067	28067	28066	28066	0.0	0.0	0.0
Pears	16463	16463	16462	16462	0.0	0.0	0.0
Plums	24436	24436	24436	24436	0.0	0.0	0.0
Potatoes	39530	39838	40075	40096	0.8	1.4	1.4
Prunes	32461	32461	32460	32460	0.0	0.0	0.0
Rice	17537	17537	17536	17536	0.0	0.0	0.0
Safflower	32799	32991	33263	33347	0.6	1.4	1.7
Silage	9956	10274	10605	10723	3.2	6.5	7.7
Sugar Beets	40350	40350	40350	40350	0.0	0.0	0.0
Tomatoes Fresh)	185.08	185488	185584	185798	0.0	0.0	0.0
Tomatoes (Packaging)	48273	48520	48858	48944	0.5	1.2	1.4
Walnuts	20091	20091	20091	20091	0.0	0.0	0.0
Wheat	3357	3410	3461	3480	1.6	3.1	3.7

Table A3-9
San Joaquin Valley Consumers' Surplus Changes by Crop by Scenario

	Consumers' Surplus				Percent Change		
Crop	Base ($ thous.)	Scenario 1 ($ thous.)	Scenario 2 ($ thous.)	Scenario 3 ($ thous.)	Scenario 1	Scenario 2	Scenario 3
Alfalfa	53362	55485	57522	57522	3.98	7.8	7.8
Almonds	63012	63012	63012	63012	0.0	0.0	0.0
Apples	310	310	310	310	0.0	0.0	0.0
Asparagus	1879	1879	1879	1879	0.0	0.0	0.0
Avocados	654	654	654	654	0.0	0.0	0.0
Barley	4110	4362	4620	4709	6.13	12.41	14.57
Beans	34578	35376	36071	36387	2.31	4.32	5.23
Cantaloupe	16312	16312	16312	16312	0.0	0.0	0.0
Carrots	3962	10730	11435	11530	170.82	188.62	191.01
Cauliflower	1007	1007	1007	1007	0.0	0.0	0.0
Corn	1604	1657	1707	1727	3.30	6.42	7.67
Cotton	18402	19797	22949	23527	7.58	24.71	27.85
Grain (Hay)	1226	1289	1351	1376	5.14	10.20	12.23
Grain (Sorghum)	326	329	336	340	0.92	3.07	4.29
Grapes	225752	233806	239197	239417	3.57	5.96	6.05
Lemons	8315	8315	8315	8315	0.0	0.0	0.0
Lettuce	85206	89755	90807	94636	5.34	6.57	11.07
Nectarines	16889	16889	16889	16889	0.0	0.0	0.0
Onions	5708	5708	5708	5708	0.0	0.0	0.0
Oranges	144220	144220	144220	144220	0.0	0.0	0.0
Pasture	14160	15632	17085	17671	10.40	20.66	24.80
Peaches	18896	18896	18896	18896	0.0	0.0	0.0
Pears	6806	6806	6806	6806	0.0	0.0	0.0
Plums	23839	23839	23839	23839	0.0	0.0	0.0
Potatoes	16590	16989	17141	17179	2.41	3.32	3.55
Prunes	2548	2548	2548	2548	0.0	0.0	0.0
Rice	6113	6113	6113	6113	0.0	0.0	0.0
Safflower	19611	19847	20181	20284	1.20	2.91	3.43
Silage	8965	9290	9627	9747	3.63	7.38	8.72
Sugar Beets	21793	21793	21793	21793	0.0	0.0	0.0
Tomatoes (Fresh)	82283	73152	73350	73846	-11.1	-10.86	-10.25
Tomatoes (Packaging)	23312	23528	23823	23898	0.93	2.19	2.51
Walnuts	11884	11884	11884	11884	0.0	0.0	0.0
Wheat	1132	1169	1205	1218	3.27	6.45	7.60

Table A3-10
CAR Model Region 11 Consumers' Surplus Charges by Crop by Scenario

	Consumers' Surplus				Percent Change		
Crop	Base ($ thous.)	Scenario 1 ($ thous.)	Scenario 2 ($ thous)	Scenario 3 ($ thous.)	Scenario 1	Scenario 2	Scenario 3
Alfalfa	19285	20368	21448	21448	5.62	11.22	11.22
Almonds	18347	18347	18347	18347	0.0	0.0	0.0
Apples	310	310	310	310	0.0	0.0	0.0
Asparagus	--	--	--	--	--	--	--
Avocados	--	--	--	--	--	--	--
Barley	2495	2663	2836	2891	6.73	13.67	15.87
Beans	3743	3862	3967	4019	3.18	5.98	7.37
Cantaloupe	12975	12975	12975	12975	0.0	0.0	0.0
Carrots	3962	10730	11435	11530	170.82	188.62	191.01
Cauliflower	--	--	--	--	--	--	--
Corn	74	76	79	80	2.95	7.12	8.23
Cotton	13354	14360	16603	17011	7.53	24.33	27.39
Grain (Hay)	277	288	298	301	3.97	7.58	8.66
Grain (Sorghum)	102	104	107	107	1.96	4.90	4.90
Grapes	36292	37545	38576	38604	3.45	6.29	6.37
Lemons	3240	3240	3240	3240	0.0	0.0	0.0
Lettuce	85206	89755	90807	94636	5.34	6.57	11.07
Nectarines	1428	1428	1428	1428	0.0	0.0	0.0
Onions	5654	5654	5654	5654	0.0	0.0	0.0
Oranges	19137	19137	19137	19137	0.0	0.0	0.0
Pasture	834	1024	1227	1282	22.78	47.12	53.72
Peaches	1458	1458	1458	1458	0.0	0.0	0.0
Pears	--	--	--	--	--	--	--
Plums	1821	1821	1821	1821	0.0	0.0	0.0
Potatoes	14751	15052	15283	15284	2.04	3.61	3.61
Prunes	--	--	--	--	--	--	--
Rice	4656	4656	4656	4656	0.0	0.0	0.0
Safflower	11977	12173	12449	12552	1.64	3.94	4.80
Silage	580	605	664	673	4.31	14.48	16.03
Sugar Beets	5006	5006	5006	5006	0.0	0.0	0.0
Tomatoes (Fresh)	1839	1849	1869	1875	0.54	1.63	1.96
Tomatoes (Packaging)	8718	8813	8945	8995	1.09	2.60	3.18
Walnuts	784	784	784	784	0.0	0.0	0.0
Wheat	337	351	365	369	4.15	8.31	9.50

Table A3-11
CAR Model Region 10 Consumers' Surplus Charges by Crop by Scenario

Crop	Consumers' Surplus				Percent Change		
	Base ($ thous.)	Scenario 1 ($ thous.)	Scenario 2 ($ thous.)	Scenario 3 ($ thous.)	Scenario 1	Scenario 2	Scenario 3
Alfalfa	18284	18905	19466	19466	3.40	6.46	6.46
Almonds	13222	13222	13222	13222	0.0	0.0	0.0
Apples	--	--	--	--	--	--	--
Asparagus	--	--	--	--	--	--	--
Avocados	654	654	654	654	0.0	0.0	0.0
Barley	905	953	1005	1027	5.3	11.05	13.48
Beans	5032	5187	5320	5380	3.08	5.72	6.92
Cantaloupe	--	--	--	--	--	--	--
Carrots	--	--	--	--	--	--	--
Cauliflower	592	592	592	592	0.0	0.0	0.0
Corn	172	180	188	192	4.65	9.30	11.63
Cotton	4204	4534	5310	5453	7.85	26.31	29.71
Grain (Hay)	168	174	203	212	9.52	20.83	26.19
Grain (Sorghum)	71	71	73	73	0.0	2.82	2.82
Grapes	142899	146584	150338	150511	2.58	5.21	5.33
Lemons	5075	5075	5075	5075	0.0	0.0	0.0
Lettuce	--	--	--	--	--	--	--
Nectarines	15194	15194	15194	15194	0.0	0.0	0.0
Onions	--	--	--	--	--	--	--
Oranges	125083	125083	125083	125083	0.0	0.0	0.0
Pasture	3203	3644	4166	4410	13.77	30.07	37.68
Peaches	5139	5139	5139	5139	0.0	0.0	0.0
Pears	--	--	--	--	--	--	--
Plums	21962	21962	21962	21962	0.0	0.0	0.0
Potatoes	--	--	--	--	--	--	--
Prunes	1935	1935	1935	1935	0.0	0.0	0.0
Rice	134	134	134	134	0.0	0.0	0.0
Safflower	--	--	--	--	--	--	--
Silage	1342	1404	1470	1505	5.07	9.54	12.15
Sugar Beets	2569	2569	2569	2569	0.0	0.0	0.0
Tomatoes (Fresh)	29455	30312	30323	30832	2.91	2.95	4.67
Tomatoes (Packaging)	344	350	351	354	1.74	2.03	2.91
Walnuts	3621	3621	3621	3621	0.0	0.0	0.0
Wheat	256	265	275	279	3.52	7.42	8.98

Table A3-12
CAR Model Region 8 Consumers' Surplus Charges by Crop by Scenario

Crop	Consumers' Surplus Base ($ thous.)	Consumers' Surplus Scenario 1 ($ thous.)	Consumers' Surplus Scenario 2 ($ thous.)	Consumers' Surplus Scenario 3 ($ thous.)	Percent Change Scenario 1	Percent Change Scenario 2	Percent Change Scenario 3
Alfalfa	7980	8179	8365	8365	2.49	4.82	4.82
Almonds	19493	19493	19493	19493	0.0	0.0	0.0
Apples	--	--	--	--	--	--	--
Asparagus	--	--	--	--	--	--	--
Avocados	--	--	--	--	--	--	--
Barley	306	324	340	346	5.88	11.11	13.07
Beans	15198	15471	15712	15842	1.80	3.38	4.24
Cantaloupe	3337	3337	3337	3337	0.0	0.0	0.0
Carrots	--	--	--	--	--	--	--
Cauliflower	415	415	415	415	0.0	0.0	0.0
Corn	147	153	158	160	4.08	7.48	8.84
Cotton	844	903	1036	1063	6.99	22.75	25.95
Grain (Hay)	781	817	850	863	4.61	8.83	10.5
Grain (Sorghum)	112	113	114	115	0.89	1.79	2.68
Grapes	9344	9625	9811	9826	3.01	5.00	5.16
Lemons	--	--	--	--	--	--	--
Lettuce	--	--	--	--	--	--	--
Nectarines	267	267	267	267	0.0	0.0	0.0
Onions	54	54	54	54	0.0	0.0	0.0
Oranges	--	--	--	--	--	--	--
Pasture	5821	6287	6706	6864	8.01	15.20	13.76
Peaches	10148	10148	10148	10148	0.0	0.0	0.0
Pears	--	--	--	--	--	--	--
Plums	--	--	--	--	--	--	--
Potatoes	--	--	--	--	--	--	--
Prunes	613	613	613	613	0.0	0.0	0.0
Rice	594	594	594	594	0.0	0.0	0.0
Safflower	488	494	498	500	1.23	2.05	2.46
Silage	4779	4943	5093	5144	3.43	6.57	7.64
Sugar Beets	3576	3576	3576	3576	0.0	0.0	0.0
Tomatoes (Fresh)	27363	17339	17386	17391	-36.63	-36.46	-36.44
Tomatoes (Packing)	2994	3019	3046	3054	0.84	1.74	2.00
Walnuts	3965	3965	3965	3965	0.0	0.0	0.0
Wheat	85	88	90	91	3.53	5.88	7.06

Table A3-13
CAR Model Region 3 (San Joaquin County) Consumers' Surplus Charges by Crop for Each Scenario

Crop	Consumers' Surplus				Percent Change		
	Base ($ thous.)	Scenario 1 ($ thous.)	Scenario 2 ($ thous.)	Scenario 3 ($ thous.)	Scenario 1	Scenario 2	Scenario 3
Alfalfa	7813	8033	8243	8243	2.82	5.50	5.50
Almonds	11950	11950	11950	11950	0.0	0.0	0.0
Apples	--	--	--	--	--	--	--
Asparagus	1879	1879	1879	1879	0.0	0.0	0.0
Avocados	--	--	--	--	--	--	--
Barley	404	422	439	445	4.46	8.66	12.62
Beans	10605	10856	11072	11146	2.37	4.40	5.10
Cantaloupe	--	--	--	--	--	--	--
Carrots	--	--	--	--	--	--	--
Cauliflower	--	--	--	--	--	--	--
Corn	1211	1248	1282	1295			
Cotton	--	--	--	--	--	--	--
Grain (Hay)	--	--	--	--	--	--	--
Grain (Sorghum)	41	41	42	42	0.0	2.44	2.44
Grapes	37217	40052	40472	40476	7.62	8.75	8.76
Lemons	--	--	--	--	--	--	--
Lettuce	--	--	--	--	--	--	--
Nectarines	--	--	--	--	--	--	--
Onions	--	--	--	--	--	--	--
Oranges	--	--	--	--	--	--	--
Pasture	4302	4677	4986	5115	8.72	15.90	18.90
Peaches	2151	2151	2151	2151	0.0	0.0	0.0
Pears	6806	6806	6806	6806	0.0	0.0	0.0
Plums	56	56	56	56	0.0	0.0	0.0
Potatoes	1839	1937	1858	1895	5.33	1.30	3.05
Prunes	--	--	--	--	--	--	--
Rice	729	729	729	729	0.0	0.0	0.0
Safflower	7146	7180	8234	8232	0.48	1.23	1.20
Silage	2264	2338	2400	2425	3.27	6.01	7.11
Sugar Beets	10642	10642	10642	10642	0.0	0.0	0.0
Tomatoes (Fresh)	23626	23652	23772	23748	0.11	0.62	0.52
Tomatoes (Packaging)	11256	11346	11481	11495	0.80	2.00	2.12
Walnuts	3514	3514	3514	3514	0.0	0.0	0.0
Wheat	454	465	475	479	2.42	4.63	5.51

Table A3-14
Statewide Producers' Surplus Charges by Crop by Scenario

Crop	Producers' Surplus				Percentage Change		
	Base ($ thous.)	Scenario 1 ($ thous.)	Scenario 2 ($ thous.)	Scenario 3 ($ thous.)	Scenario 1	Scenario 2	Scenario 3
Alfalfa	141809	144816	147826	147826	2.1	4.2	4.2
Almonds	108387	108404	108442	108449	0.0	0.0	0.0
Apples	5452	5453	5453	5453	0.0	0.0	0.0
Asparagus	7701	7702	7702	7702	0.0	0.0	0.0
Avocados	35959	35959	35959	35959	0.0	0.0	0.0
Barley	38029	39598	41245	41817	4.1	8.5	10.0
Beans	39259	39687	40074	40249	1.1	2.1	2.5
Cantaloupe	17466	17468	18474	17475	0.0	0.0	0.0
Carrots	7750	7778	7805	7829	0.4	0.7	1.0
Cauliflower	7012	7013	7013	7013	0.0	0.0	0.0
Corn	40476	41526	42513	42905	2.6	5.0	6.0
Cotton	235398	251149	286709	293207	6.7	21.8	24.5
Grain (Hay)	3793	3863	3933	3960	1.8	3.7	4.4
Grain (Sorghum)	9673	9744	9837	9876	0.7	1.7	2.1
Grapes	180910	185240	189210	189380	2.4	4.6	4.7
Lemons	37519	37520	37522	37522	0.0	0.0	0.0
Lettuce	67190	67192	67206	67214	0.0	0.0	0.0
Nectarines	6806	6807	6809	6809	0.0	0.0	0.0
Onions	18617	18618	18622	18622	0.0	0.0	0.0
Oranges	40073	40084	40105	40106	0.0	0.1	0.1
Pasture	35448	36363	37311	37678	2.6	5.3	6.3
Peaches	18859	18864	18873	18875	0.0	0.1	0.1
Pears	11838	11840	11843	11844	0.0	0.1	0.1
Plums	18353	18355	18359	18359	0.0	0.0	0.0
Potatoes	30854	31261	31587	31614	1.3	2.4	2.5
Prunes	18804	18806	18808	18808	0.0	0.0	0.0
Rice	10271	102740	102781	102791	0.0	0.1	0.1
Safflower	15137	15194	15284	15306	0.4	1.0	1.1
Silage	9238	9459	9669	9749	2.4	4.7	5.5
Sugar Beets	67993	68003	68022	68026	0.0	0.0	0.0
Tomatoes (Fresh)	54165	54179	54216	54216	0.0	0.1	0.1
Tomatoes (Packaging)	96404	96869	97514	97676	0.5	1.2	1.5
Walnuts	41267	41277	41295	41297	0.0	0.0	0.0
Wheat	60462	61244	62028	62313	1.3	2.6	3.1

Table A3-15
Statewide Acreage Shifts by Crop by Scenario

	Acreage				Percentage Change		
Crop	Base	Scenario 1	Scenario 2	Scenario 3	Scenario 1	Scenario 2	Scenario 3
Alfalfa	1091660	1075876	1059689	1059688	-1.5	-3.0	-3.0
Almonds	295106	295106	295106	295106	0.0	0.0	0.0
Apples	19456	19456	19456	19456	0.0	0.0	0.0
Asparagus	26845	26845	26845	26845	0.0	0.0	0.0
Avocados	37689	37689	37689	37689	0.0	0.0	0.0
Barley	946900	945543	942845	941336	-0.1	-0.4	-0.6
Beans	195510	188808	182796	180007	-3.4	-6.5	-7.9
Cantaloupe	55809	55809	55809	55809	0.0	0.0	0.0
Carrots	34214	34028	33839	33653	-0.5	-1.1	-1.6
Cauliflower	29605	29605	29605	29605	0.0	0.0	0.0
Corn	29332	391592	289942	289224	-0.6	-1.2	-1.4
Cotton	1498985	1483144	1430551	1419393	-1.1	-4.6	-5.3
Grain (Hay)	22863	227349	225794	225164	-0.7	-1.3	-1.6
Grain (Sorghum)	137345	137396	137466	137474	0.0	0.1	0.1
Grapes	618209	600019	583037	582300	-2.9	-5.7	-5.8
Lemons	47795	47795	47795	47795	0.0	0.0	0.0
Lettuce	173832	173049	172419	171916	-0.5	-0.8	-1.1
Nectarines	14573	14573	14573	14573	0.0	0.0	0.0
Onions	32866	32866	32866	32866	0.0	0.0	0.0
Oranges	186733	186733	186733	186733	0.0	0.0	0.0
Pasture	1026190	1027788	1028347	1026520	0.2	0.1	0.0
Peaches	65849	65849	65849	65849	0.0	0.0	0.0
Pears	35491	35491	35491	35491	0.0	0.0	0.0
Plums	26111	26111	26111	26111	0.0	0.0	0.0
Potatoes	49751	48485	47466	47378	-2.5	-4.6	-4.8
Prunes	71342	71342	71342	71342	0.0	0.0	0.0
Rice	498591	498592	498592	498592	0.0	0.0	0.0
Safflower	150545	149189	147194	146658	-0.9	-2.2	-2.6
Silage	130074	129096	128224	127822	-0.8	-1.4	-1.7
Sugar Beets	196578	196578	196578	196578	0.0	0.0	0.0
Tomatoes (Fresh)	30280	29979	29748	29635	-1.0	-1.8	-2.1
Tomatoes (Packaging)	236464	234792	232485	231930	-0.7	-1.7	-1.9
Walnuts	179048	179048	179048	179048	0.0	0.0	0.0
Wheat	713050	710077	706994	705680	-0.4	-0.9	-1.0
State Total	9374681	9305698	9197261	9175266	-0.7	-1.9	-2.1

Table A3-16
San Joaquin Valley Acreage Shifts by Crop by Scenario

Crop	Acreage				Percentage Change		
	Base	Scenario 1	Scenario 2	Scenario 3	Scenario 1	Scenario 2	Scenario 3
Alfalfa	539593	529045	517805	517804	-2.0	-4.0	-4.0
Almonds	215239	215239	215239	215239	0.0	0.0	0.0
Apples	1390	1390	1390	1390	0.0	0.0	0.0
Asparagus	18540	18540	18540	18540	0.0	0.0	0.0
Avocados	687	687	687	687	0.0	0.0	0.0
Barley	557134	557364	556253	555279	0.0	-0.2	-0.3
Beans	107069	99063	96970	93519	-7.5	-9.4	-12.7
Cantaloupe	37345	37345	37345	37345	0.0	0.0	0.0
Carrots	11385	11253	11120	10971	-1.2	-2.3	-3.6
Cauliflower	2790	2790	2790	2790	0.0	0.0	0.0
Corn	228940	227260	225657	224958	-0.7	-1.4	-1.7
Cotton	1401745	1386206	1334260	1323215	-1.1	-4.8	-5.6
Grain (Hay)	63368	63939	64310	64424	0.9	1.5	1.7
Grain (Sorghum)	66000	66067	67956	66173	0.1	3.0	2.6
Grapes	489406	473803	458609	458419	-3.2	-6.3	-6.3
Lemons	8335	8335	8335	8335	0.0	0.0	0.0
Lettuce	18071	17815	17570	17360	-1.4	-2.8	-3.9
Nectarines	14573	14573	14573	14573	0.0	0.0	0.0
Onions	14864	14864	14864	14864	0.0	0.0	0.0
Oranges	124973	124973	124973	124973	0.0	0.0	0.0
Pasture	441200	458557	473163	478275	3.9	7.2	8.4
Peaches	45663	45663	45663	45663	0.0	0.0	0.0
Pears	11720	11720	11720	11720	0.0	0.0	0.0
Plums	24747	24747	24747	24747	0.0	0.0	0.0
Potatoes	25590	24447	23522	23442	-4.5	-8.1	-8.4
Prunes	9083	9083	9083	9083	0.0	0.0	0.0
Rice	56516	56516	56516	56516	0.0	0.0	0.0
Safflower	83763	82829	81432	81081	-1.1	-2.8	-3.2
Silage	117691	116981	116384	116080	-0.6	-1.1	-1.4
Sugar Beets	102529	102529	102529	102529	0.0	0.0	0.0
Tomatoes (Fresh)	14522	14279	14061	13978	-1.7	-3.2	-3.8
Tomatoes (Packaging)	113868	112356	110263	109765	-1.3	-3.2	-3.6
Walnuts	99661	99661	99661	99661	0.0	0.0	0.0
Wheat	219935	217206	214364	213135	-1.2	-2.5	-3.1

Table A3-17

Acreage Shifts by CAR Model Region in the San Joaquin Valley by Crop by Scenario

	Acreage				Percent Change		
	Base	Scenario 1	Scenario 2	Scenario 3	Scenario 1	Scenario 2	Scenario 3
Region 11 Total	2096042	2090304	2048061	2040497	-0.3	-2.3	-2.7
Region 10 Total	1308803	1295140	1270837	1269756	-1.0	-2.9	-3.0
Region 8 Total	786217	776426	774049	771915	-1.3	-1.6	-1.8
Region 3 Total	932921	924065	913655	908683	-1.0	-2.1	-.2.6
SJV Total	5123983	5085935	5006602	4990851	-0.7	-2.3	-2.6

Table A3-18

CAR Model Region 11 Acreage Shifts by Crop by Scenario

	Acreage				Percent Change		
Crop	Base	Scenario 1	Scenario 2	Scenario 3	Scenario 1	Scenario 2	Scenario 3
Alfalfa	214603	212835	210227	210226	-0.8	-2.0	-2.0
Almonds	64196	64196	64196	64196	0.0	0.0	0.0
Apples	1390	1390	1390	1390	0.0	0.0	0.0
Asparagus	--	--	--	--	--	--	--
Avacados	--	--	--	--	--	--	--
Barley	330634	332673	333754	333829	0.6	0.9	1.0
Beans	11980	11409	11879	10614	-4.8	-9.2	-11.4
Cantaloupe	29110	29110	29110	29110	0.0	0.0	0.0
Carrots	11385	11253	11120	10971	-1.2	-2.3	-3.6
Cauliflower	--	--	--	--	--	--	--
Corn	11050	11049	11043	11039	-0.0	-0.1	-0.1
Cotton	976800	966865	933230	926176	-1.0	-4.5	-5.2
Grain (Hay)	6500	6460	6412	6390	-0.6	-1.4	-1.7
Grain (Sorghum)	32140	32297	32487	32557	0.5	1.1	1.3
Grapes	79722	76984	74391	74298	-3.4	-6.7	-6.8
Lemons	3591	3591	3591	3591	0.0	0.0	0.0
Lettuce	17021	16769	16527	16320	-1.5	-2.9	-4.1
Nectarines	1497	1497	1497	1497	0.0	0.0	0.0
Onions	12634	12634	12634	12634	0.0	0.0	0.0
Oranges	21521	21521	21521	21521	0.0	0.0	0.0
Pasture	22500	26102	29535	30288	16.0	31.3	34.6
Peaches	4209	4209	4209	4209	0.0	0.0	0.0
Pears	--	--	--	--	--	--	--
Plums	2793	2793	2793	2793	0.0	0.0	0.0
Potatoes	23500	22502	21710	21704	-4.2	-7.6	-7.6
Prunes	--	--	--	--	--	--	--
Rice	15865	15865	15865	15865	0.0	0.0	0.0
Safflower	52200	51762	51095	50863	-.8	-2.1	-2.6
Silage	8360	8455	8897	8915	1.1	6.4	6.6
Sugar Beets	24126	24126	24126	24126	0.0	0.0	0.0
Tomatoes (Fresh)	550	541	530	525	-1.7	-3.7	-4.6
Tomatoes (Packaging)	43030	42456	41641	41325	-1.3	-3.2	-4.0
Walnuts	5400	5400	5400	5400	0.0	0.0	0.0
Wheat	67735	67569	67251	67125	-0.3	-0.7	-0.9

Table A3-19
CAR Model Region 10 Acreage Shifts by Crop by Scenario

	Acreage				Percent Change		
Crop	Base	Scenario 1	Scenario 2	Scenario 3	Scenario 1	Scenario 2	Scenario 3
Alfalfa	176750	171900	167152	167152	-2.7	-5.4	-5.4
Almonds	39897	39897	39897	39897	0.0	0.0	0.0
Apples	--	--	--	--	--	--	--
Asparagus	--	--	--	--	--	--	--
Avocados	687	687	687	687	0.0	0.0	0.0
Barley	120900	120109	118969	118381	-0.7	-1.6	-2.1
Beans	17630	16643	15745	15319	-5.6	-10.7	-13.1
Cantaloupe	--	--	--	--	--	--	--
Carrots	--	--	--	--	--	--	--
Cauliflower	2575	2575	2575	2575	0.0	0.0	0.0
Corn	29370	29449	29481	29479	0.3	0.4	0.4
Cotton	355345	350924	335970	332769	-1.2	-5.5	-6.4
Grain (Hay)	7025	7396	7762	7917	5.3	10.5	12.7
Grain (Sorghum)	20860	20826	20776	20747	-0.2	-0.4	-0.5
Grapes	314075	304508	294651	294717	-3.0	-6.2	-6.2
Lemons	4744	4744	4744	4744	0.0	0.0	0.0
Lettuce	--	--	--	--	--	--	--
Nectarines	12816	12816	12816	12816	0.0	0.0	0.0
Onions	--	--	--	--	--	--	--
Oranges	103452	103452	103452	103452	0.0	0.0	0.0
Pasture	98000	105129	112821	116141	17.3	15.1	18.5
Peaches	13848	13848	13848	13848	0.0	0.0	0.0
Pears	--	--	--	--	--	--	--
Plums	21662	21662	21662	21662	0.0	0.0	0.0
Potatoes	--	--	--	--	--	--	--
Prunes	4090	4090	4090	4090	0.0	0.0	0.0
Rice	4270	4270	4270	4270	0.0	0.0	0.0
Safflower	--	--	--	--	--	--	--
Silage	18540	18562	18559	18608	0.1	0.1	0.4
Sugar Beets	11564	11564	11564	11564	0.0	0.0	0.0
Tomatoes (Fresh)	3962	3921	3917	3889	-1.0	-1.1	-1.8
Tomatoes(Packaging)	1868	1826	1821	1796	-2.3	-2.5	-3.9
Walnuts	31535	31535	31535	31535	0.0	0.0	0.0
Wheat	57200	56669	55935	55563	-0.1	-2.2	-2.9

Table A3-20
CAR Model Region 8 Acreage Shifts by Crop by Scenario

	Acreage				Percent Change		
Crop	Base	Scenario 1	Scenario 2	Scenario 3	Scenario 1	Scenario 2	Scenario 3
Alfalfa	76900	73269	75063	73269	-4.7	-2.4	-4.7
Almonds	76911	76911	76911	76911	0.0	0.0	0.0
Apples	--	--	--	--	--	--	--
Asparagus	--	--	--	--	--	--	--
Avocados	--	--	--	--	--	--	--
Barley	50200	50169	50258	50110	-0.1	0.1	-0.2
Beans	42509	37909	40080	36758	-10.8	-5.7	-13.5
Cantaloupe	8235	8235	8235	8235	0.0	0.0	0.0
Carrots	--	--	--	--	--	--	--
Cauliflower	215	215	215	215	0.0	0.0	0.0
Corn	25220	25127	25187	25099	-0.4	-0.1	-0.5
Cotton	69600	65060	68417	64270	-6.5	-1.7	-7.7
Grain (Hay)	27473	27487	27518	27458	0.1	0.2	-0.1
Grain (Sorghum)	3300	3282	3291	3278	-0.5	-0.3	-0.7
Grapes	38686	36714	37566	-5.1	-2.9	-5.3	
Lemons	--	--	--	--	--	--	--
Lettuce	--	--	--	--	--	--	--
Nectarines	260	260	260	260	0.0	0.0	0.0
Onions	360	360	360	360	0.0	0.0	0.0
Oranges	--	--	--	--	--	--	--
Pasture	78100	183295	181401	183751	2.9	1.9	3.2
Peaches	22466	22466	22466	22466	0.0	0.0	0.0
Pears	--	--	--	--	--	--	--
Plums	--	--	--	--	--	--	--
Potatoes	--	--	--	--	--	--	--
Prunes	1196	1196	1196	1196	0.0	0.0	0.0
Rice	16241	16241	16241	16241	0.0	0.0	0.0
Safflower	2463	2391	2430	2379	-2.9	-1.3	-3.4
Silage	62991	61767	62452	61518	-1.9	-0.9	-2.3
Sugar Beets	16575	16575	16575	16575	0.0	0.0	0.0
Tomatoes (Fresh)	5100	4901	4993	4866	-3.9	-2.1	-4.6
Tomatoes (Packaging)	13900	13463	13683	13396	-3.1	-1.6	-3.6
Walnuts	31316	31316	31316	31316	0.0	0.0	0.0
Wheat	16000	15440	15712	15333	-3.5	-1.8	-4.2

Table A3-21
CAR Model Region 3 (San Joaquin County)
Acreage Shifts by Crop by Scenario

	Acreage				Percent Change		
Crop	Base	Scenario 1	Scenario 2	Scenario 3	Scenario 1	Scenario 2	Scenario 3
Alfalfa	71340	69247	67157	67157	-2.9	-5.9	-5.9
Almonds	34235	34235	34235	34235	0.0	0.0	0.0
Apples	--	--	--	--	--	--	--
Asparagus	18540	18540	18540	18540	0.0	0.0	0.0
Avocados	--	--	--	--	--	--	--
Barley	55400	54324	55361	52959	-1.9	-3.7	-4.4
Beans	34950	33102	31437	30828	-5.3	-10.1	-11.8
Cantaloupe	--	--	--	--	--	--	--
Carrots	--	--	--	--	--	--	--
Cauliflower	--	--	--	--	--	--	--
Corn	163300	166575	160006	159341	-1.1	-2.0	-2.4
Cotton	--	--	--	--	--	--	--
Grain (Hay)	223700	22565	22649	22659	0.9	1.2	1.3
Grain (Sorghum)	9700	9653	9611	9591	-0.5	-0.9	-1.1
Grapes	56923	54745	52853	52749	-3.8	-7.2	-7.4
Lemons	--	--	--	--	--	--	--
Lettuce	1050	1046	1043	1040	-0.4	-0.7	-0.9
Nectarines	--	--	--	--	--	--	--
Onions	1870	1870	1870	1870	0.0	0.0	0.0
Oranges	--	--	--	--	--	--	--
Pasture	142600	145925	147512	148095	2.3	3.4	3.9
Peaches	5140	5140	5140	5140	0.0	0.0	0.0
Pears	11720	11720	11720	11720	0.0	0.0	0.0
Plums	292	292	292	292	0.0	0.0	0.0
Potatoes	2090	1945	1812	1738	-7.0	3.3	-16.8
Prunes	3797	3797	3797	3797	0.0	0.0	0.0
Rice	20140	20140	20140	20140	0.0	0.0	0.0
Safflower	29100	28637	27946	27839	-1.6	-4.0	-4.3
Silage	27800	27512	27161	27039	-1.0	-2.3	-2.7
Sugar Beets	50174	50174	50174	50174	0.0	0.0	0.0
Tomatoes (Fresh)	4910	4824	4713	4698	-1.7	-4.0	-4.3
Tomatoes (Packaging)	55070	54391	53338	53248	-1.2	-3.1	-3.3
Walnuts	31410	31410	31410	31410	0.0	0.0	0.0
Wheat	79000	77256	75738	75114	-2.2	-4.1	-4.9

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APPENDIX A4

ABBREVIATIONS, ACRONYMS AND GLOSSARY OF SELECTED TERMS*

A4.1 ABBREVIATIONS AND ACRONYMS

(See also Table 4.6, attached, for definition of regression variables.)

AP	air pollution
APCD	air pollution control district
ARB	Air Resources Board
ATP	adenosine triphosphate
BOR	Bureau of Reclamation
CAC	County Agricultural Commissioner
CAR	California Agricultural Resources Model
CARB	California Air Resources Board
CDFA	California Department of Food and Agriculture
CDM	EPA's Climatological Dispersion Model
CF	carbon filtered air
CS	consumer's surplus
D	demand
DWR	Department of Water Resources
EPA	Environmental Protection Agency
LP	linear programming
MVP	marginal value product
NCC	National Climatic Center
NCLAN	National Crop Loss Assessment Network
NF	nonfiltered air
O_3	ozone
OCS	ordinary consumer's surplus
ORBES	Ohio River Basin Energy Study
PPHM	parts per hundred million
PR	producer's rent
QP	quadratic programming
R^2	coefficient of determination
S	supply
SCS	Soil Conservation Service
SJV	San Joaquin Valley
SNAAQS	Secondary National Ambient Air Quality Standards
SO_2	sulfur dioxide
USDA	United States Department of Agriculture
USGS	United States Geological Survey
WTP	Willingness to pay
ZAPS	zonal air pollution study

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* Materials for this Appendix contributed by Malcolm Dole of the California Air Resources Board.

Table 4-6

Regression Variables

Variable Name	Source	Explanation
COUNTY		1 = Fresno, 2 = Kern, 3 = Kings, 4 = Madera, 5 = Merced, 6 = San Joaquin 7 = Stanislaus, 8 = Tulare
YEAR		1970 - 1981: Code as 70-81
YIELD	1,2	Yield per harvested acre in tons
HACRE	1,2	Harvested acres
CHACRE		Change in harvested acres from the prior year
PRICE	1	Crop price per unit weight (generally tons)
APRICE	1,4	Real crop prices: PRICE divided by an index of prices paid by farmers for all production commodities
N	3	Nitrogen, 10^3 tons. Amount used in the county and year.
P	3	Phosphorous, 10^3 tons. Amount used in the county and year.
K	3	Potassium, 10^3 tons. Amount used in the county and year.
PROD	4	U.S. output index divided by crop harvested acres (10^6).
03AVE	5	Sum of the monthly mean 0_3 level during the growing season.
03GE10	5	Sum of the hours over the growing season with $0_3 \geq 10$ pphm.
03DOS	5	Total dose over the growing season for hours with $0_3 \geq 10$ pphm.
036E6	5	Sum of the hours over the growing season with $0_3 \geq 6$ pphm.
SO2AVE	5	Sum of the monthly mean SO_2 level over the growing season.
SO2GE10	5	Sum of the hours over the growing season with $SO_2 \geq 10$ pphm.
SO2DOS	5	Total dose over the growing season for hours with $SO_2 \geq 10$ pphm.
TEMP	6	Sum of the monthly average temperatures over the growing season months.
COLD	6	Number of hours with TEMP 32^oF. over the growing season.
HOT	6	Number of days in which temperature exceeded 95^oF during each month.
HUMID	6	Average monthly relative humidity.
RAIN	6	Monthly average daily precipitation summed over the growing season months.
LABOR	4	Farm labor index per acre - Pacific Region.
MACH	4	Mechanical power and machinery index - Pacific Region.
EMP	7	Man-weeks per acre of non-harvest labor for cotton and vineyards.
PREMP		Labor productivity per acre = EMP x LAPROD.
LAPROD	4	Index of production per labor hour for U.S. fruits, nuts, and cotton.
Y70-Y81	8	Yearly dummy variables. For example, Y78 = 1 if year = 1978; Y78=0 otherwise.
C1-C8	8	County dummy variable. For example, C1 = 1 if Fresno County; C1 = 0 otherwise.

See Table 4-6 on page 4-24

A4.2 GLOSSARY OF SELECTED TERMS

consumer's surplus -- the difference between what a consumer would be willing to pay rather than do without each unit of a good and what the consumer actually pays for each unit of the good.

cross price elasticity -- a measure of the influence of the price of one good on the demand for another.

centroid of a superquad -- point at which the four 7.5 quads of a superquad meet.

degrees of freedom -- the number of linearly independent observations in a set of n observations or n minus the number of restrictions placed on the entire data set.

demand curve -- a curve showing the quantity of a good or a service that a utility maximizing consumer or consumers with a given income level will demand at each price.

distributed lags -- refers to when the effects of the independent variables on the dependent variables are spread over time.

dose -- concentration of a pollutant times its duration of exposure.

economic surplus -- the sum of consumer's plus producer's surplus.

elasticity -- the relative response of one variable to a small percentage change in another variable. When the producer or consumer is relatively (un)responsive to price changes, the elasticity is said to be price (in)elastic. The price elasticity is defined as the percentage change in the quantity purchased divided by the percentage change in price.

elasticity of supply -- the relative responsiveness of a producer supplying commodities or services divided by the percentage change in price

factor input -- an economic resource which goes into the production of a good.

heteroskedasticity -- occurs when the variances of the error term are not constant over the sample region.

income effect -- a term used in demand analysis to indicate the increase or decrease in the amount of a good that is purchased because of a price-induced change in the purchasing power of a fixed income.

income substitution effect -- indicates the increase or decrease in the amount of a good that is purchased because of a price induced change in the purchasing power of a fixed income.

inelastic elasticity -- (see elasticity).

input-output coefficients -- represent the amount of input required to produce a unit of output.

least squares -- an estimation method which calculates the points whose distances squared to the observations have the minimum total.

lognormal distribution -- the continuous probability distribution of a variable whose log values have a bell-shaped normal distribution.

marginal physical product -- the addition to total output due to the addition of the last unit of an input, when the amount of all other inputs are held constant.

multicollinearity -- when estimating a linear regression equation the independent variables may be correlated with each other as well as with the selected dependent variable.

New Source Performance Standards -- establish allowable emission limitations for categories of emission sources and requires meeting a percentage reduction for those categories.

Ordinary consumer's surplus -- (see consumer's surplus).

peak growing season -- April through October

perfect competition -- an idealized market condition where there is perfect information, many buyers and sellers, and the product is homogenous so that no single buyer or seller can influence the price.

pollution episode -- occurs when the accumulation of air pollutants has attained levels which could, if sustained or exceeded, lead to a substantial threat to the health and welfare of the population.

price effects -- the change in the amount of consumption or production produced by a change in price.

principle component analysis -- a statistical technique which reduces the number of explanatory variables to a subset that captures the most variation of the dependent variable.

producer's rent -- the return on capital

producer's surplus -- the difference between the price that a producer sells a good or service for and the amunt that he would be willing to sell for rather than not provide the good.

production function -- the combination of land, labor, materials and equipment needed to produce different levels of output.

quasi-rents -- returns above costs.

quad -- a 7.5 minute quadrangle

robust -- a criteria which relates to the sensitivity of point estimation and other inference procedures to departures from specifying assumptions regarding models and prior distributions and to unusual or outlying data.

serial correlation -- when the error terms are not independent of each other.

statistical confidence intervals -- this interval is a probabilistic estimate of a range in which the population (as opposed to the sample) coefficient may lie with a certain statistical probability.

superquad -- four 7.5 minute quadrangles.

supply curve -- a typical short run or long run supply curve represents the marginal cost of production and equals the minimum monetary compensation a producer will accept and still supply the commodity.

t-test -- a procedure which tests a hypothesis based on a sample estimation against an alternative using the t-ratio (estimated parameter divided by its standard error).

unstable regression coefficients -- when the estimated parameters (coefficients) of an equation do not consistently pass the significance test over samples or for which the estimated value changes dramatically across alternative specifications.

welfare measure of a price change -- change in consumer's surplus.

willingness to pay -- the maximum amount an individual will pay to obtain an additional amount of a good.

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