6.0 RESULTS

Sections 6.1 to 6.3 summarize the results of the field data estimation of yield loss functions for the ten primary study crops. Statistically significant effects of ozone (O_3) were found for four crops, and of sulfur dioxide (SO_2) for one crop. Overall, the results indicate this approach can identify the more ozone sensitive crops in the SJV, although the exact relationships between yields and ozone are difficult to isolate and the effects of ozone on the less sensitive crops are difficult to capture.

Section 6.4 reports the estimated yield losses from O_3 and SO_2 for all crops in the San Joaquin Valley included in the California Agricultural Resources (CAR) model, and reports other related assumptions used in calculating losses under the alternative scenarios. Where the regression results are used they are reasonably consistent with the chamber study results, and do not indicate actual losses in the field are being significantly mitigated by any measures other than changes in crop variety or acreage allocations. Air pollution crop yield damages range from zero to 34 percent, depending upon the crop.

The CAR model reveals significant benefits would have resulted from air pollution control in the SJV in 1978. As yields in the SJV increase, small decreases in price, and in acreage in the SJV and statewide occur to offset some of the economic gains. The importance of using an economic-behavior model rather than the simple damage-function approach is illustrated for grapes, where the damage-function approach estimates economic losses several times larger than those predicted with the economic model.

6.1 EFFECTIVENESS OF THE REGRESSION APPROACH IN ESTIMATING YIELD LOSSES FROM O_3 AND SO_2

The yield function regression results revealed relative ozone sensitivities largely consistent with the rankings expected from the chamber study results (See Figure A2-1). The yield function regressions for dry beans and cotton showed a statistically significant negative relationship between ozone and yields in all specifications. The basic yield function specifications for potatoes and lettuce showed a consistently negative but not statistically significant relationship between ozone and yields for some ozone measures. This was apparently the result of small sample sizes (26 and 34 observations respectively), and because the crops are grown during seasons with lower ozone levels, making detection of an ozone-yield relationship difficult. Modifications of the potatoes equation showed statistically significant results for both O_3 and SO_2. The yield function for wine and non-wine grapes showed some statistically significant negative effects of ozone at higher ozone levels, but not in the basic linear specification. The other five crops did not show statistically significant negative effects of ozone in any specifications used. Overall, these results suggest that ozone is causing yield losses in the SJV, but the field data regression approach only captures the effects for the most sensitive crops -- crops that experience damages at low ozone thresholds and experience high rates of damage above these thresholds.

Sulfur dioxide effects were only found for potatoes. Sulfur dioxide ozone interaction variables were never found to be negative and statistically significant. These SO_2 results are attributed to the low level of SO_2 during most crops' growing seasons, and due to multicollinearity problems.

Several circumstances contribute to the difficulty of isolating a statistically significant effect of ozone on yields for crops in the SJV. Probably most important, the magnitude and range of ozone levels in the SJV are low enough that the effects of ozone on most crops are likely to be small, and for less sensitive crops the effects of ozone may be close to zero. While air pollution induced losses may be economically important, their magnitude is small compared to the effects on yields from changes in the weather, pest infestations, state and federal crop programs, etc. Consequently, detections of ozone-yield relationships at low ozone levels may be overwhelmed by other simultaneous events. Second, substantial measurement errors inherent in the field data regression approach hinder the ability to detect the air pollution-yield relationship. For example, using county level data introduces a considerable amount of measurement error because yields, ozone levels, and other growing conditions can vary significantly within a county. Another source of measurement error is the inability to precisely measure or incorporate and adequately quantify variables for all important factors which affect yields. Measurement error in the included explanatory variables, as in the case for the O_3 and SO_2 measures, biases the corresponding coefficients toward zero (Kmenta, 1971) and increases noise in the equation, making the detection of a statistically significant relationship difficult. Finally, the lack of degrees of freedom and the high correlation across observations often reduce the ability of the researcher to detect statistically significant relationships.

Comparisons with other attempts to use the field data regression approach serve to highlight the importance of these limitations in the regression approach for less sensitive crops. Adams et al. (1979) applied a regression approach to analyze ozone effects on crop yields in the South Coast and South San Joaquin Valley air basins. The researchers were unable to find statistically significant results for any crop using very simple specifications with yields as a function of ozone and acreage only. On the other hand, Leung et al. (1981, 1982) appeared to be successful in using the field data regression approach to detect ozone-yield relationships in the South Coast and Central Coast air basins. One reason Leung et al. may have been successful where Adams et al. were not, is their increased effort to quantify and include weather and other agricultural variables, to reduce measurement error in the equations.

Comparing the Leung et al. effort to the current SJV effort highlights the reason the regression yield function estimation approach is limited for less sensitive crops in areas like the SJV. Although there are several differences in the specification of the yield functions between the two efforts, we do not believe these differences are the cause of the differences in the ability to find statistically significant ozone yield results. Generally, we have improved upon their ozone variable and equation specifications. The important difference between the two studies is the magnitude and variation in the ozone levels in the two studies areas. This is illustrated in Table 6.1 for 1978 when the annual averages and average daily hourly-maximum levels are reported for the counties in the two study areas.* The ozone levels in the Leung et al. study area are on average 20 to 100 percent higher than in the SJV. The differences in the ranges of ozone levels are even more important. Ranges (minimum to maximum values) in the Leung et. al. study area are 1.5 to 2.4 times as large as in the SJV, with the increased spread occurring at the higher ozone values.

This difference in the ozone levels has two important implications for estimating ozone-yield relationships for crops that are not highly sensitive to ozone. First, the crops in the Leung et al. study area were exposed, on average, to much higher ozone levels in some counties, thereby increasing the likelihood that damage thresholds were exceeded. This

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* Annual averages are used for this comparison, rather than growing season averages, because Leung et al. did not report ozone means or ranges for their study. The comparison between the two study areas should be relatively the same whether annual or growing season ozone levels are used.

Table 6-1

Ozone Levels in the Leung et al. Study Counties and in the San Joaquin Valley

	Annual Mean (ppm)	Daily maximum Hourly Mean (ppm)
Leung et al. (1981) counties		
Los Angeles	.036	.099
Orange	.021	.064
Riverside	.034	.089
San Bernadino	.043	.109
Santa Barbara	.022	.045
Ventura	.029	.068
San Joaquin Valley counties		
Fresno	.031	.057
Kern	.029	.059
Kings	.021	.039
Merced	.026	.055
San Joaquin	.026	.058
Stanislaus	.028	.066
Tulare	.035	.065

Source: California Air Resources Board "Air Quality Data", 1978 ciated with statistically detectable changes in crop yields than in the SJV. The second implication is purely statistical. The ability to detect and precisely estimate a relationship is increased as the spread of the explanatory variable increases (Kmenta, 1971). The greater range of ozone levels in the Leung et al. study area increases the ability of the regression estimation technique to overcome measurement error and to detect an ozone-yield relationship for any given level of error. This is illustrated in Figure 6.1 where the ozone range in the Leung et al. study area is sufficient to estimate a downward sloping curve, even with large measurement errors, while the same is not true for the SJV area.

A second benefit of the larger ozone range in a study such as Leung et al., is that a crop may have a relatively low (or zero) sensitivity to ozone below some threshold. This is illustrated for a hypothetical crop in Figure 6.2, where the marginal rate of damage for ozone increases as ozone increases, especially above O_3*. In this case, there are significant crop losses in the SJV in some counties and some years when O_3 exceeds O_3*, but with any unexplained variation in the data (data points not exactly on the regression line) the analyst will not likely detect the effect. With the larger ozone range in Leung et al., it is more likely that any such thresholds will be exceeded. The ozone values experienced in the SJV are sufficiently low, although they do create yield losses, that the ability of the regression approach to overcome threshold effects and measurement errors is limited, especially for intermediate and ozone tolerant crops.

The results of this study, combined with those of Adams et al. (1979), Leung et al. (1981) and Math Tech (Manual, et al. 1981), suggest that the use of field data to estimate yield functions will be effective for measuring crop damage due to air pollution when air pollution levels are high enough to cause significant damage (this will depend on the crop) and there is a fairly wide range of air pollution levels over the study area so as to increase the signal-to-error ratio. It is reassuring that the yield losses estimated with this field data regression approach for the SJV were consistent with the relative rankings expected from the chamber studies, and the actual yield loss estimates for the more sensitive crops were within the range of those found in the chamber studies (Section 6.4). This indicates it is not inappropriate to apply the yield loss estimates from the chamber studies to estimating crop losses in the field, as was done for most of the crops in the SJV in the subsequent economic analysis.

Figure 6-1

Hypothetical Crop Damage Functions Over Different Ozone Intervals

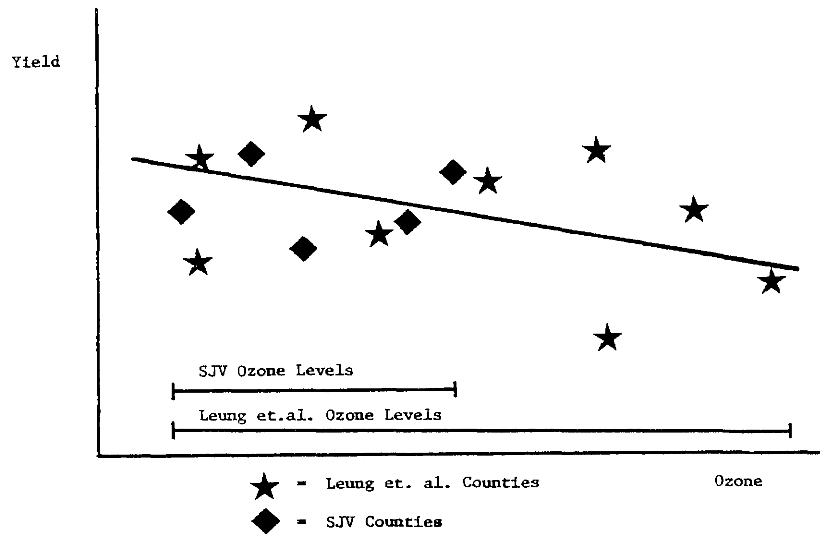
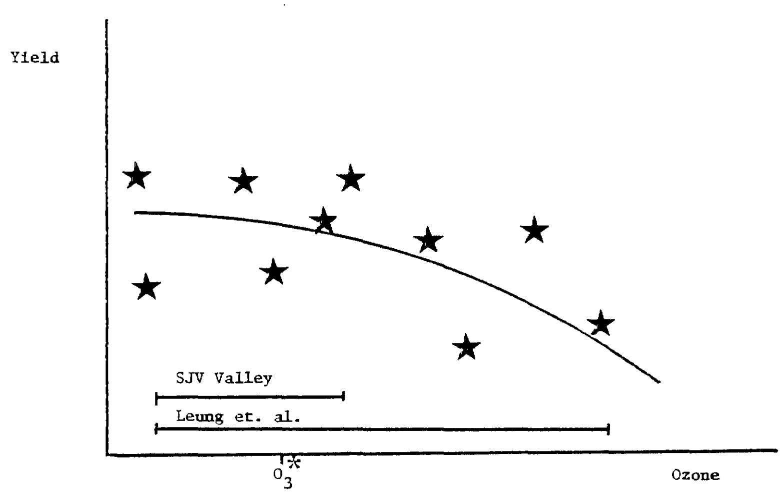


Figure 6-2

Hypothetical Yield Functions with Thresholds



6.2 GENERAL REGRESSION RESULTS

Section 6.3 discusses specific regression results for each crop individually. Some results are consistent across all crops and need not be repeated for each crop. These results are discussed in this section (the regression variables are defined on page 4-24).

The basic linear equations explain 25 to 50 percent of the variation in crop yields for most of the crops. The coefficients and their significance varied from crop to crop. In some cases, dummy variables seemed appropriate for particular years or particular counties when differences in yields across these years or counties were not being explained by the independent variables. The inclusion of one or more dummy variables generally increased the variation in yields explained by the equation to between 50 percent and 75 percent. Although the coefficients for these dummy variables are sometimes difficult to interpret, our concern was primarily to hold as much of the variation in yields as constant as possible in order to isolate the effects of air pollution.

Serious multicollinearity occurred among many of the independent variables in several cases, and this posed some problems in the interpretation of some of the coefficients.*

Several of the variables showed significant time trends. Ozone levels in the SJV were generally increasing over the 1970-1981 time period. Yields for many of the crops were also increasing over this period, making it important to include a variable that captured the general increases in productivity over that time period; otherwise, one would find the spurious result that ozone increases yields. PROD, an output per acre index defined for different crop groups in the U.S., was included for this purpose. For most crops with a fairly strong positive time trend in yields, PROD showed a significant positive coefficient. The LABOR and CAPITAL variables also showed strong time trends (negative for the former and positive for the latter) making it impossible to decipher which might best represent the changes in crop productivity over time. PROD was selected as the most general measure reflecting changes in inputs as well as technology. Usually when PROD showed a strong positive coefficient, ozone showed a statistically significant negative coefficient, at least for the crops expected to be more sensitive.

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* An often used rule of thumb is that when the correlation between explanatory variables exceeds the equation R^2, the coefficients may be unstable and unreliable.

The results for the different ozone measures were as expected in terms of lower elasticities for the threshold measures (03GE6, 03GE10, 03DOS) as opposed to the mean measure (03AVE). (See page 4-24 for definitions of these air quality measures.) 03GE10 and 03DOS gave virtually the same results in the basic specifications, so 03DOS was dropped from subsequent analyses. For crops where the ozone variable was significant, 03GE10, on average, out performed the others in terms of expected results and statistical signficance of the coefficent, although the implicit yield losses from ozone were often not substantially different due to the choice of the ozone measure. (See also Section 6.4 below.)

A comforting result was that the stability, or robustness, of the ozone coefficients seemed to increase in direct proportion to the expected sensitivity of the crop to ozone and to the sample size used in the analysis. Yet, even for the crops for which the ozone coefficients were negative and significant, the ozone coefficients often changed dramatically (100 percent) with changes in the yield function specification. Often this appeared to be due to problems with the data or unique county effects which could be captured with dummy variables or other special variables. To ensure the research did not simply massage the data until the expected results were found, each specification change was done according to the research plan, and all likely dummy variables were predetermined. Further, among the theoretically and statistically acceptable set of results for each crop, the most conservative estimates were usually selected for use in the scenario calculations.

HACRE was included in the initial specification for all crops on the assumption that it might capture differences in economies of scale or in conditions across counties that led to more acreage being planted in one crop. For many crops, HACRE showed a positive coefficient. Increases in HACRE for perennial crops could, however, be associated with reductions in yield because it may take a few seasons for the crop to mature to its full yielding potential. CHACRE (HACRE this year minus HACRE last year) showed a negative coefficient for several of the perennial crops.

Inflation adjusted price (APRICE) had a significant positive coefficient for some crops (dry beans, alfalfa and some lettuce specifications), but was generally insignificant or positive. This lends mixed support to the hypothesis that harvested yields may be somewhat different than actual or potential yields in the fields, and that prices are a potential influence.

In most cases, alternative specifications and adjustments, even when they improved the explanatory power of the equations, did not cause the ozone coefficients to become negative or statistically significant if they were not already negative and close to significant in the basic specification.

For a few crops, the residuals from the basic specifications showed a pattern of larger errors in counties where HACRE was smaller. This suggested the possibility that measurement error was greater in the counties where the crop was smaller (heteroskedasticity), perhaps due to greater potential for unique circumstances on an individual farm influencing the yields for the county. To adjust for this, the dependent and independent variables were weighted by alternative functions of HACRE, giving greater weight in the estimation to the counties with higher HACRE. The explanatory power of the equation greatly increased with this adjustment, but generally made very little difference in the estimated effect of ozone on yields.

To test if aggregating ozone levels across the entire growing season was obscuring a relationship between yields and ozone during a crucial part of the growing season, the ozone measures for the growing season were separated into three measures for 03AVE and 036E10 -- one each for the early season, middle season and late season (by thirds) for each crop. These seasonal variables did not show any statistically significant coefficients for crops for which the ozone measure for the entire growing season did not show a statistically significant coefficient. When the entire growing season measure did show a statistically significant negative coefficient, none of the seasonal breakdown variables showed distinctly superior explanatory power. Differences in seasonal ozone responses were found for cotton and grapes. Based on these results, the measures for the entire growing season were used throughout the rest of the analysis.

The yields of perennial crops could potentially be affected by ozone levels in previous years. The only perennial for which current year ozone effects were significant was grapes. The coefficients for ozone measures from previous years were statistically insignificant or mixed positive and negative, contrary to expectations and with no clear consistency, even for grapes. This does not mean ozone in previous years may not be influential, but the effects are probably less important than current year ozone levels. Since most of the perennials did not show current year effects in the yield equations, it is not surprising that a discernable pattern of previous year influences did not emerge.

In many years and counties, the ozone levels in the SJV may not have been high enough to cause yield reductions in the less sensitive crops. It was hypothesized that a significant ozone-yield relationship might emerge if the equations were estimated for a restrictive functional form or for the higher ozone observations only, such as for values in excess of O_3* in Figure 6.2. The idea, using the regression approach, is that observations below 0_3* obscure the negative ozone yield relationship above 0_3*, even with nonlinear specifications. This thresholds approach seemed to work for grapes, as discussed below, but not for any of the less sensitive crops.

In considering SO_2 for possible crop damages in the SJV, it became apparent that only in the winter months in Kern County were SO_2 levels high enough to be significantly different from zero. Since the SO_2 variables were positive in Kern County and near zero elsewhere, this introduced the danger that unaccounted for differences between Kern and the other counties would be artificially correlated with the difference in SO_2 levels. This would bias the SO_2 coefficient and overwhelm any SO_2 effect. Sulfur dioxide was included in the initial equations for all crops, but the coefficients were often positive and statistically significant, creating concern that we were in fact obtaining a "Kern County effect" rather than an SO_2 effect. The variable was therefore dropped for all crops except potatoes and lettuce, which are important Kern County crops and grow during the cooler months when SO_2 levels are highest. (See Section A2.8 for further discussion). These crops are also grown in only a few counties in the SJV, increasing the possibility of capturing the effect of changes in SO_2 levels over time in Kern rather than just the differences between Kern and other counties.

No definitive pattern of best specifications emerged concerning alternative functional forms, which is not surprising given the data did not reveal a simple negative ozone-yield relationship for many of the crops. In most cases, the nonlinear functional forms were not found to be an improvement over simple linear or quadratic specifications because the significance of the coefficients and the explanatory power of the equations did not increase with the use of these specifications. Therefore, in most cases, the linear and quadratic functional form results are the only ones discussed below.

Due to the limited ozone data available for the early study years (1970-1974), a different procedure was used to develop estimates of crop exposures for these years. To see if the different estimation procedure may have introduced any systematic biases in the ozone coefficient, the sample was split for several crops into 1970 - 1974 and 1975 - 1981. The results of the subsamples were not always consistent with the total sample results, but no systematic differences among the two subsamples and the full sample were found.

6.3 REGRESSION RESULTS BY CROP

The crop specific results are discussed for the individual crops in order of expected sensitivities.

Dry Beans

Dry beans were expected to be very sensitive to ozone. The regression results were consistent with this expectation. The basic linear specification showed statistically significant negative coefficients for all four ozone measures.

The basic linear specification was selected for the final specification because the quadratic terms in the nonlinear specifications were largely insignificant and the adjustment for number of harvested acres resulted in elasticities at the means almost identifical to those from the linear equations. When county dummies were added, three counties -- Fresno, Kings and Stanislaus -- were statistically significant. The distribution of varieties within the dry bean category varies in a well defined manner across counties. In the north the primary varieties are lima and kidney. In the south blackeyes predominate. The fact that per acre yields of blackeye peas are less, but blackeyes are also more pollution tolerant than most other variables (Brewer 1982, CDFA 1982) seems to justify the inclusion of county dummy variables. Otherwise lower yields in the southern portion of the valley would be over attributed to higher air pollution.

It should be noted that the inclusion of these dummy variables reduced the ozone coefficient by up to one-half, depending upon the specification. If in fact the difference in yields across counties is not affected by variety differences (although this appears likely, based upon California Department of Agriculture location maps of dry bean varieties), the ozone damages are underestimated by the inclusion of these dummy variables. In either case, this seems to highlight the difficulty with the data and specifications in the field data regression approach to estimating yield losses.

When the county dummies were added, the HACRE coefficient switched from positive to negative, which contradicts our hypothesis that HACRE can serve as a proxy for beneficial growing conditions across the counties. Changes in HACRE over time may be causing the inexplicable negative coefficient.

APRICE and PROD showed positive coefficients. TEMP and RAIN were insignificant while COLD had a statistically significant negative coefficient. The fertilizer variables showed mixed signs and significance reflecting possible multicollinearity problems. The results for equations with O3AVE and 03GE10 were used for the damage estimates. These estimated equations are reported in Table 6-2. Both of these equations explain about 75 percent of the variation in yields, and the implied yield losses are very consistent.

Potatoes

The basic linear specification for potatoes showed positive coefficients for the ozone variables and the coefficient for PROD was insignificant in spite of a positive time trend in YIELD. This reflects a problem of very high positive correlations through time between yields, productivity, and ozone, amplified by the limited number of observations; a classic multicollinearity problem. To capture the effect of PROD (apparently not a good measure for potatoes but all that was available) and to eliminate the positive time trend in YIELD, we divided YIELD by PROD and re-estimated the equations, even though this approach can only be defended weakly.

The potato crop is grown primarily in Kern and San Joaquin counties, and has occasionally been grown in Kings and Madera. The Kern potatoes are grown mostly during the winter and harvested in the spring, whereas in the other counties they are planted in the spring and harvested in the summer and fall. This makes the pooling of yield data across these counties somewhat inappropriate, so the yield functions were estimated with and without Kern County to test for consistency of the results. When the entire sample was used, the coefficient for 03AVE was positive, but insignificant; the coefficient for 03GE6 was negative, but insignificant; and the coefficient for 03GE10 was negative and only significant at the 15 percent level (one-tailed test) with an elasticity of .05. Kern County has low ozone levels in the potato analysis since the growing season is during the winter months. Kern also has higher yields than the other counties, creating the possi-

TABLE 6.2
Selected Dry Beans Specifications

Dependent Variable: Yield   Ozone variable: O3AVE

Variable Name	Estimated Coefficient	T-Ratio (73 DF)	Elasticity At Means
HACRE	-.635E-05	-2.01	-.702E-01
APRICE	.249E-03	1.86	.110
N	.102E-01	2.80	.307
P	-.154E-01	-1.34	-.136
K	-.988E-03	-.704E-01	-.323E-02
PROD	.433E-01	1.64	.678
03AVE	-.802E-02	-2.01	-.270
TEMP	-.114E-02	-.698	-.550
RAIN	.601E-02	.335	.116E-01
COLD	-.248E-01	-3.16	-.147E-01
C01 (Fresno)	-.491	-7.18	-.649E-01
C03 (Kings)	.683	7.57	.225E-01
C07 (Stan)	.183	2.53	.242E-01
Intercept	.996	1.25	-

$R^2 = .76$ $\bar{R}^2 = .72$ F = 18.6   N = 87

Dependent Variable: Yield   Ozone Variable: O3AVE

Variable Name	Estimated Coefficient	T-Ratio (73 DF)	Elasticity At Means
HACRE	-.569E-05	-1.82	-.629E-01
APRICE	.268E-03	2.02	.118
N	.908E-02	2.62	.273
P	-.126E-01	-1.13	-.111
K	.871E-03	.633E-01	.284E-02
PROD	.335E-01	1.42	.525
03GE10	-.803E-03	-2.24	-.532E-01
TEMP	-.115E-02	-.703	-.550
RAIN	.577E-02	.327	.111E-01
COLD	-.221E-01	-3.01	-.131E-01
C01 (Fresno)	-.489	-7.25	-.647E-01
C03 (Kings)	.696	7.91	.230E-01
C07 (Stan)	.189	2.64	.250E-01
Intercept	.914	1.14	

$R^2 = .77$ $\bar{R}^2 = .73$ F = 18.9   N = 87 bility that the ozone coefficient is picking up some effect of differences between the counties other than ozone levels. When Kern county was dropped, the ozone coefficients and statistical significance increased by 100 percent indicating much stronger ozone effects than would be expected from the chamber studies on potatoes. The equations estimated without Kern County are based on a very few observations (14). We decided to use the more moderate results from the 03GE10 equation with the whole sample, even though the t-ratios are quite low, in order to be conservative in the estimates, since the results at least confirmed that the ozone coefficient is not just picking up a Kern County effect, and because these estimates were most similar to chamber study results.

HACRE picked up a strong Kern County effect, because there is much higher potato acreage in Kern, and HACRE was highly correlated with TEMP (-.9) due to the differences in the growing seasons. HACRE was therefore dropped. The negative coefficient on TEMP could be a Kern County effect rather than a temperature effect alone. Examining simple plots of yields versus ozone, a shift was suspected between 1970-1975 and between 1976-1981, so a dummy variable (D1) was added for 1970-1975. It had a negative and statistically significant coefficient.

The R^2 indicates the final equation explains about 75 percent of the variations in YIELD/PROD, although the F statistic is not very high due to the low degrees of freedom. Nonlinear forms were not estimated due to the degrees of freedom limitation. A measure of SO_2 was included in each equation and in most cases showed a statistically significant negative coefficient. Sulfur dioxide effects were also estimated using only spring potatoes in Kern County. The implied yield sensitivity to SO_2 was consistent across all alternative specifications, although the coefficients for Kern County were larger. Therefore, the results from a whole sample equation seem conservative among the set of estimated results. Sulfur dioxide and ozone interaction terms showed either positive or insignificant coefficients. Problems with multicollinearity among the three pollution variables make it difficult to detect any interaction effects. The interaction term was therefore dropped.

The results from the selected O3GE10 equation are given in Table 6-3. It should be noted that the significance of the O_3 and SO_2 coefficient is very low, however this specification provided the most conservative yield loss estimates and in no other equations did the t-ratios for these coefficients exceed 2.

TABLE 6.3
Selected Potatoes Specifications

Dependent Variable: Yield/Prod   Ozone Variable: 03GE10

Variable Name	Estimated Coefficient	T-Ratio (15 DF)	Elasticity At Means
APRICE	.298E-03	.598	.297E-01
N	-.800E-02	-1.54	-.300
P	.133E-01	.833	.157
K	.160E-01	.909	.595E-01
O3GE10	-.184E-02	-1.1	-.49E-01
SO2GE10	-.681E-02	-1.2	-.33E-01
TEMP	-.342E-02	-3.12	-1.41
RAIN	-.487E-02	-.386	-.239E-01
COLD	-.107E-02	-1.26	-.332E-01
D1	-.110	-1.83	-.509E-01
Intercept	2.67	4.79	

$R^2 = .76$ $\bar{R}^2 = .60$ F = 4.7   N = 26

Cotton

The basic linear specification for cotton showed statistically significant negative coefficients for every ozone measure. As with dry beans, and as expected, the elasticities were higher for O3AVE than for O3GE6 and O3GE10. A linear specification was chosen for the final specification because the quadratic terms in the nonlinear equations were not statistically significant, and the implied elasticities at the means were very close to those from the linear equations. A 1978 dummy variable was added because 1978 was known to be a low yield year due to bad weather (too much rain at the wrong times) and the residuals from the first estimation showed yields in 1978 were being consistently overpredicted. With the inclusion of the 1978 dummy variable, the ozone coefficients and the implied yield losses dropped by approximately half.

The selected yield loss estimates were calculated using the equations with the 1978 dummy variable, although there is the possibility that the harmful effects of higher ozone levels as experienced in 1978 were to some extent being picked up by the dummy variable, introducing some downward bias in the ozone coefficient. It seemed more likely, however, that the ozone coefficient without the 1978 dummy was biased upward because the weather variables in the equations were not picking up the full impact of the 1978 circumstances, and ozone levels were high in 1978. When the 1978 dummy was added, the sign of the RAIN coefficient switched from negative to positive and the R^2 increased from .44 to .79 for the O3AVE equation, and from .66 to .79 for the O3GE10 equation.

This supports the hypothesis that the weather variables alone did not capture the entire effect of the adverse weather conditions which occurred in 1978. The choice of lower damage estimates was also made because much of the San Joaquin Valley cotton acreage had, by the late 1970s, been switched to the more ozone resistant variety SJ-2. The estimation results for the selected specifications for O3AVE and O3GE10 are given in Table 6.4. The implied yield losses are comparable across these two specifications. When seasonal ozone variables were used, similar total results were obtained, although the yield response to ozone increased through the three subseasons.

The cotton equations were also estimated using USDA data for yields. These data were somewhat different from the data from county agriculture commissioners. These results showed slightly stronger ozone effects, but the coefficients were not statistically different. This is a reassuring confirmation of the estimated ozone effects. To be consistent with the other crops, the results using the agriculture commissioners' data were used to calculate the yield losses for the various scenarios.

Lettuce

Lettuce is grown in Fresno and Kern counties and in some years in Kings and San Joaquin counties. The sample size was therefore fairly small (34 observations). The growing season covers late summer, fall, winter and early spring. The basic linear specification showed positive, and in some cases statistically significant coefficients for the ozone measures. Again, there was a strong positive time trend in YIELD and in the ozone measures and PROD was not picking this up. A dummy variable was added for 1970-1975 to allow for a possible shift in YIELD from these earlier years to the later years. The dummy variable showed a statistically significant negative coefficient, and when the dummy was included in the equation, the ozone coefficients that were previously positive and significant became statistically insignificant. The coefficient for O3GE10 became negative, but was also statistically insignificant.

TABLE 6.4

Selected Cotton Specifications

Dependent Variable: Yield   Ozone Variable: O3AVE

Variable Name	Estimated Coefficient	T-Ratio (59 DF)	Elasticity At Means
HACRE	.281E-06	1.70	.116
APRICE	-.271E-04	-.539	-.688E-01
N	.891E-03	.654	.697E-01
P	.723E-04	.205E-01	.159E-02
K	-.453E-02	-.942	-.273E-01
PROD	-.328E-02	-.644	-.991E-01
03AVE	-.258E-02	-1.39	-.214
TEMP	.163E-03	.220	.187
COLD	-.147E-01	-5.22	-.223E-01
RAIN	.212E-01	2.92	.926E-01
PREMP	.237E-01	3.49	.984E-01
Y78	-.246	-9.84	-.466E-01
Intercept	.401		1.05

$R^2 = .82$ $\bar{R}^2 = .78$ F = 22.0   N = 72

Dependent Variable: Yield   Ozone Variable: 03GE10

Variable Name	Estimated Coefficient	T-Ratio (59 DF)	Elasticity At Means
HACRE	.233E-06	1.54	.965E-01
APRICE	-.273E-04	-.574	-.693E-01
N	.106E-02	.798	.830E-01
P	-.995E-04	-.286E-01	-.219E-02
K	-.391E-02	-.860	-.236E-01
PROD	-.296E-02	-.587	-.896E-01
03AVE	-.319E-03	-1.72	-.509E-01
TEMP	.354E-03	.479	.405
COLD	-.138E-01	-5.20	-.210E-01
RAIN	.178E-01	2.39	.774E-01
PREMP	.217E-01	3.61	.901E-01
Y78	-.219	-7.15	-.415E-01
Intercept	.240	.633	

$R^2 = .82$ $\bar{R}^2 = .78$ F = 22.5   N = 72

PROD remained statistically insignificant. In order to force the incorporation of PROD, YIELD was divided by PROD as was done with potatoes, to create a new dependent variable with less of a positive time trend. This caused very little change in the ozone coefficients, which remained statistically insignificant. Throughout these variations, HACRE was insignificant. APRICE was significant and positive for the 1975-1981 subsample analyses only. The explanatory power of the equations in all the specifications attempted was weak, with F statistics never exceeding 3. The explanatory variables were not explaining variations in YIELD very successfully.

Lettuce is grown in Kern County during the winter months when SO_2 levels may be high enough to cause some crop damage. Sulfur dioxide measures were therefore included in each of the specifications, but they never showed a statistically significant coefficient.

Grapes

Grapes were separated into wine and non-wine varieties to allow for possible variations in sensitivity to air pollution. A large proportion of both the wine and non-wine crop is Thompson Seedless, which have been found to be somewhat less sensitive to ozone than other wine grapes (Table A2.4).

The basic linear specification did not show any statistically significant negative coefficients for the ozone measures for wine or non-wine grapes, although the coefficient for O3AVE for wine grapes was negative and indicated an elasticity with respect to YIELD of .15 at the mean. The residuals for wine grapes showed large errors for Kings County. Acreage was very small for Kings relative to the other counties, so it was dropped from the sample. The ozone-yield plots for wine grapes showed a potential split between yields in the southern counties and yields in the northern counties, so a dummy variable (COL) was added for Merced, San Joaquin and Stanislaus counties, which showed a strong negative coefficient throughout the remaining estimations. These adjustments greatly improved the explanatory power of the wine equations. Similar efforts with non-wine grapes were not successful.

The nonlinear specifications for both wine and non-wine grapes showed statistically significant coefficients for the linear and the squared ozone terms, and indicated a positive relationship in the lower ozone levels and downward turn in the yield-ozone relationship at the higher ozone levels. There is no evidence that ozone ever has a positive effect on crops, so it was hypothesized that there was an ozone threshold below which no effect on yields was occurring, or that measurement error was overwhelming a small relationship, and that an increasingly steep relationship existed at the higher ozone levels. Regressions restricting the sample to only observations with higher ozone values seemed to support this, however it is difficult to extrapolate such results to lower ozone levels, as would be necessary in the scenario calculation. Alternatively, dropping the linear term and estimating the yield function with only a squared ozone variable would force the hypothesized relationship.

For wine grapes, ozone measures in the specification had statistically significant coefficients (about 10 percent significance for O3AVE and O3GE10 and about five percent for O3GE6 -- one tailed test). The O3GE6 measure was chosen for the selected wine grape specification because it was consistent with the expectations from preliminary chamber study results, and showed better explanatory power than the linear specification. The results are given in Table 6.5. It should be noted that the same equation specification using O3GT10 or O3AVE, rather than O36T6, implied yield losses from ozone were within 20 percent of those predicted by the selected equation. The alternate approach of estimating linear and quadratic yield loss equations with the low ozone observations removed from the sample (those less than the O_3* threshold) provided results consistent with the selected specification, even with the use of several different thresholds.

The same results were not obtained for non-wine grapes, where the squared pollution measures did not show statistically significant coefficients. Statistically significant coefficients were obtained in the first nonlinear specification, but as with wine grapes, the results indicated a positive yield-ozone relationship at the lower ozone levels, turning sharply negative at the higher levels: a theoretically unlikely result. The explanatory power of the non-wine equations was also quite weak. Yield losses were therefore calculated for all grapes using the wine equation. This introduces the possibility of upward bias in the yield loss estimate if non-wine grapes are less sensitive than wine grapes.

Wine grapes showed large increases in HACRE over the study period, and the change in HACRE variable (CHACRE) had a statistically significant negative coefficient. PROD had a positive significant coefficient. The weather variables and APRICE were insignificant, and PREMP (the vineyard labor productivity variable) was weakly positive.

TABLE 6.5

Selected Wine Grapes Specification

Dependent Variable: Yield

Variable Name	Estimated Coefficient	T-Ratio (59 DF)	Elasticity At Mean*
CHACRE	-.119E-03	-2.60	-.190E-01
APRICE	-.643E-03	-.191	-.130E-01
N	-.450E-01	-1.75	-.191
P	-.278E-01	-.321	-.346E-01
K	.351	3.17	.172
PROD	.899E-01	1.72	.468
036SQ	-.166E-05	-1.71	-.609E-01
TEMP	-.870E-02	-.668	-.632
RAIM	-.432E-01	-.551	-.223E-01
COLD	.143E-01	.463	.291E-01
PREMP	.351E-01	1.17	.695E-01
COL	-3.76	-8.15	-.226
Intercept	11.3	1.57	

$R^2 = .63$ $\bar{R}^2 = .56$ F = 8.5 N = 72

* The elasticity reported is for yield with respect to the squared ozone term (O3GSQ). The elasticity of yield with respect to O3GE6 at the mean is - .109.

Seasonal ozone variables did not improve the specifications, although depending upon the specification, the middle or late growing season ozone coefficients were slightly larger than the coefficients for the other parts of the growing season. Similarly, lagged total growing season ozone and lagged partial growing season ozone variables were examined, but the coefficients were statistically insignificant and in some cases positive.

Alfalfa

Alfalfa was expected to be sensitive enough to ozone to show some yield losses in the SJV. However, none of the estimated yield equations showed a negative relationship between alfalfa yields and ozone, although considerable effort was made with different specifications. Given conclusive chamber study evidence, this was interpreted as an indication of the weakness in the data and the yield function estimation approach, not as an indication that alfalfa is not affected by ozone in the SJV.

Ozone showed positive and sometimes significant coefficients in the basic linear specification. Unlike most of the crops, alfalfa yields did not show a positive time trend and PROD did not have a significant coefficient. HACRE and APRICE showed positive and significant coefficients. TEMP showed a significant positive coefficient and rain a significant negative coefficient. Bad weather in 1978 was known to have affected yields and in particular, 1978 yields in the southern counties were overpredicted by the first equations. A dummy variable for 1978 in Fresno, Kern, Kings and Tulare counties showed a significant negative coefficient, but the ozone coefficients remained positive, although insignificant.

The nonlinear equations with a squared ozone term added and the 1978 dummy included indicated a positive yield-ozone relationship over most of the ozone range. Threshold equations were estimated for those observations where ozone exceeded the sample mean, yet they showed even stronger positive coefficients for ozone.

The two variable plots for yield and ozone for each county over the twelve year period revealed that a positive relationship existed in some counties and a negative relationship existed in others. No explanation for this dichotomy was apparent (i.e. there was no obvious differentiation such as big HACRE versus small HACRE or northern versus southern valley which would justify separating the counties). The equations were adjusted to give more weight to the counties with more acreage, but again the ozone coefficients remained positive.

Annual dummies (0, 1 values) were added for each year to see if a negative relationship would emerge across counties on the possibility that the positive time trend in the ozone variable might be obscuring a negative relationship with yields. Again the positive coefficients remained.

Alfalfa is a three year crop, so variables for ozone in the two previous years were added instead of current year ozone. The results for O3AVE showed a negative but insignificant coefficient for the first preceding year and a positive, significant coefficient for the second. The results for O3GE10 showed positive, significant coefficients for both preceding years.

Tomatoes

Tomatoes were divided into fresh and processing varieties. It was expected on the basis of chamber studies that tomatoes would show yield losses from ozone damage in the SJV. The basic linear equation for processing tomatoes showed statistically insignificant coefficients for the ozone variables — negative for O3AVE and positive for O3GE6 and O3GE10. The basic linear specification for fresh tomatoes showed statistically significant positive coefficients for all of the ozone measures. Alternative specifications were estimated for processing tomatoes on the assumption that if these did not show a significant ozone effect, neither would fresh tomatoes.

The nonlinear specifications showed a positive yield-ozone relationship over most of the range. Dropping observations for ozone levels below the mean resulted in positive ozone coefficients for O3AVE and O3GE10. Adjustments for HACRE, giving more weight to counties with larger acreage, still resulted in positive ozone coefficients.

Tomato yields had a positive time trend over the study period, as did the ozone measure. The PROD coefficients were statistically insignificant throughout all specifications, so the positive time trend might have been obscuring any true negative relationship between yield and ozone. To test for this, dummy variables were added for each year, so the estimated equation would reflect only cross county variations. The ozone coefficients remained positive.

Peaches

Peach yields were available for freestone and cling peaches in all counties except Kern. In Kern these were reported as combined yields. Freestones and clings were examined separately to allow for the possibility of different responses to ozone and other variables, so Kern County was dropped. Acreage in Kern was a small fraction of total peaches in the SJV.

In the basic linear specification, cling peaches showed a statistically significant negative coefficient for all ozone measures, while freestones showed an insignificant positive coefficient for all ozone measures. The elasticities implied by the coefficients for cling peaches were, contrary to chamber study evidence, higher than for dry beans and cotton. They were therefore examined for their robustness. Cling peaches showed a general decrease in HACRE over the study period, with some surprisingly large changes from year to year. Yields seemed to neither decrease nor increase consistently with these changes, and in fact jumped erratically for a couple counties. Tulare and Kings Counties in particular showed wide fluctuations in acreage and yields which seemed to be the opposite of ozone's fluctuations. These counties have relatively few cling peach acres. When the sample was reduced to the three counties in which 75 percent of the SJV cling peaches are grown, the ozone coefficients became positive and almost significant for O3AVE, positive and insignificant for O3GE6, and negative and insignificant for O3GE10.

PROD had a positive and significant coefficient throughout the different specifications and samples, picking up a positive time trend in yields. HACRE, contrary to expectations, showed a negative coefficient throughout which was frequently significant. For cling peaches, HACRE and the ozone variables were negatively correlated (-.44, -.41 and -.21 for O3AVE, O3GE6 and O3GE10, respectively), but their coefficients had opposite signs. This indicates multicollinearity might also have been causing some of the unexpected results.

Freestone peaches showed some peculiarity in the data with three counties (Merced, Stanislaus, and San Joaquin), reporting much higher yields but much lower prices so price received per-acre yield was still comparable. This suggests the possibility of different reporting methods. To check for the effect of this on the results, the equation was estimated with a dummy variable for these counties and estimated for the remaining counties when these three counties were dropped altogether. In both cases all of the ozone coefficients were positive.

On the basis of the freestone results, the instability of the clingstone results, and the indication from chamber studies that peaches are relatively insensitive to ozone at levels that occur in the San Joaquin Valley, yield effects for the alternative ozone variables were estimated to be zero. It should be stressed that the regression results suggest more analysis of ozone damages to peaches, especially at ozone levels equal to or above the highest ozone levels experienced in the valley, may be merited and may reveal significant damages.

Oranges

Oranges were divided into valencia and navel varieties. Neither type was expected to be sensitive to ozone levels typically experienced in the SJV, although damages may occur at the highest levels experienced in the SJV and at typical ambient levels in the South Coast Air Basin. The basic linear specification for valencias showed a statistically insignificant negative coefficient for O3AVE and a significant positive coefficient for O3GE10. It was noticed that yields increased sharply for 1979 to 1981, and this increase was not explained by the regression variables. A dummy variable added for these three years had a significant positive coefficient. The negative coefficient for O3AVE remained insignificant, and the positive coefficient for O3GE10 became insignificant. Multicollinearity between PROD and the ozone variables seemed to be a problem, with PROD showing a negative coefficient in many of the specifications. The nonlinear specifications showed insignificant coefficients for all of the ozone terms, both linear and squared. Results were much the same for navel oranges.

Oranges are a perennial crop so lagged ozone variables were added, but they did not show any significant negative coefficients.

It was concluded that since the data did not reveal a negative relationship between orange yields and ozone, and chamber studies suggest oranges are relatively insensitive to ozone damages at levels typically experienced in the San Joaquin Valley, yield losses for the scenarios were estimated to be zero.

Almonds

Almonds were expected to be the least sensitive crop of the ten for which yield equations were estimated. Given the results for alfalfa, tomatoes, peaches and oranges, it was not surprising to find statistically insignificant ozone coefficients for all of the ozone variables. This was the case even though PROD showed a significant positive coefficient in most of the specifications.

Based on these results and the expected insensitivity of almonds to damage from ozone exposure, the yield losses for the scenarios were estimated to be zero.

6.4 YIELD ADJUSTMENT COEFFICIENTS

Method for Calculating Yield Adjustment Coefficients

Yield adjustment coefficients for each crop and CAR model region for each scenario as compared to the 1978 base case, were calculated using a three-step procedure.

STEP 1: Damage functions were selected from one of four alternative approaches, which in order of priority were:

- o Use of the San Joaquin Valley regression results reported in Section 6.3.
- o Use of NCLAN or ERC regression results based upon chamber study results.
- o Assignment of yield adjustment coefficients for similar crops for which figures exist.
- o Assignment of zero yield adjustment coefficients and other restrictive assumptions.

The selected specifications are reviewed in detail below.

STEP 2: Values were calculated for each relevant O_3 measure for each scenario. O3GE10, O3AVE and O3GE6 values for the base case equalled existing 1978 conditions over the daytime hours during the growing season, and were defined separately for each crop in each county. (See Section 4.2.) O3GE10 values for Scenario 1 were defined as 50 percent of the hours for the base case for all crops and regions. Under Scenario 2, O3GE10 was forced to zero for all crops and regions. O3GE10 is not an appropriate measure for analysis under Scenario 3, and was not used. O3AVE and O3GE6 were also determined separately for all crops and counties for all scenarios due to differences in local conditions and growing seasons. These values were calculated through the assumption that the growing season daytime hourly values are distributed lognormally. (For discussion of the lognormal distribution, see Larsen, 1971.) The existing 1978 distribution was plotted on lognormal paper, then shifted (geometric mean and standard geometric error reduced) such that a lognormal distribution was retained, but the desired 10 or 8 pphm level was reached (with .2 percent exceedences) and with the number of hours with readings equal to or lower than 1 pphm held constant. This resulted in the standard geometric error changing at about one-fourth the rate of the change of the geometric mean, which is consistent with evidence suggested by Pollack (1975). For example, on Scenario 1, the distribution was shifted from the 1978 existing conditions, such that the percent of hours for which O_3 equalled or exceeded 10 pphm was reduced by half, while the number of hours with readings equal to or lower than 1 pphm was constant. From the graph of the shifted distribution, one can then read the projected O3AVE and O3GE6 values. For Scenario 2 (Scenario 3) the distribution was shifted such that the number of hours equalling or exceeding 10 (8) pphm equalled approximately .2 percent of the total daytime growing season hours, and the number of hours with readings equal to or lower than 1 pphm again held constant.* Estimated baseline and alternative scenario ozone measures are illustrated for selected crops in Table 6.6

STEP 3: Yield improvements for each crop in each county were calculated by evaluating the selected damage function and O_3 values for 1978 and the alternative scenarios. Where the San Joaquin Valley regressions were used, the yield adjustment factors were based upon actual 1978 yields. The regression equation intercepts were adjusted such that the actual 1978 ozone-yield values were on the regression line. The yields for the alternative scenarios were then calculated using the coefficient relating yields to ozone levels, holding all other variables constant. This was done for each county individually.

*As an example, for cotton in Fresno County, the 1978 values for daytime growing season hours for O3AVE and O3GE10 were 5.65 pphm and 143 hours. The standard geometric mean and deviation for use in the lognormal distribution calculations were 4.963 and 1.664. The O3GE10 for Scenarios 1 and 2 were 72 and 0 hours. The calculated O3AVE values for Scenarios 1, 2 and 3 are 4.95, 3.38, and 2.99.

Table 6-6

Estimated Baseline and Alternative Ozone Measures for Selected Crops in 1978

	Baseline 1978	Scenario 1 (12 pphm)	Scenario 2 (10 pphm)	Scenario 3 (8 pphm)
Grapes 03AVE (8 mo)				
Fresno	5.54	4.85	3.40	3.0
Kern	6.00	5.23	3.35	3.0
Kings	5.43	4.74	3.91	3.0
Madera	5.39	4.76	3.39	3.0
Merced	5.36	4.75	3.38	3.0
San Joaquin	5.35	4.65	3.56	3.0
Stanislaus	5.52	4.83	3.40	3.0
Tulare	6.28	5.46	3.32	3.0
Cotton 03AVE (7 mo)				
Fresno	5.70	4.95	3.38	3.0
Kern	6.36	5.54	3.32	3.0
Kings	5.80	5.05	3.37	3.0
Madera	5.69	5.01	3.36	3.0
Merced	5.63	5.00	3.35	3.0
San Joaquin	--	--	--	--
Stanislaus	--	--	--	--
Tulare	6.65	5.79	3.29	3.0
Cotton 03GT10 (Hrs/7 mo)				
Fresno	143	71	0	NA
Kern	193	86	0	NA
Kings	156	78	0	NA
Madera	137	68	0	NA
Merced	128	64	0	NA
San Joaquin	--	--	--	--
Stanislaus	--	--	--	--
Tulare	214	107	0	NA
Potatoes 03GE10				
Kern	1	.5	0	NA
San Joaquin	108	54	0	NA
Potatoes 03AVE				
Kern	3.75	3.75	3.30	3.0
San Joaquin	5.44	4.80	3.40	3.0

Table 6-6

Estimated Baseline and Alternative Ozone

Measures for Selected Crops in 1978
(continued)

	Baseline 1978	Scenario 1 (12 pphm)	Scenario 2 (10 pphm)	Scenario 3 (8 pphm)
Dry Beans 03GE10				
Fresno	145	72	0	NA
Kern	192	96	0	NA
Kings	--	--	--	--
Madera	137	68	0	NA
Merced	139	69	0	NA
San Joaquin	156	78	0	NA
Stanislaus	160	80	0	NA
Tulare	231	115	0	NA
Dry Beans 03AVE				
Lettuce 03AVE				
Fresno	4.63	4.0	3.69	3.2
Kern	5.17	4.43	3.56	3.12
Kings	4.71	4.07	3.67	3.2
Tomatoes 03AVE				
Fresno	5.0	4.2	3.5	3.0
Kern	5.7	4.9	3.3	3.0
Kings	4.9	4.1	3.2	3.0
Madera	5.1	4.2	3.5	3.0
Merced	5.1	4.2	3.5	3.0
San Joaquin	5.2	4.5	3.1	3.0
Stanislaus	5.5	4.7	3.4	3.0
Tulare	6.0	4.9	3.7	3.0

Selected San Joaquin Valley Regression Results

Selected regression results for cotton, grapes, potatoes, and dry beans reported in Section 6.3 were used. The individual regressions were selected based upon the strength of the regressions, as discussed for each crop above, consistency with chamber study evidence and conceptual consistency,* and are summarized in Table 6-7.

For grapes, the specification with O3GE6 squared was used for all calculations. For dry beans, the O3GE10 specification was felt to be superior and was used for Scenarios 1 and 2, while the O3AVE specification was used for Scenario 3 for conceptual consistency. For Scenario 2, the dry bean yield changes using the O3GE10 specification were about 10 percent smaller rather than with the O3AVE specification. For cotton, the O3GE10 results were stronger, but posed problems when applied to the scenario calculations. The Scenario 2 yield improvements with O3GE10 were larger than the Scenario 3 results with 03AVE--an inconsistent finding. Therefore, the O3AVE specification was used for all cotton scenarios; however, the O3GE10 results were roughly 10 percent larger for Scenario 2, and 100 percent larger for Scenario 1. For potatoes, the O3GE10 specification was used for Scenarios 1 and 2, and for Kern County for Scenario 3. A different specification examining only summer potatoes and using O3AVE was statistically weak, but was used for Scenario 3 in San Joaquin County.

The San Joaquin Valley regression estimates appear quite reasonable, if not conservative. As indicated in Appendix 2, grape yield losses were expected to be between those for cotton and alfalfa. These results are very close to the lower alfalfa figures. Potatoes also seem consistent with the chamber study evidence provided. Regression analysis based on the NCLAN chamber study results, (Heck et al. 1983) provide substantiation for the cotton and dry bean results (where x = seasonal daytime O3AVE):

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*O3GE10 equals 0 for Scenario 2, and is undefined for Scenario 3. Therefore, only regressions with O3GE6 or O3AVE could be used for Scenario 3.

Table 6-7
Selected Yield Functions

I. SJV Field Data Regression Results[1]

Crop	Equation	
Dry Beans	y = 1.3255 - .00802 (O3AVE) (-2.01)	N = 87, DF = 73, R^2 = .7682
	y = 1.1043 - .000871 (O3GE10) (-2.24)	N = 87, DF = 73, R^2 = .7710
	y = 1.044 tons/acre O3AVE = 69.2 O3GE10 = 69.12	
Cotton	y = .5345 - .00259 (O3AVE) (-1.39)	N = 72, DF = 59, R^2 = .8179
	y = .4624 - .000319 (O3GE10) (1.73)	N = 72, DF = 59. R^2 = .8209
	y = .440 tons/acre O3AVE =36.5 O3GE10 = 70.1	
Grapes	y = 7.629 - .00000166 $(O3GE6)^2$ (-1.72)	N = 72, DF = 59, R^2 = .8209
	y = 7.628 tons/acre O3GE6 = 494.7	
Potatoes	YP = 1.0872 - .00185 (O3GE10) - .0068 (SO_2GE10) (-1.17) (-1.30)	N = 26, DF = 15, R^2 = .7613
	YP = 1.004 O3GE10 = 26.9 SO_2GE10 = 4.9	

II. NCLAN Regression Results[2]

Crop (Variety)	Equation
Corn (Pooled)	y = 12277.3 - 301727 (x^2)
Wheat (Pooled)	y = 4852.8 - 169239 (x^2)
Grain Sorghum (Dekalb, A28+)	y = 8157.6 - 72388.3 (x^2)
Lettuce (Empire)	y = 1065 - 5978 (x)
Tomatoes (Murietta)	y = 67.1 - 38.85 (SO_2) - 1703 (x^2)

Table 6.7
Selected Yield Functions
(continued)

III. Brewer and Ashcroft[3]

Crop	Equation
Alfalfa	% $Y = -11.5 - .00677\ (O3GE10) - .00133\ (SO_2GE10)$ (-4.6) (-2.3) $N=11,\ DF=8,\ R^2=.796$

VI. Legend

Y	=	yield per acre
YP	=	yield adjusted by national productivity index
O3AVE	=	average hourly 0_3 per month summed over growing season pphm
O3GE10	=	number growing season daytime hours where $03 \leq 10$ pphm
O3GE6	=	number growing season daytime hours where $03 \leq 6$ pphm
SO_2GE10	=	number growing season daytime hours where $SO_2 \leq 10$ pphm
x	=	average daytime hourly 03 over the growing season in ppm
SO_2	=	average daytime SO_2 over the growing season

Note: Scenarios represent approximate hourly O standards. See Chapter 2.

Surces: Other variables evaluated at their means.

1. T-ratios reported in parentheses under air pollution coefficients. One tailed statistical tests are appropriate.

2. Heck et al. (1983)

3. Regressions on Brewer and Ashcroft results (1982). (See Appendix A2.)

Crop		Equation	
Cotton	Acala, SJ-2	$y = 1526.4\ e^{-\left(\frac{x}{.198}\right)^{1.28}}$	(6.1)
Dry Beans	California Light Red	$y = 2887 - 16304\ X$	(6.2)

Applying the NCLAN regression results to our ozone values results in yield adjustment values for cotton that are about 25 percent lower than the SJV results for each scenario, and for dry beans that are nearly identical for Scenario 1 and about one-third larger for Scenarios 2 and 3. These differences between the estimates could be attributed to differences in the mix of varieties used in the NCLAN experiments and those in the field, small differences in the measurement of the O3AVE variable, the fact that our calculations are tied to actual 1978 yield values rather than predicted values, differences in the range of observations over which the functions are estimated, and the differences in functional forms. Given the acknowledged uncertainty in ozone-yield loss estimates, these results are quite consistent.

Other Regression Analyses

Alfalfa yield adjustment factors were calculated from Equation A2.3, estimated by ERC using the more conservative WL 512 chamber study results of Brewer and Ashcroft (1982). This equation uses an O3GE10 ozone measure. Because there is little evidence that alfalfa yields are affected by exposures to ozone below 10 pphm, the yield losses for Scenario 3 are set equal to those for Scenario 2, which is felt to be a conservative assumption. Lettuce, tomatoes, corn, wheat, and grain sorghum yield adjustment coefficients were calculated using NCLAN regression analyses based on chamber study results (Heck et al., 1983) as provided in Table 6-7. NCLAN chamber studies were selected because many were conducted on California, and due to the consistent methodology across the studies with the design of our field dated regression analysis. This is particularly true with respect to the use of an ozone measure of average daytime hourly readings.

Assignment of Yield Adjustment Coefficients for Other Crops

Yield adjustment coefficients were assigned to the remaining crops based upon available chamber study evidence. These other crops were rated as sensitive, intermediate or tolerant, and assigned were yield adjustment coefficients from similar crops in the same category. (See Appendix Section A2.7 for further discussion). Available evidence suggested that many crops would experience zero or near zero yield losses at the ozone levels experienced in the SJV. These crops were assigned zero yield adjustment coefficients. For other crops the evidence was either inconclusive or insufficient to suggest what yield adjustments would be. (No chamber study or field data regression studies have been undertaken.) These crops were assigned zero yield adjustment coefficients and, further, the acreage planted in these crops was constrained to the amount of acreage in the existing 1978 base case. Crops where these assumptions were made are indicated by a check in the column of Table 6-8 labeled "Acreage Fixed." These crops account for less than eight percent of agriculture revenues in the SJV.

These acreage assumptions are conservative because ozone yield losses can only be equal to or greater than zero. The acreage assumption requires further discussion. Using apples and grapes as examples, if air pollution conditions improve, the yield per acre of grapes will increase, while the yield per acre of apples remains constant. Consequently, there would be incentive to substitute acreage out of apples and into grapes. If the zero yield adjustment assumption for apples is incorrect, the acreage substitution that would be predicted in the CAR model would be incorrect (overstated). While unlikely, this incorrect substitution could offset the understatement of benefits due to understating the yield adjustment coefficient. However, whether the zero yield adjustment is correct or not, combined with the fixed acreage assumption, the benefit estimates are understated.

6.5 ECONOMIC MEASURES OF AIR POLLUTION DAMAGES TO AGRICULTURE IN THE SAN JOAQUIN VALLEY

Estimation of the economic effects of air pollution yield reductions in the SJV was performed using the CAR model discussed in Chapter 5. Effects are estimated for changes in production, acreage, prices, resource use, and economic welfare (consumers' and producers' surplus) measures.

Table 6-8
Yield Adjustment Coefficients*

	Acreage Fixed	Scenario 1 (12 pphm)				Scenario 2 (10 pphm)				Scenario 3 (8 pphm)			
CAR Model Area		3	8	10	11	3	8	10	11	3	8	10	11
<u>Crop</u>													
Almonds		0	0	0	0	0	0	0	0	0	0	0	0
Alfalfa and Alfalfa Seed		4.9	4.0	5.4	5.3	10.0	8.0	10.7	11.1	10.0	8.0	10.7	11.1
Apples	x	0	0	0	0	0	0	0	0	0	0	0	0
Asparagus	x	0	0	0	0	0	0	0	0	0	0	0	0
Avacados	x	0	0	0	0	0	0	0	0	0	0	0	0
Barley		4.0	3.8	3.9	3.6	7.5	7.4	8.4	7.5	9.0	8.8	10.6	8.7
Cantelope	x	0	0	0	0	0	0	0	0	0	0	0	0
Carrots		1.8	2.2	3.9	2.2	4.7	4.4	4.0	4.5	4.9	5.1	6.5	6.7
Cauliflower	x	0	0	0	0	0	0	0	0	0	0	0	0
Corn		2.7	2.7	2.8	1.5	5.1	5.3	6.0	4.3	6.1	6.2	7.6	4.9
Cotton		--	5.0	5.5	4.8	--	18.0	22.2	17.0	--	21.0	22.4	19.3
Dry Beans		7.4	7.3	8.5	7.7	14.8	14.6	17.0	15.4	17.5	18.9	21.4	19.5
Grain Hay		4.0	3.8	3.8	3.6	7.5	7.4	8.4	7.5	9.0	8.8	10.6	8.7
Grain Sorghum		.9	.9	.9	.8	1.7	1.7	2.2	1.9	2.1	2.1	2.9	2.3
Grapes		5.4	4.9	4.4	6.4	10.2	8.4	9.1	12.5	10.5	8.7	9.3	12.7
Lemons		0	0	0	0	0	0	0	0	0	0	0	0
Lettuce		--	--	4.8	5.3	--	--	7.2	9.7	--	--	10.9	13.3
Nectarines		0	0	0	0	0	0	0	0	0	0	0	0
Onions, dry	x	0	0	0	0	0	0	0	0	0	0	0	0
Oranges	x	0	0	0	0	0	0	0	0	0	0	0	0
Pasture, Irrigated		4.0	3.8	3.8	3.6	7.5	7.4	8.4	7.5	9.0	8.8	10.6	8.7
Peaches		0	0	0	0	0	0	0	0	0	0	0	0
Pears	x	0	0	0	0	0	0	0	0	0	0	0	0
Plums	x	0	0	0	0	0	0	0	0	0	0	0	0
Potatoes		12.2	--	--	6.0	24.5	--	--	11.1	32.4	--	--	11.1
Prunes	x	0	0	0	0	0	0	0	0	0	0	0	0
Rice		0	0	0	0	0	0	0	0	0	0	0	0

Table 6-8

Yield Adjustment Coefficients

(continued)

	Acreage Fixed	Scenario 1 (12 pphm)				Scenario 2 (10 pphm)				Scenario 3 (8 pphm)			
CAR Model Area		3	8	10	11	3	8	10	11	3	8	10	11
Crop													
Safflower		1.8	2.2	3.9	2.2	4.7	4.4	4.0	5.4	4.9	5.1	6.5	6.7
Silage		2.7	2.7	2.8	1.5	5.1	5.3	6.0	4.3	6.1	6.2	76	4.9
Sugar Beets		0	0	0	0	0	0	0	0	0	0	0	0
Tomatoes		1.8	2.2	3.9	2.2	4.7	4.4	4.0	5.4	4.9	5.1	6.5	6.7
Walnuts	x	0	0	0	0	0	0	0	0	0	0	0	0
Wheat		4.0	3.8	3.8	3.6	7.5	7.4	8.4	7.5	9.0	8.8	10.6	8.7

* Coefficients represent the percent increase in yields per acre under the scenarios as compared to actual 1978 yields.

Scenarios represent alternative approximate hourly ozone standards (see Chapter 2).

Production and Acreage Effects

The varying levels of ozone in the San Joaquin Valley have differential effects on the various study crops and regions. These changes in production, in turn, alter the relative economic returns to cropping alternatives. Despite the use of a 1978 base year, the CAR model assumes that the changes in expected yield depression from ozone will take place slowly enough for farmers to anticipate the price effects and adjust accordingly.

Estimates of the projected production levels by selected crop and region under the 1978 base case and three ozone-level scenarios, are summarized in Table 6-9. In general, increased yields due to reduced ozone levels result in increased total production of the major crops in each region and statewide. Among the crops, cotton shows the most substantial change in production levels, with statewide production increasing from the base case by 3.6 to 12.6 percent under the alternative Scenarios. For crops that supply a major portion of U.S. demand, and are therefore relatively price responsive, production changes are lower. Examples of these crops are lettuce, grapes and tomatoes, where increases in per acre yields are largely offset by reduction in planted acreage due to price and revenue effects of greater production. Increased yields for low-valued crops such as alfalfa are substantially offset by reductions in planted acreages. For example, alfalfa yields are estimated to increase by about 10 percent under Scenario 2, but statewide production increases by only 1.9 percent.

Although some regional variation in acreage response is evident, regional shifts generally parallel statewide changes and no major shifts in regional acreage are evident.

In Table 6-10, projection of regional and statewide acreages by selected crops under the base case and alternative scenarios are presented. Under each scenario, planted acreage in each region and statewide generally decreases. This is the result of the decrease in expected price and revenues which could result from increased yields and supplies. Acreage reductions are largest for the high-value, price-sensitive crops. For grapes, lettuce, and tomatoes, the reduction in acreage relative to the base is reported in Table 6-11.

Table 6-9

Projected Production Levels for Selected Crops Under Alternative Ozone Scenarios*

(tons)

Area/Crop	1978 Existing Production	Scenario 1 (12 pphm) Production	Scenario 1 (12 pphm) % Change	Scenario 2 (10 pphm) Production	Scenario 2 (10 pphm) % Change	Scenario 3 (8 pphm) Production	Scenario 3 (8 pphm) % Change
San Joaquin County (Region 3)							
Alfalfa	345,007	351,311	+1.8	357,255	+3.6	357,255	+3.6
Barley	39,547	40,385	+2.1	41,028	+3.7	41,307	+4.5
Carrots	- NA -						
Corn	283,744	288,333	+1.6	292,192	+3.0	293,754	+3.5
Cotton	- NA -						
Table Grapes	190,614	191,066	-0.2	190,867	+0.1	190,777	+0.1
Lettuce	11,540	11,493	-0.4	11,460	-0.7	11,434	-0.9
Tomatoes	668,137	671,758	+0.5	677,412	+1.4	677,618	+1.4
Wheat	67,094	68,261	+1.7	69,225	+3.2	69,600	+3.7
Northern (Region 8)							
Alfalfa	499,081	506,674	+1.5	513,545	+2.9	513,546	+2.9
Barley	54,000	55,432	+2.7	56,675	+5.0	56,277	+4.5
Carrots	- NA -						
Corn	71,120	72,942	+2.6	74,601	+4.9	75,173	+5.7
Cotton	31,668	32,704	+3.3	34,937	+10.3	35,413	+11.8
Raisin Grapes	52,127	53,151	+2.0	53,506	+2.7	53,578	+2.8
Lettuce	- NA -						
Tomatoes	350,558	352,603	+0.6	354,479	+1.1	355,116	+1.3
Wheat	34,226	34,882	+1.9	35,455	+3.6	35,673	+4.2
Eastern (Region 10)							
Alfalfa	1,132,819	1,159,506	+2.4	1,182,647	+4.4	1,182,647	+4.4
Barley	117,390	182,239	+2.7	187,447	+5.7	189,963	+7.1
Carrots	- NA -						
Corn	83,411	85,990	+3.1	88,738	+6.4	90,088	+8.0
Cotton	157,773	164,232	+4.1	279,072	+13.5	181,692	+15.2
Raisin Grapes	172,4070	1,743,597	+1.1	1,763,892	+2.3	1,764,775	+2.4
Lettuce	- NA -						
Tomatoes	40,255	40,879	+1.5	40,818	-1.4	41,210	+2.4
Wheat	97,889	100,367	+2.5	103,124	+5.3	104,349	+6.6

Table 6-9

(continued)

Projected Production Levels for Selected Crops Under Alternative Ozone Scenarios*

(tons)

Area/Crop	1978 Existing Production	Scenario 1 (12 pphm)		Scenario 2 (10 pphm)		Scenario 3 (8 pphm)	
		Production	% Change	Production	% Change	Production	% Change
Westside (Region 11)							
Alfalfa	1,143,688	1,194,289	+4.4	1,244,553	+8.8	1,244,549	+8.8
Barley	480,412	500,903	+4.3	521,649	+8.6	527,711	+9.8
Carrots	201,287	203,336	+1.0	205,499	+2.1	206,915	+2.8
Corn	35,913	36,451	+1.5	37,437	+4.2	37,631	+4.8
Cotton	501,098	520,173	+3.8	559,938	+11.7	566,820	+13.1
Raisin Grapes	256,963	261,813	+1.9	265,209	+3.2	265,257	+3.2
Lettuce	213,784	221,852	+3.8	227,744	+6.5	232,227	+8.6
Tomatoes	1,020,671	1,029,145	+0.8	1,041,030	+2.0	1,045,943	+2.5
Wheat	129,893	134,196	+3.3	138,510	+6.6	139,742	+7.6
STATE TOTALS							
Alfalfa	6,625,407	6,689,366	+1.0	6,749,848	+1.9	6,749,847	+1.9
Barley	917,526	944,857	+3.0	972,347	+6.0	981,572	+7.0
Carrots	582,163	583,325	+0.2	584,552	+0.4	585,356	+0.5
Corn	995,590	1,009,840	+1.4	1,023,048	+2.8	1,028,327	+3.3
Cotton	736,047	762,476	+3.6	819,011	+11.3	828,936	+12.6
Raisin Grapes	2,033,154	2,058,561	+1.2	2,082,606	+2.4	2,083,610	+2.5
Lettuce	2,388,993	2,389,729	0	2,390,268	+0.1	2,390,679	+0.1
Tomatoes	5,651,784	5,666,277	+0.3	5,685,978	+0.6	5,691,009	+0.7
Wheat	1,230,343	1,240,366	+0.8	1,250,093	+1.6	1,253,588	+1.9
Table Grapes	494,362	498,750	+0.9	502,782	+1.7	502,922	+1.7

*Scenarios represent alternative approximate hourly ozone standards.

Table 6-10

Projected Acreage for Selected Crops Under Alternative Ozone Scenarios*

Area/Crop	1978 Existing Acreage	Scenario 1 (12 pphm)		Scenario 2 (10 pphm)		Scenario 3 (8 pphm)	
		Acreage	% Change	Acreage	% Change	Acreage	% Change
San Joaquin County (Region 3)							
Alfalfa	50,366	48,888	-3.0	47,413	-5.9	47,413	-5.9
Barley	22,093	21,689	-1.9	21,324	-3.5	21,172	-4.2
Carrots	- N/A -						
Corn	79,037	78,202	-1.1	77,443	-2.1	77,121	-2.4
Cotton	- NA -						
Table Grapes*	20,343	19,346	-4.9	18,477	-9.2	18,433	-9.4
Lettuce	1,050	1,043	-0.7	1,046	-0.4	2,040	-0.9
Tomatoes	27,920	27,576	-0.13	27,042	-3.2	16,997	-3.3
Wheat	27,274	26,686	-2.2	26,172	-4.1	25,960	-4.8
Northern (Region 8)							
Alfalfa	76,900	75,063	-2.4	73,269	-4.7	73,269	-4.7
Barley	36,000	35,602	-1.1	35,180	-2.3	35,013	-2.7
Carrots	- NA -						
Corn	25,220	25,187	-0.1	25,127	-0.4	25,099	-0.5
Raisin Grapes*	7,072	6,875	-2.8	6,694	-5.3	6,688	-5.4
Lettuce	- NA -						
Tomatoes	13,900	13,683	-1.6	13,463	-3.1	13,396	-3.6
Wheat	13,700	15,414	-1.8	15,145	-3.5	15,039	-4.2
Eastern (Region 10)							
Alfalfa	165,375	160,596	-2.9	155,960	-5.7	155,960	-5.7
Barley	109,500	108,282	-1.1	106,747	-2.5	106,006	-3.2
Carrots	- NA-						
Corn	29,370	29,449	+0.3	29,481	+0.4	29,479	+0.4
Cotton	355,345	350.924	-1.2	335,970	-5.5	332,769	-6.4
Raisin Grapes*	207,220	220,736	-3.1	194,325	-6.2	194,059	-6.4
Lettuce	- NA-						
Tomatoes	1,868	1,826	-2.3	1,821	-2.5	1,796	-3.9
Wheat	48,460	47,862	-1.2	47,089	-2.8	46,710	-3.6

*Table grapes used in Region 3, raisin grapes in Regions 8,10,11

Table 6-10

(continued)

Projected Acreage for Selected Crops Under Alternative Ozone Scenarios*

Area/Crop	1978 Existing Production	Scenario 1 (12 pphm) Acreage	Scenario 1 (12 pphm) % Change	Scenario 2 (10 pphm) Acreage	Scenario 2 (10 pphm) % Change	Scenario 3 (8 pphm) Acreage	Scenario 3 (8 pphm) % Change
Westside (Region 11)							
Alfalfa	157,100	155,790	-0.8	153,877	-2.1	153,876	-2.1
Barley	292,934	294,822	+0.6	295,887	+1.0	295,968	+1.0
Carrots	11,385	11,253	-1.2	11,120	-2.3	10,971	-3.6
Corn	11,050	11,049	0	11,043	-0.1	11,039	-0.1
Cotton	976,800	966,865	-1.0	933,230	-4.5	926,176	-5.2
Raisin Grapes	25,094	24,020	-4.3	23,022	-8.3	22,986	-8.4
Lettuce	17,021	16,769	-1.5	16,527	-2.9	16,320	-4.1
Tomatoes	43,030	42,456	-1.3	41,641	-3.2	41,325	-4.0
Wheat	58,775	58,601	-0.3	58,295	-0.8	58,178	-1.0
STATE TOTALS							
Alfalfa	1,013,448	998,229	-1.5	982,882	-3.0	982,881	-3.0
Barley	564,100	563,452	-0.1	561,691	-0.4	560,533	-0.6
Carrots	34,214	34,028	-0.5	33,839	-1.1	33,653	-1.6
Corn	293,322	291,592	-0.6	289,942	-1.2	289,224	-1.4
Cotton	1,498,984	1,483,144	-1.1	1,430,552	-4.6	1,419,393	-5.3
Raisin Grapes	239,388	231,632	-3.2	224,044	-6.4	223,733	-6.5
Table Grapes	68,418	65,993	-3.5	63,798	-6.8	63,715	-6.9
Lettuce	173,832	173,049	-0.5	172,419	-0.8	171,916	-1.1
Tomatoes	236,464	234,792	-0.7	232,485	-1.7	231,930	-1.9
Wheat	559,350	556,648	-0.5	553,846	-1.0	552,654	-1.2

* Scenarios represent alternative approximate hourly ozone standards.

Table 6-11

Change in Acreage for Grapes, Lettuce and Tomatoes by Region

	Percent Change in Acreage from Base Case		
	Scenario 1 (12pphm)	Scenario 2 (10pphm)	Scenario 3 (8pphm)
Grapes			
Region 3	- 4.9	- 9.2	- 9.4
Region 8	- 2.8	- 5.3	- 5.4
Region 10	- 3.1	- 6.2	- 6.4
Region 11	- 4.3	- 8.3	- 8.4
Statewide	- 3.2	- 6.4	- 6.5
Lettuce			
Region 3	- 0.4	- 0.7	- 0.9
Region 11	- 1.5	- 2.9	- 4.1
Statewide	- 0.5	- 0.8	- 1.1
Tomatoes			
Region 3	- 1.3	- 3.2	- 3.3
Region 8	- 1.6	- 3.1	- 3.6
Region 10	- 2.3	- 2.5	- 3.9
Region 11	- 3.2	- 1.3	- 4.0
Statewide	- 0.5	- 1.7	- 1.2

As indicated by the information in Table 6-9, production levels for these crops are projected to increase. The results therefore suggest that per acre yield increases will be partially offset by reductions in planted acres.

Because price is relatively inelastic with respect to California production levels, acreage reduction for cotton is much smaller in response to equivalent yield increases than the crops discussed above. For example, cotton yields in Region 11 are estimated to increase by 17 percent under Scenario 2, while planted acreage declines by only 4.5 percent.

Regional Production Shifts

Under the alternative scenarios, ozone pollution in areas of California outside the San Joaquin Valley are assumed to stay constant at the 1978 base levels. As yields are varied in the study area, comparative cost-of-production advantages between the SJV and other production regions will be altered.

In Table 6-12, estimates of the shares of total state production, by selected crops for the study regions are presented. In general, the interregional shifts in production due to changes in ozone incidence appear to be relatively minor. For example, tomato production in the San Joaquin study region accounts for 36.8 percent of statewide production under the base case. Under the different scenarios, the largest change is a 0.4 percent increase in total state share. Similar results are found for cotton, where the SJV share is 93.8 percent for the base case and 93.3 to 94.6 percent under the alternative scenarios. These results are consistent with the earlier discussion of offsetting yield and price effects (Chapter 5). As yields increase, expected prices decrease, and planted acreages decline. For lower-valued crops such as alfalfa and barley, price effects are weaker and some production shifts among regions are predicted.

Price Effects

As yields increase, market prices will be affected. This is particularly true for crops such as grapes and tomatoes, for which SJV production represents a large portion of national supplies. These price changes, however, are predicted to be largely offset by farmers' response in terms of decreasing (with ozone reductions) planted acreage. Projected prices for selected crops under the base case and alternative scenarios as presented in Table 6-13. For most crops, projected price changes relative to the base case are less than one percent. Small declines in prices are forecast because yield increases are not totally offset by acreage reductions. Projected prices change up to 2.4 percent. Price changes are most significant for grapes. The relative sensitivity of grape prices reflects the SJV's dominant position in national markets and the lag time involved in changing acreages for perennial crops. For the high value crops, a comparatively small percentage change in price can have a significant effect on net revenues.

Table 6-12

Regional Production Shifts For Selected Crops Under Alternatiive Ozone Scenarios
(tons)

Area/Crop	1978 Existing Production	% of State	Scenario 1 (12 pphm) Production	Scenario 1 (12 pphm) % of State	Scenario 2 (10 pphm) Production	Scenario 2 (10 pphm) % of State	Scenario 3 (8 pphm) Production	Scenario 3 (8 pphm) % of State
(Region 3)								
Alfalfa	345,007	5.2	351,311	5.3	357,255	5.3	357,255	5.3
Barley	39,547	4.3	40,385	4.3	41,028	4.2	41,307	4.2
Carrots	- NA -							
Corn	283,744	28.5	288,333	28.6	292,192	28.6	293,754	28.6
Cotton	- NA -							
Table Grapes	190,614	38.6	191,066	38.3	190,867	38.0	190,777	37.9
Lettuce	11,540	0.5	11,493	0.2	11,460	0.2	11,434	0.2
Tomatoes	668,137	11.8	671,758	11.9	677,412	11.9	677,618	11.9
Wheat	67,094	5.5	68,261	5.5	69,225	5.5	69,600	5.6
(Region 8)								
Alfalfa	499,081	7.5	506,674	7.6	513,545	7.6	513,546	7.6
Barley	54,000	5.9	55,432	5.9	56,675	5.8	56,277	5.7
Carrots	- NA -							
Corn	71,120	7.1	72,942	7.2	74,601	7.3	75,173	7.3
Cotton	31,668	4.3	32,704	4.3	34,937	4.3	35,413	4.3
Raisin Grapes	52,121	2.6	53,151	2.6	53,506	2.6	53,578	2.6
Lettuce	- NA -							
Tomatoes	350,558	6.2	352,603	6.2	354,479	6.2	355,116	6.2
Wheat	34,226	2.8	34,882	2.8	35,455	2.8	35,673	2.8
(Region 10)								
Alfalfa	1,132,819	17.0	1,159,506	17.3	1,182,647	17.5	1,182,647	17.5
Barley	117,390	12.8	182,239	19.3	187,447	19.3	189,963	19.4
Carrots	- NA -							
Corn	83,411	8.4	85,990	8.5	88,738	8.7	90,088	8.8
Cotton	157,773	21.4	164,232	21.5	179,072	21.9	181,692	21.9
Raisin Grapes	1,724,070	84.8	1,743,597	84.7	1,763,891	84.7	1,764,775	84.7
Lettuce	- NA -							
Tomatoes	40,255	0.7	40,879	0.7	40,818	0.7	41,210	0.7
Wheat	97,889	8.0	100,367	8.1	103,124	8.2	104,349	8.3

Table 6-12

Regional Production Shifts For Selected Crops Under Alternatiive Ozone Scenarios
(tons)

Area/Crop	1978 Existing Production	% of State	Scenario 1 (12 pphm)		Scenario 2 (10 pphm)		Scenario 3 (8 pphm)	
			Production	% of State	Production	% of State	Production	% of State
(Region 11)								
Alfalfa	1,143,688	17.3	1,194,289	17.9	1,244,553	18.4	1,244,549	18.4
Barley	480,412	52.4	500,903	53.0	521,649	53.6	527,711	53.8
Carrots	201,284	35.6	203,336	20.1	205,499	35.2	206,915	35.3
Corn	35,913	3.6	36,451	3.6	37,437	3.7	37,631	3.7
Cotton	501,198	68.1	520,173	68.2	559,938	68.4	566,820	68.4
Raisin Grapes	256,963	12.6	261,813	12.7	265,209	12.7	265,257	12.7
Lettuce	213,784	8.9	221,852	9.0	227,744	9.6	232,227	9.7
Tomatoes	1,020,671	18.1	1,029,145	18.2	1,0410,030	18.3	1,045,943	18.4
Wheat	129,893	10.6	134,196	10.8	138,510	11.1	139,742	11.1
San Joaquin Valley Total								
Alfalfa	3,120,595	47.1	3,211,779	48.0	3,2,000	48.9	3,297,997	48.9
Barley	691,349	75.3	778,959	82.4	806,799	83.0	815,258	83.1
Carrots	201,287	35.6	203,336	20.1	205,499	35.2	206,915	35.3
Corn	474,188	47.6	483,716	47.9	492,968	48.2	496,646	48.3
Cotton	690,539	93.8	717,109	94.1	773,947	94.5	783,925	94.6
Raisin Grapes	2,033,154	100.0	2,058,561	100.0	2,082,606	100.0	2,083,610	100.0
Lettuce	225,324	9.4	233,345	9.8	239,204	10.1	243,661	10.2
Tomatoes	2,079,622	36.8	2,094,385	37.0	2,113,739	37.2	2,119,887	37.2
Wheat	32,9102	26.7	337,706	27.2	346,324	27.7	349,364	27.9

* Scenarios represent alternative approximate hourly ozone standards.

Table 6-13

Projected Prices for Selected Crops Under Alternative Ozone Scenarios*
(1978 $/ton)

Crop	1978 Existing Price	Scenario 1 (12 pphm)		Scenario 2 (10 pphm)		Scenario 3 (8 pphm)	
		Price/Unit	% Change	Price/Unit	% Change	Price/Unit	% Change
Alfalfa	77.44	77.13	-0.4	76.84	-0.8	76.84	-0.89
Barley	127.04	126.84	-0.2	126.61	-0.4	126.53	-0.4
Carrots Q1*	160.85	169.79	0.0	167.73	-0.1	160.68	-0.1
Carrots Q2	160.85	160.79	0.0	167.73	-0.1	160.68	-0.1
Carrots Q3	160.85	160.79	0.0	167.73	-0.1	160.68	-0.1
Carrots Q4	160.85	160.79	0.0	167.73	-0.1	160.68	-0.1
Corn	136.79	136.73	0.0	136.68	-0.1	136.66	-0.1
Cotton	1,406.04	1,404.12	-0.1	1,400.03	-0.4	1,399.31	-0.5
Raisin Grapes	153.04	151.75	-0.8	150.53	-1.6	150.48	-1.7
Table Grapes	233.56	230.61	-1.3	227.89	-2.4	227.79	-0.25
Lettuce Q1	174.91	174.72	-0.1	174.58	-0.2	174.48	-0.2
Lettuce Q2	174.91	174.72	-0.1	174.58	-0.2	174.48	-0.2
Lettuce Q3	174.91	174.72	-0.1	174.58	-0.2	174.48	-0.2
Lettuce Q4	174.91	174.72	-0.1	174.58	-0.2	174.48	-0.2
Tomatoes	61.75	61.70	-0.1	61.64	-0.2	61.63	-0.2
Wheat	138.38	138.34	0.0	138.31	-0.1	138.29	-0.1

* Q# refers to the quarter during the year

Scenarios represent alternative approximate hourly ozone standards.

Resource Use

As yields vary, demand for productive inputs will change. In Table 6-14, projected uses of land, water and nitrogen are presented under the base case and alternative scenarios. Total acreage in each region decreases as yields increase. These acreage changes do not exceed three percent in any of the regions, and are generally between one and two percent. Changes in the use of irrigation and nitrogen follow these patterns, although the percentage changes from the base case in a given region are generally smaller than the land use changes. Two reasons account for this; the larger acreages are in the more extensive field crops, such as cotton, that use less nitrogen and water per acre than the intensive high-value crops; and these extensive and comparatively low valued crops react with greater proportional acreage changes to the various ozone scenarios.

Changes in Economic Welfare

As discussed in Chapter 5, changes in market-clearing price and quantities of the study crops due to yield-induced shifts in supply will affect the economic welfare of producers and consumers in these markets. Estimates of these changes in economic welfare, as measured by consumers' and producers' surplus, are summarized in Tables 6.15 - 6.17.

A measure of the overall economic effect of the scenarios is shown in the state total row in Table 6-15. Changes in the sum of the surpluses are $42.7 million for Scenario 1, $106.1 million for Scenario 2 and $117.5 million for Scenario 3 (Table 6-14). In all scenarios the dominant economic effect falls on the producers. In dollar terms (of surplus) the benefits and losses are distributed in an approximate ratio of 1:3 between consumers and producers. For example, the change induced under Scenario 2 is $28.7 million in consumers' surplus and $78.2 million change in producers' surplus. The percentage change shows a 1:4 distribution ratio due to the larger absolute value of the consumers' surplus. The magnitude of effects among the scenarios ranges up to increases of 1.2 percent in consumers' surplus and 5.1 percent in producers' surplus under Scenario 3. The present value of the change in the objective function value for Scenario 3 relative to the base case over a 25 year period at seven percent, as an example discount rate, is approximately $1.37 billion.

Table 6-14

Projected Resource Use For Selected Crops Under Alternative Ozone Scenarios

Area/Resource	1978 Existing Resource Use	Scenario 1 (12 pphm)		Scenario 2 (10 pphm)		Scenario 3 (8 pphm)	
		Resource Use	% Change	Resource Use	% Change	Resource Use	% Change
Region 3							
Land (acres)	939,224	930,362	-0.9	919,949	-2.1	917,766	-2.3
Water (ac/ft)	2,751,751	2,732,953	-0.7	2,707,731	-1.6	2,703,817	-1.7
Nitrogen (tons)	51,426	51,019	-0.8	50,562	-1.7	50,421	-2.0
Region 8							
Land	797,149	792,754	-0.6	784,149	-1.5	782,846	-1.8
Water	2,979,740	2,969,176	-0.4	2,945,084	-1.2	2,939,790	-1.3
Nitrogen	38,808	38,687	-0.3	38,417	-1.0	38,329	-1.2
Region 10							
Land	1,473,392	1,459,629	-0.9	1,435,773	-2.5	1,434,241	-2.7
Water	5,106,755	5,066,445	-0.8	3,992,371	-2.2	3,793,404	-2.2
Nitrogen	60,833	60,495	-0.6	59,629	-2.0	59,507	-2.2
Region 11							
Land	2,096,141	2,084,421	-0.6	2,047,163	-2.3	2,039,609	-2.7
Water	6,758,678	6,717,465	-0.6	6,591,499	-2.5	6,567,268	-2.8
Nitrogen	100,497	99,890	-0.6	98,080	-2.4	97,664	-2.8
STATE TOTALS							
Land	9,524,633	9,455,654	-0.7	9,347,271	-1.9	9,325,223	-2.1
Water	33,556,458	33,375,045	-0.7	32,556,458	-1.7	32,913,970	-1.9
Nitrogen	465,477	463,130	-0.5	458,880	-1.4	457,799	-1.6

* Scenarios represent alternative approximate hourly ozone standards.

Table 6-15

Consumer's and Producer's Surplus Under Alternative Ozone Scenarios
($ millions)

Region	Base Case		Scenario 1 (12 pphm)		Scenario 2 (10 pphm)		Scenario 3 (8 pphm)	
	Consumer Surplus	Producer Surplus	Consumer Surplus	Producer Surplus	Consumer Surplus	Producer Surplus	Consumer Surplus	Producer Surplus
San Joaquin County	117.6	112.1	120.6	114.1	121.7	115.8	121.8	116.1
% Change			+ 2.6	+ 1.7	+ 3.5	+ 3.2	+ 3.6	+ 3.5
Region 8	122.2	145.3	113.7	148.1	115.1	151.3	115.5	152.1
% Change			- 6.9	+ 1.9	- 5.8	+ 4.1	- 5.4	+ 4.7
Region 10	401.7	293.4	407.9	302.3	413.8	316.7	415.0	319.5
% Change			+ 1.6	+ 3.0	+ 3.0	+ 8.0	+ 3.3	+ 3.9
Region 11	274.5	343.5	290.3	361.7	297.6	393.5	302.3	399.1
% Change			+ 5.8	+ 5.3	+ 8.4	+14.6	+10.1	+16.2
San Joaquin Total	915.9	894.3	932.4	926.1	948.2	977.3	954.7	986.8
% Change			1.8	+ 3.5	+ 3.5	+ 9.3	+ 4.2	+10.3
State Total	2,629.0	1,721.9	2,642.4	1,751.1	2,656.7	1,800.1	2,659.3	1,809.0
% Change			+ 0.5	+ 1.7	+ 1.1	+ 4.5	+ 1.2	+ 5.1

* Scenarios represent alternative approximate hourly ozone standards.

Table 6-16

Benefits of Air Pollution Improvements in the San Joaquin Valley, 1978, All Crops

(in millions of dollars)

	Scenario 1 (12 pphm)	Scenario 2 (10 pphm)	Scenario 3 (8 pphm)
I. Statewide			
Total Consumers & Producers	$42.6	$105.9	$117.4
To Consumers	13.4	27.7	30.3
To Producers	29.2	78.2	87.1
II. In the San Joaquin Valley			
To All SJV Producers	31.8	82.9	92.5
To Producers in Region 11	18.2	49.9	55.6
To Producers in Region 10	8.9	23.3	26.1
To Producers in Region 8	2.8	6.0	6.8
To Producers in San Joaquin County	1.9	3.7	4.0

Table 6-17

Producers' and Consumers' Benefits of Air Pollution Improvements in the San Joaquin Valley, 1978 Selected Crops, Scenario 3

($ millions)

Crop	Producers in the San Joaquin Valley	Producers Statewide (Including the SJV)	All Consumers
Cotton	$58.2	$57.8	$4.3
Grapes	9.2	8.5	11.0
Alfalfa	6.3	6.1	4.3
Pasture	4.2	2.3	3.2
Tomatoes	2.1	1.3	1.3
Dry Beans	1.7	0.9	1.6
Barley	3.9	3.8	0.7
Lettuce	1.0	0.1	0.9
Potatoes	1.1	0.8	0.7
Wheat	1.8	1.8	0.1
Corn	3.2	2.4	0.1

The distribution of the producers' surplus benefits in terms of percentage change from the base case differed significantly across regions. Under all improvement scenarios, San Joaquin County had the smallest percentage increase in producers' surplus while Region 11, which is largely Kern County, showed percentage gains several times greater than San Joaquin County. This regional difference is due to two factors -- the regional crop specialization and the level of ambient ozone in the 1978 base year.

The differences in regional losses emphasize the importance of a regional level analysis of the effects on producers. However, the importance of the change in consumers' surplus and the interregional price effects highlight the need to link the regions through the shared market structure. The results show the interactive and sometimes contradictory result of these two effects on the welfare of local regional producer and state and national consumers.

The importance of the use of an economic model rather than simple damage functions can be illustrated with the Scenario 3 results for cotton and grapes. The simple damage function estimate of losses (change in yield per acre times existing price and acres in the SJV) is $96.6 million, 67 percent more than the economic estimate of losses to producers statewide, and 56 percent more than the combined losses to producers and consumers. The comparison for grapes is even more dramatic because of the stronger price effect of increases in supply. The damage function approach estimate for grapes in the SJV is $71.2 million, 8.4 times that estimated with the economic and behavioral model to producers statewide, and 3.6 times the total for producers and consumers. Because of the conceptual inaccuracy of the damage function approach, such estimates for other crops were not undertaken.

6.6 ACCURACY OF THE ECONOMIC ESTIMATES

This chapter has presented point estimates of the economic benefits to agricultural producers and consumers from improvements in air pollution in the SJV. These estimates are subject to potential inaccuracies and biases, many of which cannot be quantified. Consequently, it is impossible to determine statistical confidence intervals around the point estimates. However, conservative procedures and assumptions have generally been used throughout the analysis so the reported benefit estimates are felt to be understated. This section reviews some of the more important biases and inaccuracies.

Many of the factors leading to the conclusion that the estimates are conservative concern the determination of the yield increases from improved air pollution conditions. The regression equations for estimating yield losses are subject to inaccuracies due to measurement error in the variables and functional forms specifications. This measurement error arises from the difficulty in measurement and in aggregating across large geographic areas and across the entire growing season. Changes in varieties through time further complicate the problem. For most variables, if these errors are random and uncorrelated with the O_3 and SO_2 variables, they have no biasing effect; however, measurement error in the pollution variables biases their regression coefficient toward zero, and results in smaller yield adjustment coefficients due to air pollution. (See Section 4.4.) Next, the limited ability to measure other farm input variables, especially those which might be used to mitigate ozone damages (antioxidants, water usage, etc.) can further bias the yield adjustment coefficients toward zero. (See Section 4.6)

The most important reason the estimates are felt to be conservative is that when there were several estimates which were conceptually and statistically reasonable, a conservative (lower yield loss) specification was selected. Seventeen crops were assigned zero yield losses from ozone, even though some may have experienced small damages at 1978 ozone levels, because the evidence was insufficient to estimate what those losses might have been. These crops include five of the top ten crops in the SJV in terms of gross receipts. The remaining top-ten crops include cotton, alfalfa and grapes, for which the yield loss estimates are all conservative compared to other published estimates, and tomatoes and wheat, for which the NCLAN results were used.

Factors in the execution of the CAR model contribute to providing conservative benefit estimates. Acreage changes for many crops were either limited to 0 or 10 percent, thus constraining crop substitution when it might be beneficial to increase crop substitution (See Section 5.5). Similarly, all other farm inputs are held in fixed proportion, limiting technological and input adjustments which could be beneficial. Finally, the change in price from a change in quantity coefficients in the CAR model price forecasting equations are larger than those used in other similar studies resulting in smaller changes in economic surplus due to changes in air pollution, relative to those studies. (See Chapter 5 and Appendix A1.)

Scenario 3 is a conservative estimate of the maximum ozone damage, as chamber studies have shown small yield losses for some crops when there exist prolonged exposure to O_3 levels less than 8 pphm. For crops such as alfalfa where yield losses due to exposures less than 10 pphm have not been documented, even though they might exist, the yield adjustment coefficients for Scenario 3 are set equal to those for Scenario 2.

There are at least three factors which may result in offsetting upward biases in the economic estimates. First, ozone resistant varieties are constantly being developed so yield losses from the same ozone exposure are declining. This effect is thought to be small, as it was considered in the selection of yield functions and reductions in air pollution would reduce the need for expenditures to develop ozone resistant cultivars. Second, as identified above, the CAR model forces inputs to be used in the same fixed proportion in all scenarios. However, as yields increase, so may harvesting effort and expenditures, thus offsetting some of the gains. The magnitude of this omission is uncertain, but is currently being addressed by a national economic study of ozone damage to agriculture conducted by Resources for the Future, in Washington, D.C. for the U.S. EPA Office of Air Quality Planning and Standards. The third important potential upward bias is in the design of the analysis, which considers only air quality improvements in the SJV rather than the entire state. If such improvements only occur in the SJV, the analysis of the economic benefits is sound. If, however, air quality improvements occur simultaneously throughout the state, the benefits from air quality improvements in the SJV will be overstated. Due to the dominance within the state of the SJV in the production of these agricultural crops, this effect is expected to be relatively small.

The procedures and design of the analysis are not amenable to formal statewide confidence interval determination, but some subjective comments can be made based upon the above discussions. Much larger differences in yield loss estimates for Scenario 1 occurred than for Scenarios 2 or 3 as a result of functional forms used, and the smaller interval of ozone over which yield losses are estimated. Therefore, the results for Scenarios 2 and 3 are felt to be more accurate. Confidence intervals around the economic estimates are likely to be unbalanced, with more probability of larger values than smaller values due to the predominance of procedures and biases which produce conservative estimates. Possible inaccuracies result from the yield loss estimates, the scenario calculations and the CAR model.

A subjective elicitation of the key study team members was undertaken requesting 50 percent and 90 percent confidence intervals around the estimates. The elicitation focused on the final estimates and on the estimates of selected parts of the study. The 50 percent interval was defined as the range of values with which one would take a $1 even bet that a future improved study, or "true" values if they were known, would fall in this interval. The 90 percent interval was defined as a $9 to $1 bet that future estimates, or "true" values if they were known, would fall in this interval. Six individuals participated in all or parts of solicitation for the 50 percent interval. Very few responses were given for the 90 percent interval. These estimated confidence intervals are summarized in Table 6-18.

6.7 SUMMARY

Many previous studies of the economic impacts of air pollution on agriculture have not explicitly allowed for substitution of land or fertilizer inputs, and have assumed that market prices for affected crops would remain unchanged as yields change due to pollution. This latter assumption appears particularly inappropriate for many California crops where the production is geographically and seasonally concentrated. In addition, these types of studies generally do not allow input substitution in response to changes in yields and expected prices.

In this study, farmers are assumed to respond to economic incentives which result from ozone induced yield changes. As yields increase or decrease, farmers adjust acreages to compensate for expected changes in revenues. These acreage changes do not fully offset yield changes, but the process of economic mitigation through price effects and input substitution substantially reduces the economic impact on growers.

The process of economic mitigation also transfers some of the benefits or costs to the consumer. Thus, the problem becomes one in which the California consumer has an interest as well as the producers.

Table 6-18

Uncertainties in the Estimates and Subjective Confidence Intervals*

Source	Comments	Ranges**	
		50% CI	90%CI
Yield Loss Calculation	Inaccuracies in field data, chamber studies and regression models in reflecting actual field conditions. Conservative estimates were generally selected when more than one was available. Field data regression estimates were generally very close to chamber study regression estimates.	-20% to +50%	-50% to +120%
Scenario Calculations	There are some problems in predicting the values of selected O_3 measures under each alternative scenario due to instability in the tail of the distribution of hourly O_3 readings. Conservative assumptions were used.	-10% to +10%	-20% to +30%
Economic Models	The model predicts changes in acreage, cost of production, and prices given alternative yield levels. The model predictions on acreage adjustments given actual year to year changes in yields has been found to be within +15 percent for test runs. Predictions of price changes due solely to yield changes, and predictions on the resultant values to producer and consumers have not been statistically evaluated.	-20% to +35%	-60% to +100%
Total	Some errors are additive, multiplicative and some offsetting.	-50% to +100%	-80% to +200%

* Based on subjective elicitation of study team members. Some team members only responded to parts of the elicitation. Average ranges of those participating are reported.

** The C.I.s are read, for example for yield loss calculations, as the true value is 50 percent likely to be within the range of -20 percent to +50 percent of the values reported when averaged across all crops, and so forth.

APPENDIX A1

REVIEW OF PREVIOUS ECONOMIC STUDIES

A1.1 INTRODUCTION

This section reviews selected past studies examining the economic effects of air pollution on agriculture.* Past estimation methods and results are reviewed to help establish the best approach for this effort, to identify issues which need to be addressed, and to suggest results that can be expected. The studies are reviewed in terms of the crops and locations studied, the air pollution measures employed, the procedures used, and the results obtained. Evaluation comments highlight particularly useful approaches, or important limitations.

Crop loss assessments attributable to air pollution fall within three broad categories. The first type reports crop losses in physical units such as the reduction in actual or potential crop production occurring in a given geographical area (e.g. state or region). An example of this type of loss assessment is the recent work by Loucks and Armentano (1980, 1982). An overview of some physical loss estimates is contained in Moskowitz et al. (1982). The second type of assessment translates these physical losses into a pecuniary, or dollar, value by multiplying estimated losses by a fixed acreage and crop price. Most of the early studies that reported dollar estimates of losses were of this second type. The third type can be viewed as economic assessments of vegetation damage. These studies not only provide estimates of damage or losses in dollar terms, but they also attempt to account for producers' and consumers' decisionmaking processes and associated behavior adjustments which are part of the true economic costs of crop losses due to air pollution. (See Chapter 3 for discussion.) Results reported from the last two types of studies are seldom distinguished in the popular press, however, economists generally discount the pecuniary estimates obtained from the second type of assessment effort. (Critiques of the pecuniary approach may be found in Crocker 1982 and Leung et

* Portions of Sections A1.1 and A1.2 are from Adams (1984).

al. 1978.) This review focuses on the economic assessments of crop damage attributable to O_3 and SO_2. Earlier studies of the pecuniary type will be mentioned only briefly. The studies most similar to the work undertaken here are given more detailed review.

A1.2 PECUNIARY BENEFIT ESTIMATE STUDIES

The earliest estimates of dollar losses due to oxidants were largely subjective without benefit of credible data on yield losses, and they primarily used the procedure of visually surveying losses in the field. For example, figures of $8-10 million in California and $18 million on the East Coast (NAS, 1977) were later raised to $500 million on the basis of increased awareness of potential pollution effects on plants and increased recognition of additional sensitive species. Starting in 1969, a number of states and regions developed estimates of loss due to oxidant pollution. Most of these surveys considered yield reductions on the basis of foliar injury, and made no direct assessments of growth or yield, although subjective estimates of damage were obtained.

The first national assessment was by Benedict et al. at the Stanford Research Institute (SRI) in 1971. This study made use of laboratory and field data from controlled exposure of various crops, and from models simulating formation of ozone and other oxidants. This SRI model used hydrocarbons as the basic pollutant from which to develop the model for prediction of oxidant levels, and therefore effects on various crops. The model estimated economic losses to vegetation due to exposure of existing oxidant levels to be about $125 million in 1969. Increases in crop values, better air quality data and more complete crop coverage raised the dollar loss estimates in recent years (Benedict 1973, Bland and Benedict 1979, Ryan et al. 1981) to between $1.8 and $3 billion for ozone damages. Ryan et al., for example, examined national damages from ozone in excess of the 12 pphm National Ambient Air Quality Standard in 531 counties at $1.8 billion per year using 1980 crop prices and dose response functions.

Other recent pecuniary estimations were done by Moskowitz et al. (1982), Benson et al. (1982) and Shriner et al. (1983). Moskowitz estimated ozone-induced alfalfa losses in 458 counties throughout the U.S. at $24 million per year (4 percent) using the SRI approach modified to use actual oxidant measurements, and the Oshima et al. (1976) ozone dose-response function for alfalfa. Air pollution was measured as the average and maximum seasonal dose in excess of 10 pphm, and the average U.S. price was used. Benson et al.

estimated ozone-induced losses to alfalfa, wheat, and corn in Minnesota at $36 million per year using a model specifically accounting for ozone impacts during different crop development stages. Seasonal average prices were used for each crop. (Benson et al. used a more rigorous model to provide economic estimates.) Shriner et al. estimated nationwide benefits for corn, soybeans, wheat and peanuts at $3 billion per year of controlling ozone to background levels of 2.5 pphm using chamber study dose-response information from recent National Crop Loss Assessment Network (NCLAN) experiments, simulating county ozone levels and county level prices.

A1.3 PAGE, ARBOGAST, FABIAN AND CIECKA (1982)

The purpose of this study was to estimate air pollution induced monetary losses to agricultural producers in connection with the Ohio River Basin Energy Study (ORBES). Crop loss estimates were taken from a study directed by Loucks for the EPA (Loucks et al., 1980, 1982). The crops considered were corn, soybeans and wheat. The study region included all of Kentucky and portions of Illinois, Indiana, Ohio, Pennsylvania and West Virginia. The effects of SO_2 and O_3 were considered.

Procedures Used and Results

Yield loss coefficients calculated by Loucks et al. were used. These were based on the cumulative daily exposure of crops in this area to O_3 and SO_2 from June to August in 1977. Yield losses were based on expected yields in the absence of these pollutants (except for natural background levels), based on previous field and chamber studies. Projections of potential future yield losses were then calculated based on projections of future ambient O_3 and SO_2 concentrations given alternative scenarios.

Only effects to producers were considered so only producers' surplus was estimated. Supply elasticities were estimated for each crop based on output and price data from 1965 to 1978 using a distributed lag structure. Estimated supply elasticities were .263, .56, and .187 for soybeans, wheat, and corn, respectively. To get an estimate of producers' surplus, the supply curve was extrapolated to zero output. This was done assuming a constant elasticity functional form: $Q = aP^b$. Prices were assumed to be unaffected by changes in production in the region.

The loss scenarios were for the period 1976-2000, and considered two possible growth rates for generating capacity with new source performance standards being met in each case. For the lower growth scenario, the estimated losses were \$10.3 million, \$4.3 million of which was attributable to utilities alone. For the high-growth scenario, the estimated losses were \$12.3 million, \$5.5 million of which were attributable to utilities. In both cases, about 99 percent of the losses were attributed to O_3 rather than SO_2.

Evaluative Comments

The principal limitation in the economic analysis component of this effort is that the assumption of constant output prices may not be valid where there is a regional market or where the regional production constitutes a significant proportion of the national market. This assumption will likely overstate the damage estimates, as will omission of mitigating behavior, because input and crop choice substitutions are undertaken when their costs are less than those of the yield losses.

A1.4 SMITH AND BROWN (1981)

This study attempted to incorporate the possibility that changes in yields due to reductions in ozone would cause changes in crop acreage due to different sensitivities of different crops to ozone damage. The authors made use of the results of the Ohio River Basin Energy Study (ORBES) concerning crop losses in the area attributable to ozone (Loucks et al. 1980, 1982). The crops considered were corn, wheat, and soybeans in Indiana. Yield reduction factors attributable to ambient ozone were taken from Loucks et al. and were as described under Page et al. above.

Procedures Used and Results Obtained

The Purdue Crop Budget linear programming model was used to estimate how the optimal crop acreage allocation for each crop would change given changes in yields due to reductions in ozone. The optimal allocation was expected to change due to the different sensitivities of the three crops to ozone exposures. A fairly wide range of possible yield improvement factors for reductions in ozone to background levels was considered, with the maximum being the highest estimate from the ORBES study. Soybeans are most sensitive to ozone, followed by corn and then wheat. The optimal acreage allocation was not greatly changed for the first two alternative yield improvements where soybean yields increased by up to 5 percent. At higher soy bean yield improvement levels of 26 percent (and the same relative improvement across all crops) there were significant shifts out of corn and wheat and into soybeans. The net increase in farm income under the biggest yield increase scenario for the 720 acre model farm was estimated to be $38,000 to $49,000. A hypothesized 5 percent decrease in the soybean/corn price ratio, in response to the yield and acreage change, reduces this shift to some extent, but does not eliminate it.

Evaluative Comments

This study shows that changes in yields can result in significant changes in the optimal allocation of acreage to different crops. This means benefit estimation procedures which ignore potential shifts in crops could result in significant errors in estimating agricultural benefits or costs from changes in air pollution.

There may have been some problems with the use of the linear programming model for this study because the actual crop allocation was quite different from what the model estimated to be optimal under current conditions. In some cases, the difference was as much as the differences between optimal allocations under alternative yield scenarios. The results of the model may not, therefore, be an accurate prediction of what the farmers would actually do. Also, the price change estimate used was quite arbitrary. This procedure would be improved if it were combined with a supply and demand model for predicting price changes in response to changes in crop production. The authors also note that the study's major limitation was the lack of a firm exposure-yield relationship.

A1.5 MANUEL, HORST, BRENNAN, LANEN, DUFF AND TAPIERO (1981)

This study was part of an effort to quantify the benefits of Secondary National Ambient Air Quality Standards (SNAAQS) for SO_2 nationwide. The benefit estimation scenario assumes all areas will meet the secondary standards by 1987. Benefits were calculated for reductions in damage to soybean crops in Illinois, Indiana, Iowa and Ohio (the Corn Belt region).

The study examined cotton and soybean production for a sample of counties in Alabama, Georgia, Illinois, Indiana, Iowa, Kentucky, Michigan, Minnesota, Mississippi, Ohio, Texas and Wisconsin, from data covering 1975 to 1977. These states accounted for about 70 percent of the U.S. soybean production. Yield losses were calculated with field data on yields and ambient SO_2 concentration. County level data were used and counties were selected on the basis of the availability of reliable air quality data. Pollution measures used were for the second quarter (April through June). Several monitoring stations were located in each county in the sample and several different measures of SO_2 for the county were calculated: average of 24-hour means, maximum of 24-hour means, average of second highest 24-hour reading, maximum of second highest 24-hour reading, and ratios of second highest to average measures.

Procedures Used and Results

Yields were estimated as log-linear and linear functions of SO_2 concentrations, climatological variables (second-quarter temperature and rain) and crop production variables. Fertilizer and lime use variables were used by state, and farm work-hours were used by region, since county-level measures of these variables were not available. The presence or absence of irrigation in the county was measured.

The estimated yield loss equations for cotton showed no significant effect of SO_2 on yields. The analysis for cotton was therefore carried no further.

Sulfur dioxide concentrations were not found to have a significant impact on soybean yields for the entire sample, but were significant in some cases when the sample was broken into regions. The five groups were Mississippi; Illinois, Indiana, Iowa and Ohio; Texas; Alabama, Georgia and Kentucky; and Michigan, Minnesota and Wisconsin. Significant effects of SO_2 were found in three of these regions, although the explanatory power of the equations was generally low and the significance of the other variables inconsistent across the regions. None were significant in all regions. Interaction variables between SO_2 and temperature in one case, and rain in another case, were statistically significant, indicating that SO_2 has more adverse effects on crop yields when temperatures are higher and when there is more rain.

Linear supply and demand equations were estimated for the U.S. including domestic demand for consumption and stocks and export demand. The demand analysis included price, income, and prices of substitute crops. These provided an estimate of how much the yield increase could be expected to affect soybean prices. Supply was hypothesized to be a function of the price of soybeans, the prices of substitutes, and total population. The stock and export equations included other variables. Total demand was the sum of these three components.

Benefits were estimated using a 10-percent discount rate, and assuming that SNAAQS are maintained indefinitely. Benefits were calculated in terms of reducing maximum SO_2 concentrations to national standards. In the counties studied, the average annual SO_2 level was 29.08 ug/m^3. Based on the 24-hour standard (260 ug/m^3), the present value of total producers' and consumers' surplus benefits were estimated to be $21.6 million. When the three-hour standard (1300 ug/m^3) was used, the estimated benefits were $.18 million. These are in 1980 dollars and are only for selected counties in the Corn Belt region, representing only 17.6 percent of total soybean production in the area. If other soybean producing counties in the area exceed the standards, benefits of SO_2 control would correspondingly increase.

Evaluative Comments

This study attempted to look at nationwide SO_2 effects using an economic, rather than pecuniary, approach. As such, it was an improvement over other national efforts, but because of its national focus, it was faced with several practical difficulties.

The results of the yield function estimations were weak as evidenced by the instability in the sign and significance of the coefficients for many of the variables, and low explanatory power of the equations (R^{-2} averaging under .3) across the regions. Use of the U.S. supply and demand aggregates to calculate price effects assumes there are no local effects.

No account was made for the possibility that mitigating actions on the part of farmers may have been, or could be undertaken in the future to reduce the impact of SO_2, as have been evidenced for other crops, pollutants and locations. This would likely cause an understatement of benefits as such actions had already been undertaken.

The finding of no SO_2 impacts on cotton is in contrast to chamber study results (see Appendix A2), and may be the result of difficulty in using a countywide aggregated yield approach (with statewide estimates for some variables). It may also be, as noted by the authors, that the effects are negligible for the levels of SO_2 to which cotton was exposed in the selected counties.

A1.6 ADAMS, THANAVIBULCHAI AND CROCKER (1982)

Direct economic losses attributable to ozone in four southern and central California agriculture regions were calculated. The study was the first undertaken in this major agricultural area, well known to be subject to severe air pollution episodes. The study was undertaken for the U.S. EPA to develop and test new economic methodologies to estimate agricultural damages from air pollution; specifically, the quadratic programming model approach to estimating economic welfare measures.

Fourteen annual vegetable and field crops were examined in the agricultural regions that included the Southern Desert (Imperial County), the South Coast (Los Angeles, Orange, Riverside, San Bernardino, Santa Barbara, San Diego and Ventura counties), Central Coast (Monterrey, San Benito, San Luis Obispo and Santa Cruz counties), and the Southern San Joaquin (Kern and Tulare counties). Crops included lima beans, broccoli, cantaloupe, carrots, cauliflower, celery, lettuce, onions (fresh and processing), potatoes, tomatoes (fresh and processing), cotton and sugar beets.

Effects of ambient ozone levels were considered. Ozone measures used were the annual hourly maximum level of ozone in pphm, the average monthly/hourly maximum, the cumulative ozone dose in excess of 8 pphm over the growing season (March-September) and the average hourly maximum reading.

Procedures Used and Results

Yield reductions attributable to ozone were taken from Larsen and Heck (1976). These were based on several studies of the effects of ozone exposures on foliar surface attributes of a variety of crops. Foliage damage was then translated into yield reductions using Millecan's "rule of thumb."

Yield improvements for a change in 1972-1976 maximum hourly average ozone readings of 4-10 pphm (about 6 pphm average over the entire region) to background ozone levels ranged from 0 to 22 percent. There were no yield effects expected for broccoli, cantaloupes, carrots and cauliflower. Reductions in lettuce yields were only for the South Coast region, and were small. The yield changes ranged from 0 to 22 percent in the South Coast Air Basin, from 0 to 9.5 percent in the Southern San Joaquin Air Basin, 0 to 9.4 percent in the South Desert, and 0 to 1.6 percent in the Central Coast. The largest yield effects were for lima beans, celery, cotton, potatoes, and tomatoes, in that order.

As a check on the yield reduction estimates, field data yield functions for most crops were estimated by county with annual data from 1957 to 1976. The authors assert (1982, page 45) that the ordering of crop sensitivities to ozone was the same as that predicted by Larsen and Heck (1976), and the estimated yield reductions were similar for most of the crops. As reported in Adams et al. (1979), yield equations were estimated as a function of average hourly ozone concentrations and crop acreage. While the regression equations resulted in a trend similar to the magnitude of the yield effects as those used in the analysis, a majority of the air pollution coefficients in the linear regression analysis were insignificantly different from zero, with many having positive values (some statistically significant). The coefficients of determination (R^2) ranged from 0 to .74. Due to the primitive nature of the regression yield analysis, little confidence could be placed in the results.

A quadratic programming model conceptually similar to the California Agricultural Resources model was used to estimate the economic impacts of ozone damage. The model was based on the assumption that producers maximize profits by equating demand price with marginal production costs, and that producers may change both the crop selection and inputs. Based upon estimated changes in yield, this model estimated the expected quantities of the crops and their prices in the absence of ozone. Input-output coefficients were estimated for soil type, water, fertilizer, pesticides, and labor, and available input stocks were constrained to 1976 levels. The model was based on a California crop-specific model farm, supply and demand analyses.

The authors point out that by constraining inputs per acre for each crop to remain constant, the possible mitigative adjustments on the input side are ignored and the resulting estimates of welfare effects are therefore an upper bound.* The authors' economic estimates do include farmers' adaptations to pollution in the form of altering the crop mixes. The changes in prices that would result from different crop yields were estimated with a linear price-forecasting function. The model therefore allowed for price and quantity adjustments due to differences in yields.

Total production of each crop was estimated under the 1976 ozone level, in the absence of ozone for each region, in isolation, and for the four regions combined. Welfare measures of consumers' surplus and producers' surplus were estimated from the quadratic programming profit-maximizing objective function for each air quality scenario as reported in Table A1.1. The surplus estimates were similar for the total of the four regions analyzed individually and for the four regions combined. Air pollution induced losses in producers' surplus are nearly three times those for consumers' surplus. However, omitting cotton, where changes in California production have little effect on national prices, the remaining change in producers' and consumers' surplus are nearly identical.

Losses in the southern San Joaquin Valley and the South Coast are the largest -- about five percent of each region's objective function value--and are attributed largely to reductions in cotton yields.

The authors also applied the "traditional" pecuniary method of estimating losses, which usually assigns all losses to producers. These loss estimates were $52.5 million per year, 16 percent larger than the total change in economic surplus, and 50 percent larger than the corresponding change in producers' surplus.

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* This assertion is incorrect for reductions in air pollution. Any mitigative action presently undertaken would be reflected in the 1976 input mix. These inputs are modeled to remain unchanged per acre of each crop when ozone is reduced. If reductions in ozone allow a switch to a less expensive input mix, predicted producers' and consumers' surplus would be underestimated under the zero ozone scenario, thus understating benefits of reducing air pollution.

Table A1.1

Estimated Loss Due to Air Pollution in Southern California for 1976

From Adams et al. 1982

($ millions)

	Southern Desert	South Coast	Central Coast	Southern San Joaquin	Total	Four Regions Combined
Total	5.0	13.5	0.4	24.6	43.6	45.3
Producers' Surplus	4.98	4.66	0.29	22.29	32.22	35.24
Consumers' Surplus	.11	8.86	0.12	2.26	11.36	10.06

Evaluative Comments

The use of a quadratic programming model to account for adjustments in crop prices and production quantities in the face of changes in pollution levels was an important contribution. The weakest link in this study was the use of admittedly arbitrary yield reduction estimates based on foliar damage, and linear yield loss relationships may have been extrapolated below ozone levels at which damage no longer occurs, thus overstating yield losses and economic damage.

Mitigative action on the part of producers, other than changes in crops planted, were ignored. This includes the possibility that a farmer might mitigate pollution damage by using more fertilizer or other inputs. The importance of this omission is not known, except that the estimates understate benefits of improved air quality.

A1.7 LEUNG, REED AND GENG (1982)

This study comes closest to the current San Joaquin Valley analysis because observed agricultural field data were used to estimate yield functions for the selected crops, and potential crop price effects were considered in the calculation of economic losses. The area considered was the South Coast Air Basin, where ambient air quality is among the poorest in the nation. Direct economic losses attributable to ozone were calculated from estimated supply and demand functions for the crops considered, using the estimated yield equations to determine expected supply in the absence of ozone. Secondary impacts were also estimated using an established input-output model for the State of California.

The analysis covered six counties in Southern California which encompass the South Coast Air Basin: Los Angeles, Orange, Riverside, San Bernardino, Santa Barbara, and Ventura. The nine crops considered: avocado, lemon, navel and Valencia oranges, strawberries, lettuce, celery, alfalfa, and tomatoes. The pollution considered was ozone. Sixty-one air monitoring stations in the area record hourly average O_3 concentrations.

Procedures Used and Results

Monthly/hourly average ozone concentrations were calculated from 7 a.m. to 8 p.m. since plants have little susceptibility to ozone without light. In order to represent annual measures of O_3 from these monthly averages, principal components analysis combining the average monthly readings into a yearly index were used to condense the data. The first two components were used. The first component, in most cases, gave fairly equal weight to all 12 months. Ozone was interpolated from stations to crop locations, taking mountain barriers into account.

A yield function was estimated for each crop as a function of the two ozone principal components and principal components for temperature, precipitation and humidity. Time and location variables were also included, but were generally not statistically significant. A linear form was selected over several others. The average yield reduction, comparing 1975 ozone levels to zero ozone levels, was on the order of 20 percent ranging up to 67 percent for avocados. Yield reduction estimates for a few crops that were also analyzed in this study are given in Table A1.2. A decrease in yield with higher ozone levels was not found for celery, although Adams et al. (1982) found celery to be among the most sensitive crops in this area. This difference might be attributed to the differences in the regression and chamber study approaches for estimating yield losses. Oranges were also found to be of the same, or greater, sensitivity than the other study crops, a finding inconsistent with available evidence (see Chapter 5).

Supply and demand functions were estimated from state and national data between 1958 and 1977 in order to obtain measures of consumers' and producers' surpluses lost due to ozone damage. A logarithmic demand curve for regional production was estimated as a function of local prices, other production in the U.S., U.S. aggregate personal income, and U.S. imports of the commodity. A linear regional supply curve was estimated with production as a function of lagged price and production. Prices of substitute crops were not considered in the demand analysis. Price flexibility coefficients were generally equal to or less than those estimated in the California Agricultural Resources model, used in the current San Joaquin Valley study. While "true" price flexibilities coefficients are unknown, the effect of smaller coefficients is to increase the benefit estimates of reduced air pollution. Therefore, the Leung et al. benefit estimates are larger than they would have been using the price flexibility coefficients in the CAR model.

For 1975, total consumers' surplus was estimated to have been $45.7 million less than it would have been with no ozone impacts for the crops considered. This is about 12 percent of the attainable production value. Lost producers' surplus was estimated to have been $57.3 million, or 15 percent of attainable production without ozone exposure.

The California Department of Water Resources input-output model was used to generate estimates of secondary impacts (local employment, purchases etc.) in related sectors of the California economy resulting from the ozone-induced losses for the nine crops. The total loss of value-added income estimated from this analysis was $117 million in the South Coast Air Basin and $14.1 million in the remainder of the state.

Table A1.2

Leung et al. (1982) Estimated Percentage Yield Reduction from Ozone Exposure Southern California, 1975

	Crop				
County	**Alfalfa**	**Lettuce**	**Navel Orange**	**Valencia Orange**	**Tomato**
Los Angeles	20.8	33.8	-	-	-
Orange	-	28.7	-	12.7	20.6
Riverside	20.8	-	28.1	28.3	30.8
San Bernardino	22.3	59.2	60.6	38.1	-
Santa Barbara	9.5	23.7	-	-	-
Ventura	-	34.6	-	6.2	25.3

Note: (-) indicates no estimate was made, usually because the crop was not grown in that county from 1964 to 1975.

Evaluative Comments

The most unique contribution in this effort was the use of the principal components technique to construct annual measures from the monthly ozone and weather data in an attempt to capture monthly variations, while not including 12 observations for each ozone and meteorological variable for each year. This was accomplished by the weighted summing of the monthly values into an annual index. Unfortunately, this weighting scheme is based upon the statistical variation in the monthly explanatory variables, and may not be in any way related to the variation in the crop yields attributable to these monthly variations. A more appropriate index would first eliminate the months for which the crop is not growing, or is otherwise not susceptible to changes in the exogenous factors, and then weight the remaining months according to the susceptibility of the plant in that month of its growing cycle, as was done by Benson et al. (1982). For most crops, the the first principal component for ozone weighted all 12 months nearly equally, and the second principal component roughly weighted the summer months equally with a positive value, and weighted the winter months equally with a negative value. That the winter ozone values were usually below the crop sensitivity thresholds, or that the crops were not growing and would not absorb ozone, suggests the authors could have used a simple average over the growing season and achieved nearly the same results. Further, and of great importance, the use of principal components analysis limits the interpretation of the results for alternative standards policy analysis.

A major flaw in the Leung et al. analysis is the extrapolation of linear damage functions down to zero ozone, which is well below the range of values observed in the sample (approximately 4.0-7.5 pphm daytime monthly O_3 average) and well below the O_3 average threshold at which damage could be expected. With the current distribution of O_3 hourly readings, it is unlikely that crop losses would occur at daytime O_3 average values of less than 3.0-2.5 pphm. Further, when approaching these thresholds, the marginal rate of yield improvement declines (the linear functions approach a zero slope as they approach the thresholds). Our calculations suggest the extrapolations by Leung et al. overstate the likely ozone induced yield losses by 25 percent to several hundred percent of the "true" losses, depending upon the crop and county. On average, the overstatement is likely to be at least 100 percent, with the same, although not necessarily proportional, overstatement in the economic estimates.

Another important limitation in the analysis is that mitigating behavior on the part of farmers, in terms of crop switching and changes in input combinations, was not considered.

The yield equations are limited by the inclusion of only ozone and weather variables. The effects of inputs under farmers' control, such as water and fertilizer, were ignored. If any of these omitted variables were correlated with the ozone concentrations, the yield damage estimates attributed to ozone could be biased. Unfortunately, all yield equation approaches not based on primary surveys will, to some degree, be subject to this problem.

The consideration of secondary effects through the use of a regional input-output model is an important contribution, and highlights that these added effects may substantially increase regional damages. The estimates presented by Leung et al. are likely to overestimate the secondary impacts in the region and the state. They are based on likely overestimates of the yield losses and do not account for the fact that inputs may have increased to offset pollution losses, and farmers may substitute crops to minimize losses. Finally, resources, including jobs and incomes, which are shifted out of agricultural support industries in California, may be absorbed by other California industries, thus reducing the net economic loss for the region (see Section 3.4), but they do indicate the importance of air pollution to agricultural related industries.

A1.8 CONCLUSIONS

A comparison of the pecuniary and true economic studies highlights the importance of undertaking the latter approach, which considers price changes and mitigating behavior by farmers, and which separates the impacts on producers and consumers. The studies by Adams et al., Leung et al., and Manuel et al. each found significant price effects. Adams et al. and Smith and Brown each found important changes in the allocation of acreage to different crops under different air quality scenarios.

The estimation of crop yield changes from air pollution changes must be carefully performed when using field data. Evidence from Adams et al., Mathtech, and Leung et al. suggests the regression approach can give results broadly consistent with chamber study findings, although the effectiveness of the field data regression approach used in these studies is limited at best. Further, the regression results may not be robust due to uncertainty in the correct specifications and the lack of quality data leading to multicollinearity problems and sometimes unstable regression coefficients.

The estimation of crop demand and supply is equally important for capturing market responses to changes in supply conditions, and for obtaining producers' and consumers' surplus measures. Any bias in these estimates will also bias subsequent welfare estimation. Unfortunately, it is difficult to determine which estimates most accurately reflect actual market conditions.

This analysis for the San Joaquin Valley builds upon the information and findings of the above efforts by extending the yield-air pollution regression analysis; considering alternative air quality measures; and using the best applicable farm production and demand information, as is found in the CAR model, to incorporate price changes and mitigating cropping behavior and to estimate welfare losses separately for producers and consumers. Unfortunately there are no available data to estimate input substitution mitigating behavior, and this is not incorporated in this or any previous analyses.