# CHAPTER 4 | AGRICULTURAL AND FOREST PRODUCTIVITY BENEFITS OF THE CAAA

## BACKGROUND

A significant body of literature exists addressing the effects of tropospheric ozone on plants, including commercial tree species and agricultural crops. In a companion report prepared to support the Second Prospective study, we summarize peer-reviewed research that characterizes these effects.[1] In general, elevated levels of tropospheric ozone have been shown to reduce overall plant health and growth by reducing photosynthesis and altering carbon allocation. In order to estimate the magnitude of plant growth reductions due to elevated tropospheric ozone levels, laboratory studies, such as Lee and Hogsett (1996), have developed exposure-response functions describing the functional relationship between plant yield and ozone exposure for a variety of plant species.[2] Applying exposure-response functions, this analysis estimates yield losses in agricultural crops and commercial tree species under the counterfactual, without-CAAA scenario relative to the baseline, with-CAAA scenario. Relative yield losses (i.e., reductions in crop and tree yield under the counterfactual scenario relative to the baseline scenario) measure the amount crop and tree yields would be reduced in the absence of CAAA regulations, and therefore, indicate a benefit of the CAAA.[3]

Commercial timber and agriculture operations generally manage their land to maximize profits. As such, changes in crop yields between the baseline and counterfactual scenarios may affect the distribution of commercial species planted; for example, landowners may shift production towards plants that are less sensitive to elevated ozone concentrations under the counterfactual scenario. This may occur at the individual plant level, replacing one crop or tree species for another with a higher growth rate; or, it may occur at the community level, converting agricultural lands to timberlands, or vice versa, to adjust for combined yield losses to agricultural crops and commercial trees.

[1] Industrial Economics, Inc., Effects of Air Pollutants on Ecological Resources: Literature Review and Case Studies, Draft Report to USEPA Office of Air and Radiation, February 2010.

[2] Lee, E.H. and W.E. Hogsett. 1996. Methodology for Calculating Inputs for Ozone Secondary Standard Benefits Analysis: Part II. Prepared for the U.S. EPA, Office of Air Quality Planning and Standards, Air Quality Strategies and Standards Division.

[3] Relative yield losses are estimated instead of relative yield gains because the baseline (with CAAA) scenario in this analysis defines current conditions, whereas, the counterfactual (no CAAA) scenario defines a change in current conditions. The models applied in this analysis forecast changes in yield relative to current conditions (i.e., relative to the baseline scenario).

Changes in the distribution and yield of crop and tree species may in turn affect the supply of and demand for agricultural crops and commercial tree species, resulting in changes in producer and consumer surplus within the agricultural and timber sectors of the economy. This chapter documents our approach and results to estimating the welfare effects of changes in agriculture and timber markets resulting from the passage of the CAAA; ozone concentration estimates exist for years 2000 through 2020, however, changes in ozone concentration during this period with and without the CAAA may result in welfare effects that extend beyond 2020.

This analysis finds that crop and timber yields increase over time with reductions in ozone concentration associated with implementation of the CAAA. Yield increases are greatest in the geographic areas exhibiting the largest reduction in ozone concentration with the CAAA; specifically, along the East Coast (the Southeast, in particular), in the Midwest (within the Ohio River Valley), and in California (Exhibits 4-4 and 4-5).

The remainder of this chapter consists of three sections. The first section presents the analytical framework for the overall analysis, from forecasting ozone concentrations to estimating welfare effects. The second and third sections describe, respectively, the analytical methods and results of: 1) the analysis of relative yield losses in crops and trees under the counterfactual, no CAAA scenario; and 2) the analysis of welfare effects stemming from changes in crop and tree yields (PLACEHOLDER: TO BE DEVELOPED).

## ANALYTICAL FRAMEWORK

This analysis applies three steps to estimate the welfare benefits of the CAAA with respect to commercial agriculture and timber management:

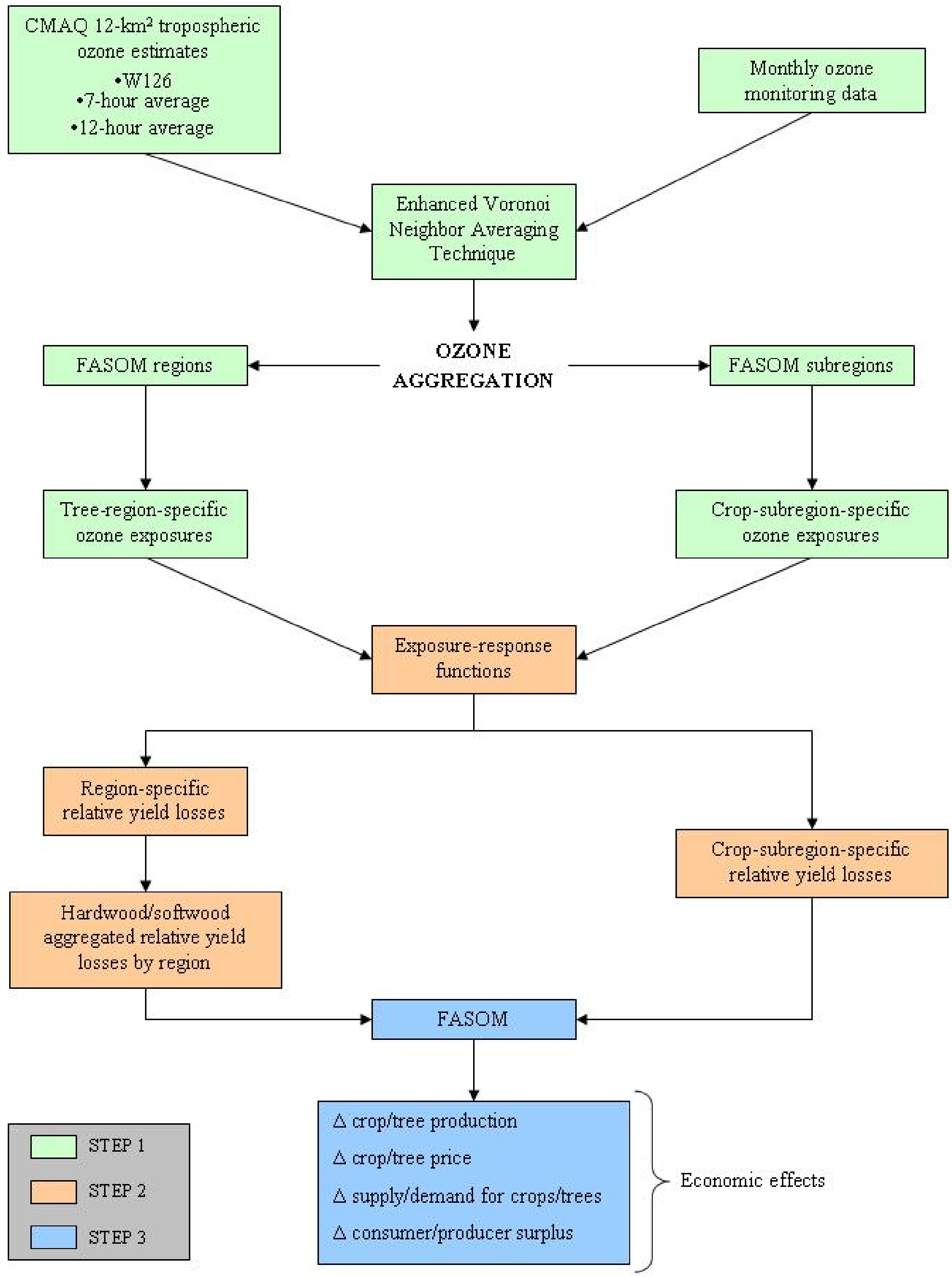
1. Estimate tropospheric ozone concentrations between 2000 and 2020 across the conterminous U.S. under two scenarios: 1) the current state of regulation, including the CAAA ("baseline scenario"); and 2) a counterfactual scenario assuming a hypothetical rollback of the CAAA ("counterfactual scenario");
2. Estimate relative yield losses for various commercial tree and agricultural crop species due to increased ozone concentrations under the counterfactual scenario (as opposed to the baseline scenario);[4] and,
3. Estimate the economic welfare effects (i.e., changes in both producer and consumer surplus) of increased yield in agricultural crops and commercial tree species under the baseline scenario relative to the counterfactual scenario.

Exhibit 4-1 describes the conceptual framework for this analysis. Additional detail on the specific models used to complete the three main steps applied in this analysis is provided in Exhibit 4-2. The following section details the first two analytic steps described above

[4] Relative yield losses indicate percentage crop and timber yields are reduced under the counterfactual scenario *relative* to the baseline scenario.

and in Exhibit 4-1, while the final section of this chapter describes the third analytical step described above and in Exhibit 4-1 (PLACEHOLDER: TO BE DEVELOPED).

**EXHIBIT 4-1 DIAGRAM OF THE ANALYTICAL STEPS APPLIED TO ESTIMATE BENEFITS OF THE CAAA WITH RESPECT TO AGRICULTURE AND COMMERCIAL TIMBER PRODUCTION**



### EXHIBIT 4-2 DETAILS ON THE FORMAT AND CONTENT OF DATA INPUT AND OUTPUT FOR THE DIFFERENT MODELS APPLIED

| MODEL | INPUT REQUIREMENTS | OUTPUT | OUTPUT FORMAT |
|---|---|---|---|
| Community Multiscale Air Quality (CMAQ) Modeling System /Enhanced Voronoi Neighbor Averaging (eVNA)[a] | Climate and contaminant parameters for CMAQ; hourly ozone monitoring data combined with CMAQ results for eVNA | Tropospheric ozone concentrations under both CAAA scenarios for 2000, 2010, and 2020 | 12-km$^2$ grid cells |
| Exposure-response Functions[b] | Crop-subregion-specific and region-specific ozone metrics (W126, 7-hour average, 12-hour average) | Relative yield losses for select agricultural crops and commercial tree species under no CAAA scenario for 2000, 2010, 2020 | Crop-subregion-specific and tree-region-specific relative yield losses |
| Forest and Agricultural Sector Optimization Model (FASOM)[c] | Relative yield losses at the subregional-level for crops and at the regional-hardwood- and regional-softwood-level for trees | Changes in consumer/producer surpluses for the agricultural and timber sectors | Changes in agricultural sector surpluses at the subregional-level and changes in the agricultural and timber surpluses at the regional- and national-levels. |

Notes:
a) CMAQ model results provided by ICF International on October 8, 2008; eVNA results provided by Stratus Consulting on July 20, 2009 and September 28, 2009.
b) Exposure-response functions used in analysis from: Lee, E.H. and W.E. Hogsett. 1996. Methodology for Calculating Inputs for Ozone Secondary Standard Benefits Analysis: Part II. Prepared for the U.S. EPA, Office of Air Quality Planning and Standards, Air Quality Strategies and Standards Division.
c) FASOM results provided by RTI International on INSERT WHEN WE RECEIVE

#### ANALYTICAL METHODS AND RESULTS: RELATIVE YIELD LOSS

This section describes the methods and results of the analysis of relative yield losses in crops and trees under the counterfactual, no CAAA scenario. As described above, there are two distinct steps necessary to estimate relative yield losses: 1) estimate tropospheric ozone concentrations over time under the baseline and counterfactual scenarios; and, 2) calculate relative yield losses based on ozone concentration estimates. The section is organized by analytic step. For each step, the methods applied to complete the step are described followed by the results of the step.

### Step 1: Estimating Tropospheric Ozone Concentrations With and Without the CAAA

This section describes the methodology used to estimate tropospheric ozone levels over time (2000-2020) both with and without the CAAA.[5] Further, this section describes the steps taken to aggregate tropospheric ozone estimates in accordance with the input requirements of exposure-response functions (Exhibit 4-2). Finally, disaggregated and aggregated tropospheric ozone estimates are presented in this section.

Tropospheric ozone concentrations were estimated using Enhanced Voronoi Neighbor Averaging (eVNA), which considers both the modeled ozone concentration results and monthly ozone monitoring data. Specifically, the Community Multiscale Air Quality (CMAQ) Modeling System version 4.6 was used to estimate tropospheric ozone concentrations at a 12 square-kilometer grid level for both the eastern and western U.S. These estimates were then adjusted according to EPA hourly ozone monitoring data (EPA Air Quality System Data for 2002) using eVNA, a modified inverse distance weighted interpolation technique in which the ozone concentration at a given point is adjusted by weighting the concentrations at surrounding points by the distance from the point of interest. The eVNA analysis is based on the assumption that the distance between points and the variation in ozone concentrations between points are correlated.[6]

This analysis considered three different ozone concentration metrics: W126, 7-hour average, and 12-hour average. These metrics are described in Exhibit 4-3. Each metric was calculated on a monthly basis for the May through September period. For the W126 metric (a cumulative exposure metric) monthly values were estimated by summing the daily W126 values for each day in the month. For the 7-hour and 12-hour averages, monthly values were estimated by taking the average 7- or 12-hour average estimated for each day in a given month. The same methodologies used to estimate monthly values were used to estimate combined W126 values and 7- and 12-hour averages for the entire May through September period.

[5] Welfare effects associated with changes in crop and commercial timber yield may be experienced beyond 2020.

[6] The eVNA methodology is described in greater detail in: EPA. 2007. Technical Report on Ozone Exposure, Risk, and Impact Assessments for Vegetation. EPA 452/R-07-002. Prepared by Abt Associates Inc. for U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards, Health and Environmental Impacts Division.

**EXHIBIT 4-3 DETAILS ON OZONE METRICS APPLIED IN EXPOSURE-RESPONSE FUNCTIONS**

| METRIC | DESCRIPTION | FORMULA |
|---|---|---|
| W126 | Weighted sum of all tropospheric ozone concentration values observed hourly between 8 am and 8 pm | $\sum_{i=8am}^{i<8pm} w_{C_i} C_i$ where: $w_{C_i} = \frac{1}{1+4403e^{-126C_i}}$ |
| 7-Hour Average | Average of all tropospheric ozone concentration values observed hourly between 9 am and 4 pm | $\frac{1}{7}\sum_{i=9am}^{i<4pm} C_i$ |
| 12-Hour Average | Average of all tropospheric ozone concentration values observed hourly between 8 am and 8 pm | $\frac{1}{12}\sum_{i=8am}^{i<8pm} C_i$ |

Note: $C_i$ = hourly ozone concentration at hour *i* in parts per million (ppm)

Sources:

1. EPA. 2007. Technical Report on Ozone Exposure, Risk, and Impact Assessments for Vegetation. EPA 452/R-07-002. Prepared by Abt Associates Inc. for U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards, Health and Environmental Impacts Division.
2. Olszyk, D.M., H. Cabrera and C.R. Thompson. 1988. California statewide assessment of the effects of ozone on crop productivity. APCA Notebook. 38(7):928-931.

The Forest and Agricultural Sector Optimization Model (FASOM), the economic model employed in this analysis, requires species growth inputs at a subregion-level for crops and at a region-level for trees; the subregions and regions defined by the model are highlighted in Exhibits 4-4 and 4-5. Subregions define state or sub-state areas. There are a total of 63 subregions defined in FASOM.[7] Regions define sets of multiple states or sub-state areas. There are a total of 11 regions defined in FASOM.[8]

Given the requirements for FASOM inputs, differences in ozone concentration were estimated at the subregion level and at the region level. Ozone metrics were aggregated by region and subregion by calculating weighted averages for the CMAQ 12 square-kilometer grid cells intersecting each region and subregion. Grid cell weights were derived by calculating the area of a grid cell intersecting a given region or subregion divided by the total area of the region or subregion. Specifically, the following equation was used to aggregate ozone metrics by region or subregion.

[7] FASOM subregions refer to each of the 48 states of the coterminous U.S. However, some states including Texas, California, Indiana, Illinois, Ohio, and Iowa are subdivided into multiple subregions.

[8] FASOM regions include: Northeast, Lake States, Corn Belt, Great Plains, Southeast, South Central, Southwest, Rocky Mountains, Pacific Southwest, Pacific Northwest (East side), and Pacific Northwest (West side).

$$C_{region/subregion} = \sum_{i=1}^{N} w_i C_i$$

$$\text{where: } w_i = \text{weight of cell } i = \frac{a_i}{\sum_{i=1}^{N} a_i} \quad (a_i = \text{area of cell } i \text{ in region/subregion})$$

$C_i$ = *W126, 7-hour average, or 12-hour average value for cell i*

*N = total number of grid cells intersecting a given region or subregion*

### Step 1 Results: Tropospheric Ozone Estimates With and Without the CAAA

Exhibits 4-4 and 4-5 present differences in W126 values with and without the CAAA by region and subregion, respectively, for each year in the analysis (differences are calculated by deducting W126 values with the CAAA from W126 values without the CAAA).[9] CMAQ estimates of tropospheric ozone levels were generated for 2000, 2010, and 2020. Thus, the results of the eVNA analysis are limited to these years.

Exhibits 4-4 and 4-5 indicate that the differences in ozone concentration between the two CAAA scenarios increase over time. That is, ozone concentrations without the CAAA increase over time while concentrations with the CAAA decrease leading to increased differences between the two scenarios. The differences in ozone concentrations vary by region and subregion. Specifically, the Pacific Southwest and Southeast regions exhibit the greatest differences in ozone concentration over time followed closely by the South Central, Cornbelt, and Northeast regions.

The subregion map (Exhibit 4-5) provides differences in ozone concentration at a finer spatial resolution than the region map. It appears that while the regions listed above exhibit the greatest differences in ozone concentration between the two scenarios, on-the-whole, some states and/or portions of states within these regions exhibit greater differences than others. Specifically, Virginia, North Carolina, South Carolina, Tennessee, and southern California exhibit the greatest differences in ozone concentration between the two scenarios over time. Secondarily, Pennsylvania, West Virginia, Kentucky, Indiana, Illinois, and Ohio exhibit large differences in ozone concentration.

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[9] Differences in 7-hour and 12-hour average ozone concentrations are not displayed because the majority of exposure-response functions used in this analysis require W126 values as a measure of ozone concentration. The geographic distribution of differences between 7-hour and 12-hour averages with and without the CAAA, in terms of the areas with the greatest or smallest differences, is similar to the differences presented in Exhibits 4 and 5. However, the magnitude of the differences between the 7-hour and 12-hour averages with and without the CAAA are smaller than the differences between the W126 data with and without the CAAA because the 7-hour and 12-hour average metrics are not additive metrics, as is the W126 metric.

**EXHIBIT 4-4 REDUCTIONS IN OZONE CONCENTRATION WITH THE CAAA BY FASOM REGION (PERIOD = MAY - SEPTEMBER; METRIC = W126)**

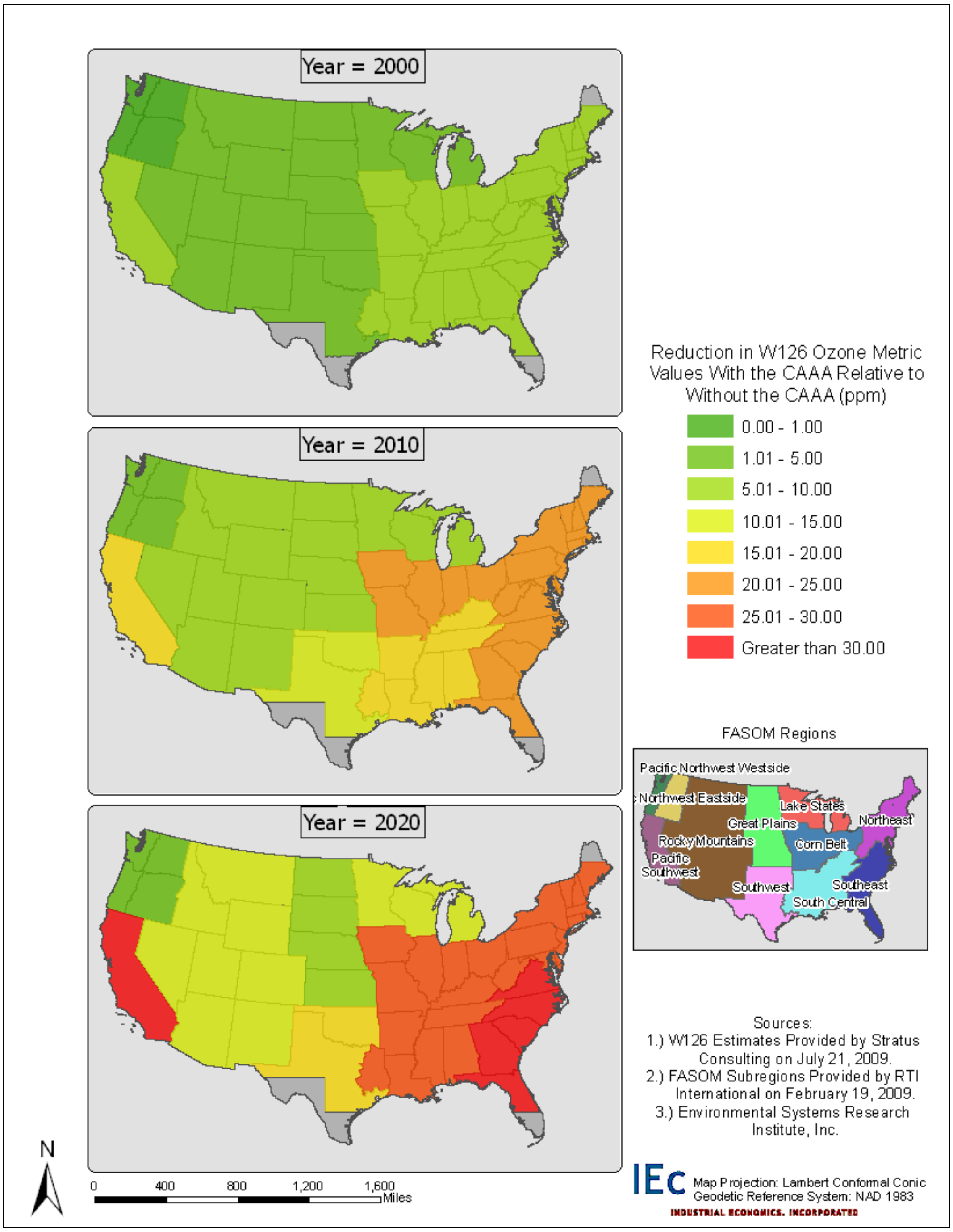
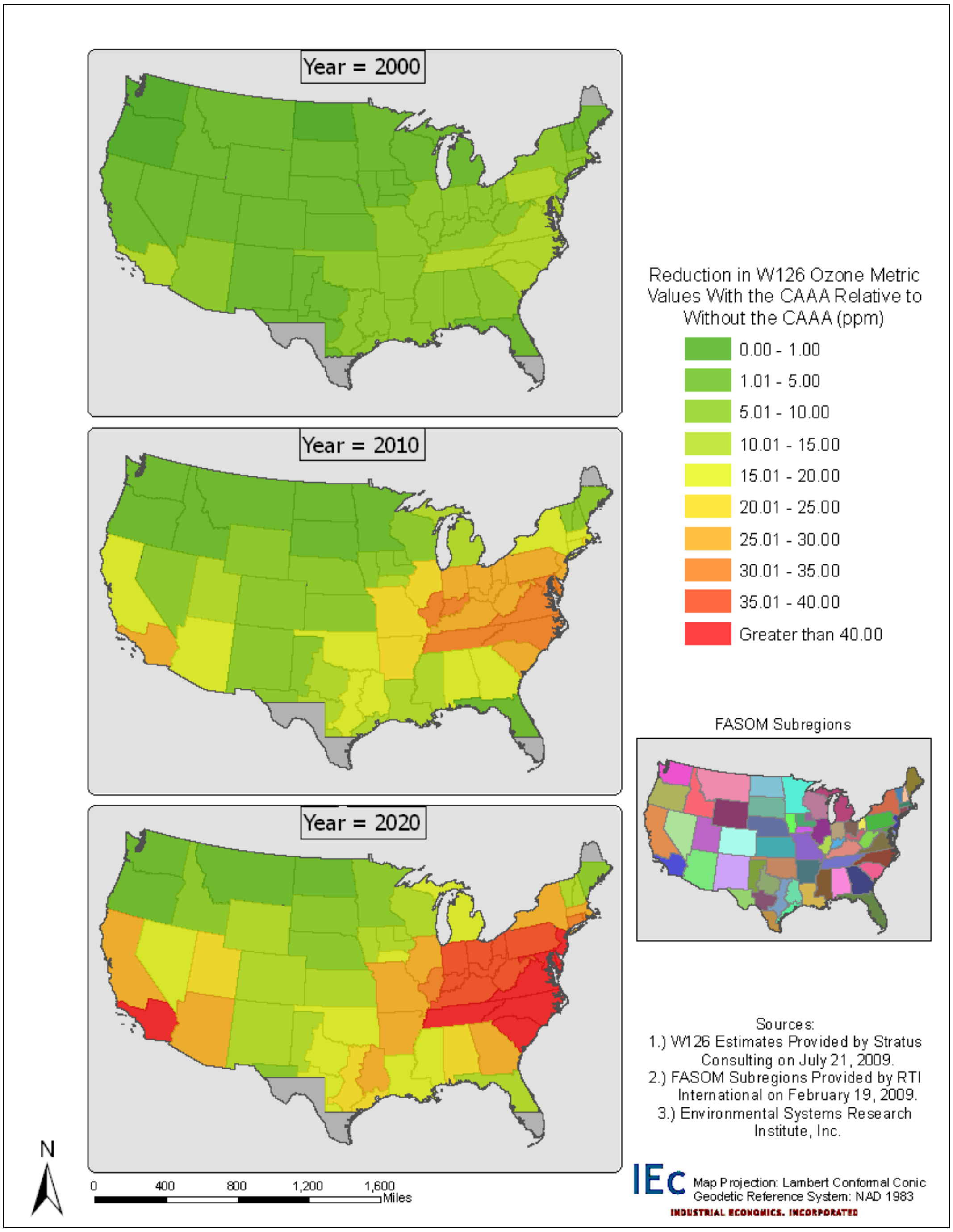


**EXHIBIT 4-5 REDUCTIONS IN OZONE CONCENTRATION WITH THE CAAA BY FASOM SUBREGION (PERIOD = MAY - SEPTEMBER; METRIC = W126)**



### Step 2: Estimating Effects of Changes in Tropospheric Ozone Concentrations on Crop and Tree Growth

This section describes the calculation of relative yield losses for crops and trees due to elevated tropospheric ozone concentrations under the counterfactual scenario. In order to estimate relative yield losses, this analysis relies on species-specific exposure-response functions that estimate plant yield as a function of W126, 7-hour average, or 12-hour average ozone metrics. This section presents the exposure-response functions applied in this analysis; describes the methodology used to derive the appropriate ozone metric inputs for each crop-subregion combination and each region; and, describes the methodology used to estimated relative yield losses based on exposure-response functions. Finally, relative yield losses are presented for select crops and forest types by FASOM region and subregion for each year in the analysis (2000, 2010, 2020).

- **Exposure-Response Functions:** Exposure-response functions are derived through laboratory studies measuring the growth effects of various ambient ozone concentrations on plants. The functions used in this analysis are either exponential or linear regression equations describing plant growth as a function of ozone concentration. The specific exposure-response functions used in this analysis are each based on one of the three different ozone concentration metrics: W126, 7-hour average, and 12-hour average, as defined in Exhibit 4-3. Exhibit 4-6 presents the exposure-response functions applied in this analysis for different crops and trees.[10]

- **Ozone Metric Inputs for Crops:** Crop-subregion-specific ozone metrics were derived by determining each crop's harvest date using, "Usual Planting and Harvesting Dates for U.S. Field Crops" released by the U.S. Department of Agriculture, and then rolling back by the number of growing days to determine the crop planting date (the period between the planting date and the harvest date is the growing period; crops are only exposed to ozone during their growing period).[11] Ozone metrics were then calculated for the growing period. Some crops, including tomatoes and potatoes, are grown throughout the year. For these crops, the growing period within the May through September period which yields the greatest difference in ozone concentration between the baseline and counterfactual scenarios was applied. The growing period for some crops falls outside of the May through September period for which ozone estimates exist (i.e., the planting date is before May 1 or the harvest date is after September 30). For these crops, the ozone metric was calculated utilizing only those growing days within the May through September period. This methodology is based on the

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[10] The crop and tree species included in Exhibit 4-6 are selected for inclusion in this analysis because: a) the functional relationship between ozone exposure and yield is established for each species (i.e., an exposure-response function has been estimated); and, b) each species is explicitly considered in FASOM.

[11] U.S. Department of Agriculture. 1997. Usual Planting and Harvesting Dates for U.S. Field Crops. USDA, National Agricultural Statistics Service. Agricultural Handbook No. 628.

assumption that ozone levels outside of the May through September period are not elevated to levels that would affect plant growth.[12]

- **Ozone Metric Inputs for Trees:** The harvest rotation for trees spans multiple years. Therefore, tree species do not have a specific growing period. Region-specific ozone metrics were derived by calculating the relevant ozone metric over the three-month period between May and September that yields the greatest difference in ozone concentration between the baseline and counterfactual scenarios for each region. This methodology is also based on the assumption that ozone levels outside of May through September are not elevated to levels that would affect plant growth.

**EXHIBIT 4-6 EXPOSURE-RESPONSE FUNCTIONS AND FUNCTION PARAMETERS FOR CROPS AND TREES**

| SPECIES | OZONE METRIC | A (PPM) | B | GROWING DAYS | FUNCTION[a] |
|---|---|---|---|---|---|
| CROP SPECIES | | | | | |
| Barley | W126 | 6,998.50 | 1.39 | 95 | $Y = Ce^{-\left(\frac{O_3}{A}\right)^B}$ |
| Corn | W126 | 97.90 | 2.97 | 83 | |
| Cotton | W126 | 96.10 | 1.48 | 114 | |
| Oranges[b] | 12-Hour Average | 53.70 | 261.10 | 214 | $Y = C[A-(B*O_3)]$ |
| Potatoes | W126 | 99.50 | 1.24 | 66 | $Y = Ce^{-\left(\frac{O_3}{A}\right)^B}$ |
| Rice[c] | 7-Hour Average | 0.20 | 2.47 | 85 | |
| Sorghum | W126 | 205.90 | 1.96 | 85 | |
| Soybeans | W126 | 110.20 | 1.36 | 93 | |
| Processing Tomatoes[c] | 12-Hour Average | 9,055.00 | 32,367.00 | 66 | $Y = C[A-(B*O_3)]$ |
| Wheat (Spring & Winter)[b] | W126 | 53.40 | 2.37 | 58 | $Y = Ce^{-\left(\frac{O_3}{A}\right)^B}$ |

[12] Given that ozone concentrations and crop growing periods vary by subregion, ozone concentration inputs are specific to each crop-subregion combination.

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| SPECIES | OZONE METRIC | A (PPM) | B | GROWING DAYS | FUNCTION[a] |
|---|---|---|---|---|---|
| TREE SPECIES | | | | | |
| Aspen | W126 | 109.81 | 1.22 | N/A | $Y = Ce^{-\left(\frac{O_3}{A}\right)^B}$ |
| Black Cherry | | 38.92 | 0.99 | | |
| Douglas Fir | | 106.83 | 5.96 | | |
| Eastern White Pine | | 63.23 | 1.66 | | |
| Ponderosa Pine | | 159.63 | 1.19 | | |
| Red Maple | | 318.12 | 1.38 | | |
| Sugar Maple | | 36.55 | 5.78 | | |
| Tulip Poplar | | 51.38 | 2.09 | | |
| Virginia Pine | | 1,714.64 | 1.00 | | |

Notes:

(a) Variables defined as follows:
*C* = theoretical constant equivalent to the theoretical yield at zero ozone exposure in the exponential functions and 2.70 in the linear functions making C*A equal to the theoretical yield at zero ozone exposure;
*A* = scale parameter for ozone exposure at which the expected growth response in 37 percent of the theoretical yield at zero ozone exposure;
*B* = the shape parameter affecting the change in the predicted rate of loss.

(b) Exposure-response functions do not exist for different types of oranges and spring wheat, both of which are included in FASOM, therefore the same function parameters are used for all orange types, and winter and spring wheat, based on the assumption that the growth of these crops is similar.

(c) The number of growing days for rice and processing tomatoes applied in the: EPA. 2007. Technical Report on Ozone Exposure, Risk, and Impact Assessments for Vegetation. EPA 452/R-07-002. Prepared by Abt Associates Inc. for U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards, Health and Environmental Impacts Division, differs from the growing days applied for these crops in this analysis. The 2007 report applied a growing period of 69 days for rice and 76 days for processing tomatoes. The use of different growing periods for these crops does not result in significant changes to relative yield loss estimates (maximum differences < +/- 0.2%).

Source:

Lee, E.H. and W.E. Hogsett. 1996. Methodology for Calculating Inputs for Ozone Secondary Standard Benefits Analysis: Part II. Prepared for the U.S. EPA, Office of Air Quality Planning and Standards, Air Quality Strategies and Standards Division.

- **Relative Yield Loss Estimation:** Relative yield losses were calculated based on exposure-response functions according to the following formula:

$$RYL = 1 - \frac{Y_{NoCAAA}}{Y_{WithCAAA}} \text{ where } Y = \textit{plant yield}$$

  Crop-subregion- and tree-region-specific relative yield losses are calculated for each year in the analysis (2000, 2010, and 2020).[13]

  Because FASOM models tree growth by hardwood and softwood forest types, relative yield losses for individual tree species were aggregated by hardwoods and softwoods. This was accomplished through averaging the relative yield losses of each hardwood and softwood species potentially present in a given region. If no hardwood or softwood species for which relative yield losses were estimated is potentially present in a region, the national average of hardwood or softwood relative yield losses was applied.

### Step 2 Results: Relative Yield Losses for Crops and Trees

Maps presenting crop-subregion- and tree-region-specific relative yield losses for the different crops and forest types included in this analysis are provided in Appendix A (Exhibits A-1 through A-13). Exhibit 4-7 provides a summary of relative yield losses by crop/forest type and year. Relative yield losses indicate a benefit of the CAAA; the larger the relative yield loss without the CAAA, the greater the crop or tree yield with the CAAA.

Outside of reductions in ozone concentration with the CAAA, a number of factors affect yield changes in crops and trees including sensitivity to ozone, geographic distribution, growing period length, and the specific time of year the growing period occurs. Given these factors, relative yield losses vary between the different crops and forest types included in this analysis, with some crops and forest types exhibiting limited changes in growth (e.g., barley, rice, and sorghum) and others exhibiting relatively great changes in growth (e.g., cotton, potato, winter wheat, hardwoods, and softwoods). In general, relative yield losses range from 0 to 23 percent across all years, crops, and forest types. Relative yield losses tend to increase over time, with the smallest yield losses occurring in 2000 and the largest occurring in 2020.

The maximum relative yield loss for crops is estimated for potatoes growing in Maryland in 2020 (relative yield loss without the CAAA equals 20.80 percent). The minimum relative yield loss is estimated for soybeans growing in Florida in 2010 (relative yield loss equals -0.55 percent). The negative relative yield loss for soybeans in Florida in 2010 indicates that soybean growth is improved without the CAAA. The growing period for soybeans in Florida is roughly mid-July through September. The negative relative yield loss is due to reductions in W126 ozone metric values under the counterfactual, no CAAA scenario in Florida in September of 2010. Ozone concentrations are lower under the baseline, with CAAA scenario in Florida for all other months in 2010. Thus, ozone

[13] Not all crop and tree species are present in every subregion or region. Relative yield gains are not estimated for crops in subregions where the given crop is not potentially present as defined by FASOM. Similarly, relative yield gains are not estimated for trees in regions where the given tree species is not potentially present as defined by FASOM.

concentrations aggregated across all months of interest, May through September, are reduced in Florida in 2010 with the CAAA (Exhibit 4-5). The negative relative yield loss for soybeans, however, is minimal given the relatively minor differences in forecast ozone concentrations between the scenarios (a relative yield loss of -0.55 percent indicates that yield with the CAAA is 99.5 percent of yield without the CAAA). No other crops exhibit negative yield losses in Florida in 2010.

Negative yield losses are also estimated for rice in the California-North and California-South subregions in 2000 (relative yield losses of -0.02 and -0.08 percent, respectively). The relative yield loss function for rice is a function of the 7-hour ozone metric (Exhibit 4-6). Although W126 ozone metric values are lower under the baseline, with CAAA scenario for all months (May through September) in these subregions, the 7-hour average values for these subregions are lower under the counterfactual, no CAAA scenario in 2000, leading to negative yield losses for rice. Similar to soybeans, the effects of the negative relative yield losses for rice are minimal given the relatively minor differences in forecast ozone concentrations between the scenarios.

Hardwood forests exhibit greater relative yield losses than softwood forests across all years in the analysis. The maximum relative yield losses in hardwoods and softwoods are estimated for the Southeast region in 2020 (relative yield losses equal 23.04 and 12.27 percent for hardwoods and softwoods, respectively). The minimum relative yield loss across both forest types is estimated for softwoods in the Pacific Northwest East region in 2000 (relative yield loss equal to 0.06 percent).

As presented in Exhibits 4-4 and 4-5, reductions in tropospheric ozone concentrations are greatest along the East Coast, particularly the Southeast, in the Midwest (within the Ohio River Valley), and in California. Relative yield losses in crops and trees, therefore, are expected to be greatest in these geographic areas because of large reductions in tropospheric ozone concentrations attributable to the CAAA. Overall, relative yield losses appear to be greatest in the geographic areas with the greatest reduction in ozone concentration (see maps in Appendix A). In particular, the greatest relative yield losses for both crops and trees occur in the Southeast, frequently in Virginia, North Carolina, South Carolina, and Tennessee.

**EXHIBIT 4-7 MINIMUM, MAXIMUM, AND AVERAGE RELATIVE YIELD LOSSES ACROSS ALL FASOM SUBREGIONS FOR CROPS AND ALL FASOM REGIONS FOR TREES BY YEAR (2000, 2010, 2020)**

| CROP/FOREST TYPE | 2000 | | | 2010 | | | 2020 | | |
|---|---|---|---|---|---|---|---|---|---|
| | MINIMUM | MAXIMUM | AVERAGE | MINIMUM | MAXIMUM | AVERAGE | MINIMUM | MAXIMUM | AVERAGE |
| Barley | 0.00% | 0.02% | 0.01% | 0.00% | 0.06% | 0.02% | 0.00% | 0.07% | 0.02% |
| Corn | 0.00% | 1.12% | 0.18% | 0.00% | 3.07% | 0.44% | 0.00% | 3.45% | 0.56% |
| Cotton | 0.00% | 6.60% | 1.15% | 0.00% | 16.67% | 3.00% | 0.00% | 20.31% | 3.81% |
| Oranges | 0.00% | 1.95% | 0.09% | 0.00% | 4.68% | 0.25% | 0.00% | 7.87% | 0.43% |
| Potato | 0.00% | 6.17% | 1.76% | 0.00% | 17.54% | 4.99% | 0.00% | 20.80% | 6.50% |
| Rice | -0.08% | 0.14% | 0.00% | 0.00% | 1.03% | 0.11% | 0.00% | 1.66% | 0.18% |
| Sorghum | 0.00% | 0.87% | 0.14% | 0.00% | 2.17% | 0.35% | 0.00% | 2.65% | 0.47% |
| Soybean | 0.00% | 3.60% | 1.24% | -0.55% | 11.73% | 3.07% | 0.00% | 12.74% | 4.26% |
| Processing Tomatoes | 0.00% | 1.82% | 0.31% | 0.00% | 5.54% | 0.96% | 0.00% | 8.21% | 1.47% |
| Spring Wheat | 0.00% | 1.50% | 0.06% | 0.00% | 3.67% | 0.15% | 0.00% | 6.98% | 0.28% |
| Winter Wheat | 0.00% | 6.53% | 1.00% | 0.00% | 18.23% | 2.49% | 0.00% | 19.23% | 3.29% |
| Hardwood Forests | 1.60% | 7.16% | 5.06% | 4.20% | 19.12% | 13.86% | 6.61% | 23.04% | 16.68% |
| Softwood Forests | 0.06% | 3.85% | 1.77% | 0.25% | 10.49% | 4.88% | 0.42% | 12.27% | 6.11% |
| Note: Negative relative yield losses indicate yield reductions with the CAAA. | | | | | | | | | |

## ANALYTICAL METHODS AND RESULTS: AGRICULTURE AND TIMBER MARKETS WELFARE EFFECTS

(PLACEHOLDER: TO BE DEVELOPED).

## APPENDIX A RELATIVE YIELD LOSS MAPS AND TABLES

This appendix provides relative yield loss maps for the crops and forest types included in the analysis. Relative yield losses are expressed as the percent reduction in the overall yield of a crop or forest type under the counterfactual (no CAAA) scenario.[14] Changes in crop yield are presented by FASOM subregion; while, changes in forest yield are presented by FASOM region. Relative yield losses are only presented for subregions and regions where the specific crop or forest type being considered is present as defined by FASOM. Exhibits A-1 through A-11 present relative yield losses for crops; Exhibits A-12 and A-13 present relative yield losses for hardwood and softwood forest types, respectively.

In addition to relative yield loss maps, this appendix provides tables presenting relative yield losses for each crop by subregion (Exhibits A-14 through A-24) and for hardwood and softwood forest types by region (Exhibits A-25 through A-32).[15] Exhibits A-14 through A-32 also present intermediate values used to calculate relative yield losses for crops and trees.

Relative yield loss tables for hardwood and softwood forest types (Exhibit A-25 through A-32) present relative yield losses for individual hardwood and softwood tree species found in each region, as well as, the average relative yield loss for all hardwood and softwood species found in each region (only average relative yield losses for hardwood and softwood forest types are used to estimate welfare effects).

None of the hardwood species, for which exposure-response functions exist, are present (as defined in FASOM) in the Great Plains, Pacific Northwest-Westside, Pacific Southwest, and Rocky Mountains regions. The average relative yield loss in hardwood forest types across all regions, for which hardwood relative yield losses are estimated, is applied as the best-estimate of hardwood relative yield losses in these regions (5.06 percent in 2000; 13.86 percent in 2010; and, 16.68 percent in 2020). None of the softwood species, for which exposure-response functions exist, are present (as defined in FASOM) in the Great Plains region. As with hardwoods, the average relative yield loss in softwood forest types across all regions, for which softwood relative yield losses are estimated, is applied as the best-estimate of softwood relative yield losses in the Great Plains region (1.77 percent in 2000; 4.88 percent in 2010; and, 6.11 percent in 2020). There is no table for the Great Plains region, given that no hardwood or softwood species, for which relative yield losses are estimated, are present in this region. Further, timber management is not defined by FASOM in either the Southwest or the Pacific Northwest-Eastside, therefore, relative yield loss tables are not presented for these regions.

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[14] Note that relative yield losses are based on ozone concentrations during the growing period for each crop and forest type, not ozone concentrations for the entire May through September period. Growing periods are specific to individual crops and subregions, and to individual regions for hardwood and softwood forest types.

[15] Relative yield loss tables for crop are split by crop; while, relative yield loss tables for hardwood/softwood forest types are split by region.

**EXHIBIT A-1 RELATIVE YIELD LOSSES IN BARLEY UNDER THE COUNTERFACTUAL (NO CAAA) SCENARIO BY FASOM SUBREGION AND YEAR BASED ON SUBREGIONAL-SPECIFIC OZONE CONCENTRATIONS AND GROWING PERIODS**

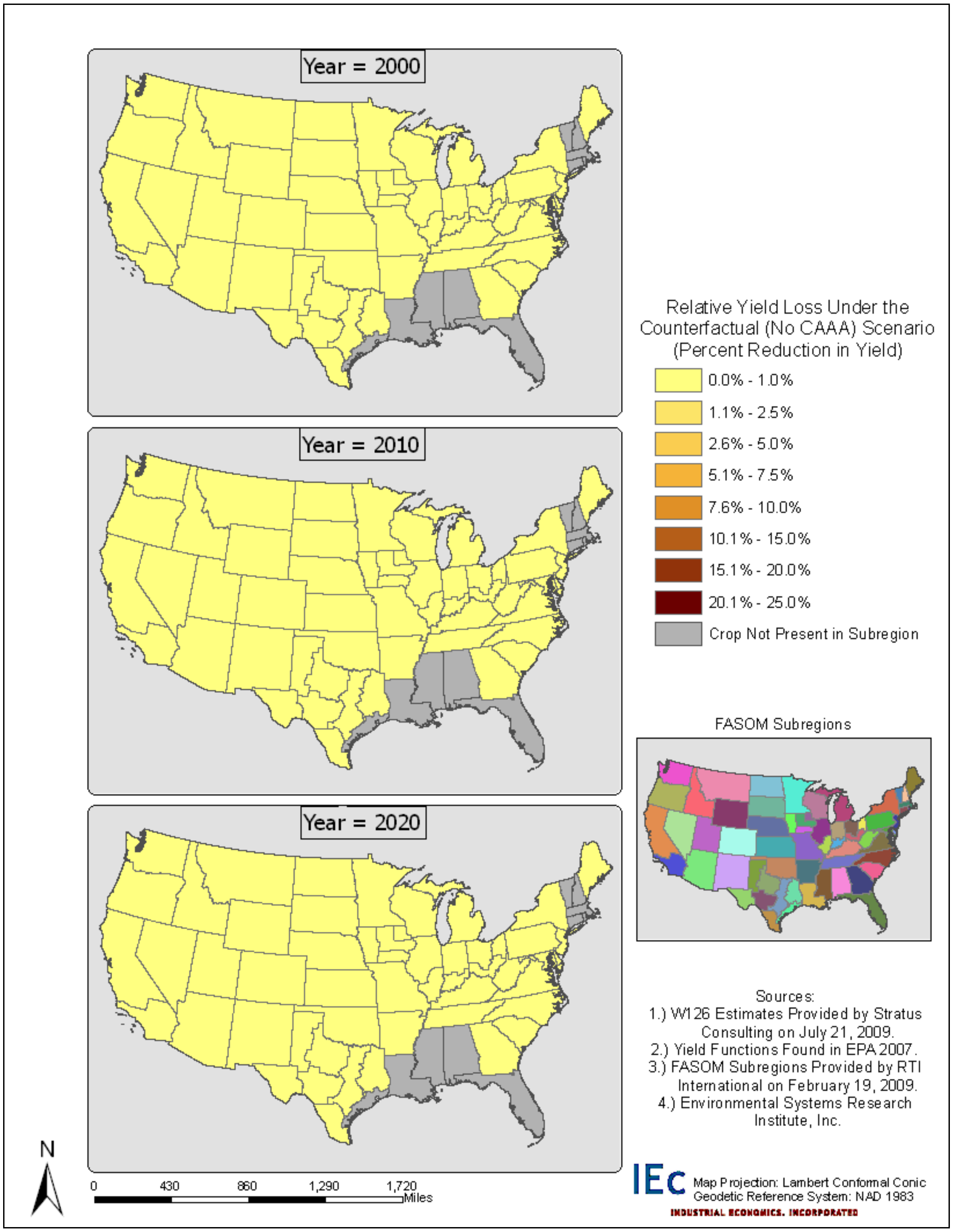


**EXHIBIT A-2 RELATIVE YIELD LOSSES IN CORN UNDER THE COUNTERFACTUAL (NO CAAA) SCENARIO BY FASOM SUBREGION AND YEAR BASED ON SUBREGIONAL-SPECIFIC OZONE CONCENTRATIONS AND GROWING PERIODS**

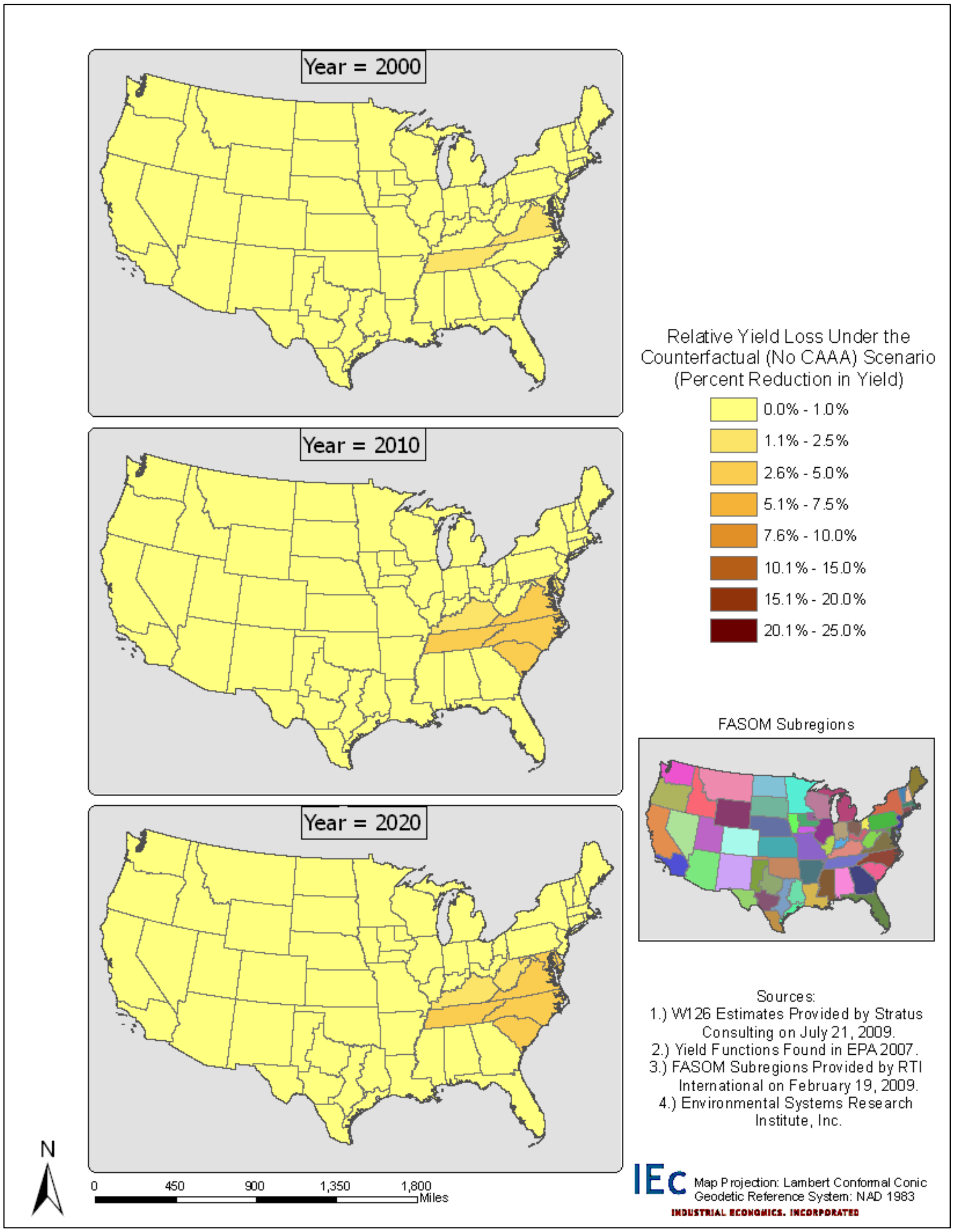


**EXHIBIT A-3 RELATIVE YIELD LOSSES IN COTTON UNDER THE COUNTERFACTUAL (NO CAAA) SCENARIO BY FASOM SUBREGION AND YEAR BASED ON SUBREGIONAL-SPECIFIC OZONE CONCENTRATIONS AND GROWING PERIODS**

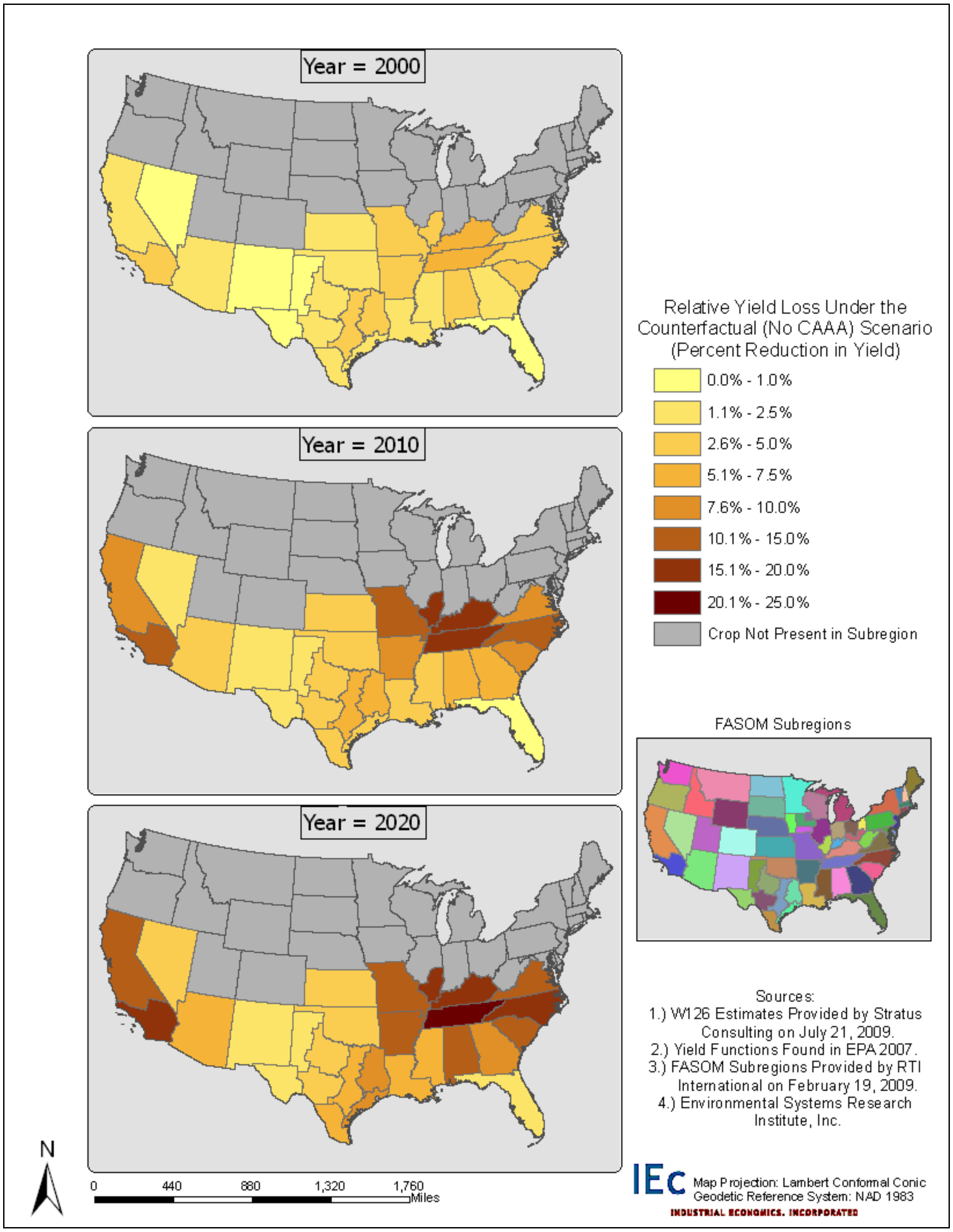


**EXHIBIT A-4 RELATIVE YIELD LOSSES IN ORANGES UNDER THE COUNTERFACTUAL (NO CAAA) SCENARIO BY FASOM SUBREGION AND YEAR BASED ON SUBREGIONAL-SPECIFIC OZONE CONCENTRATIONS AND GROWING PERIODS**

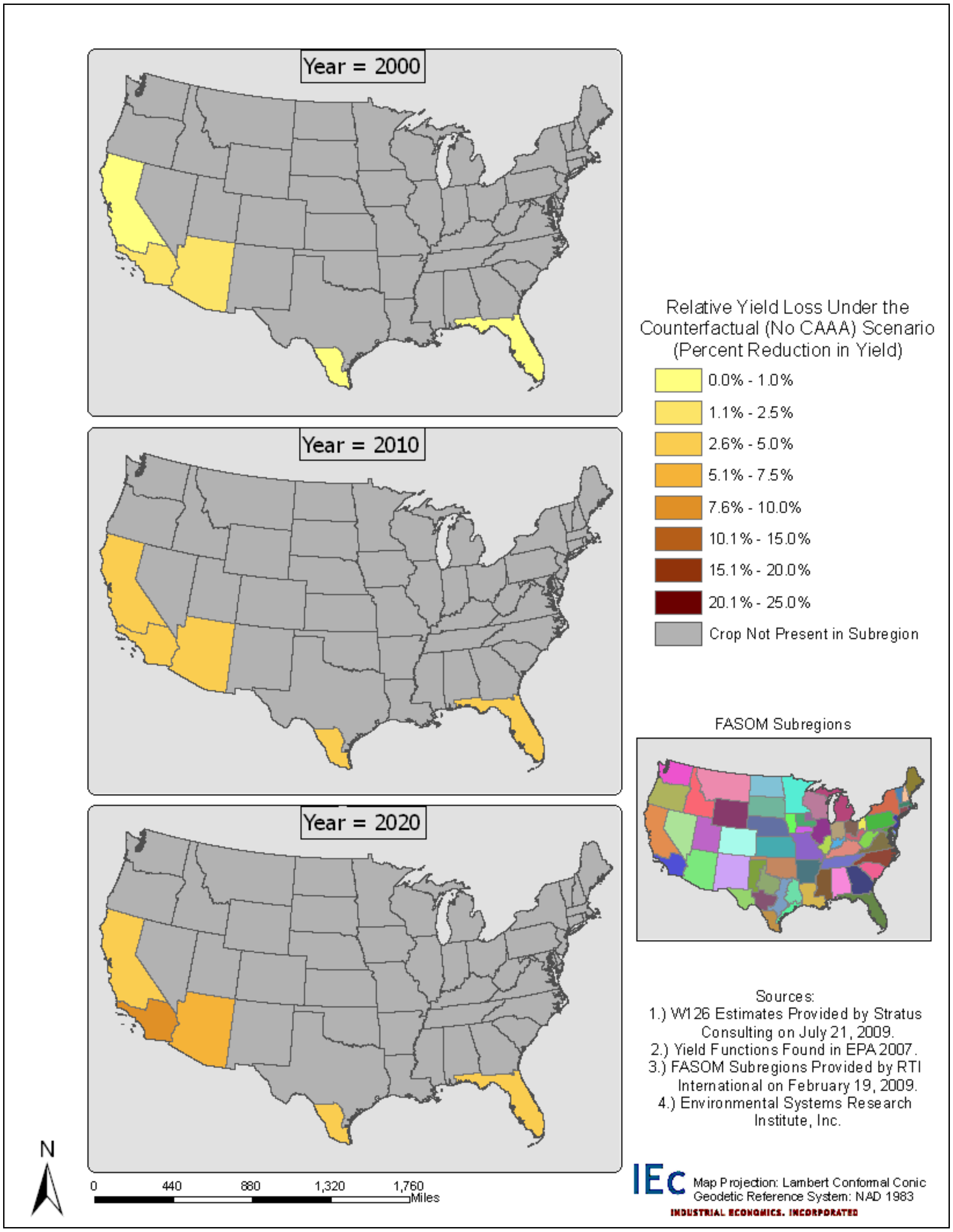


**EXHIBIT A-5 RELATIVE YIELD LOSSES IN POTATOES UNDER THE COUNTERFACTUAL (NO CAAA) SCENARIO BY FASOM SUBREGION AND YEAR BASED ON SUBREGIONAL-SPECIFIC OZONE CONCENTRATIONS AND GROWING PERIODS**

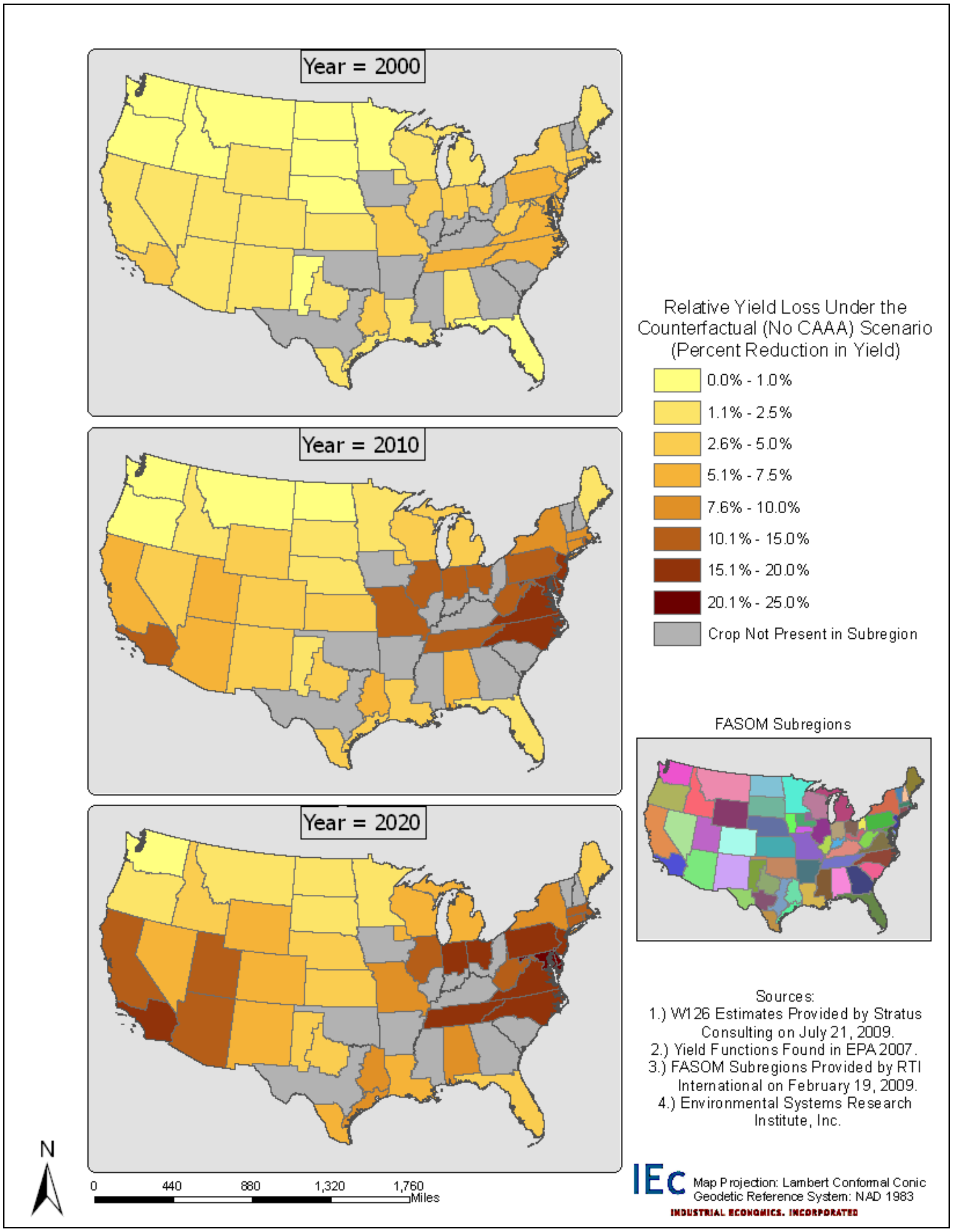


**EXHIBIT A-6 RELATIVE YIELD LOSSES IN RICE UNDER THE COUNTERFACTUAL (NO CAAA) SCENARIO BY FASOM SUBREGION AND YEAR BASED ON SUBREGIONAL-SPECIFIC OZONE CONCENTRATIONS AND GROWING PERIODS**

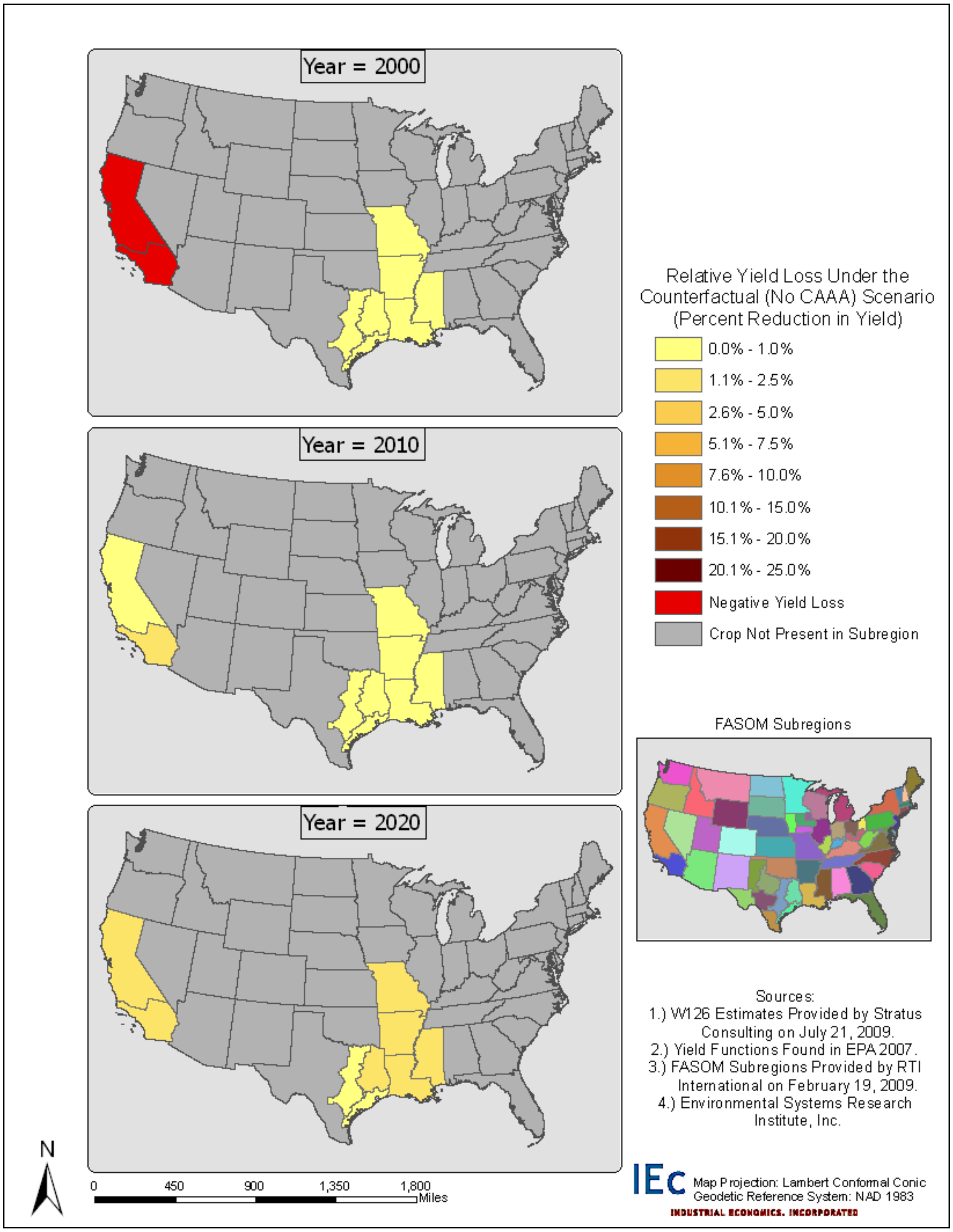


**EXHIBIT A-7 RELATIVE YIELD LOSSES IN SORGHUM UNDER THE COUNTERFACTUAL (NO CAAA) SCENARIO BY FASOM SUBREGION AND YEAR BASED ON SUBREGIONAL-SPECIFIC OZONE CONCENTRATIONS AND GROWING PERIODS**

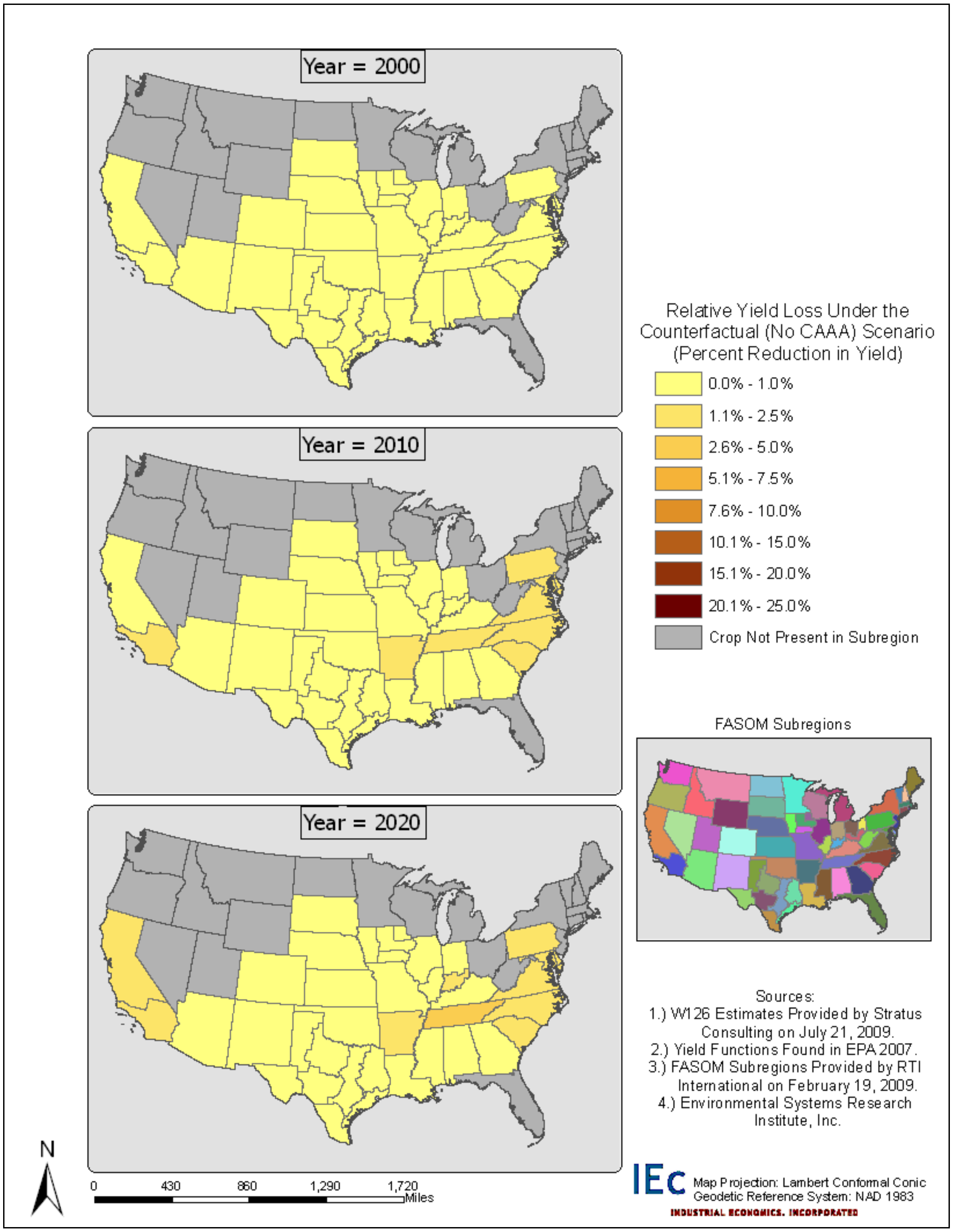


**EXHIBIT A-8 RELATIVE YIELD LOSSES IN SOYBEANS UNDER THE COUNTERFACTUAL (NO CAAA) SCENARIO BY FASOM SUBREGION AND YEAR BASED ON SUBREGIONAL-SPECIFIC OZONE CONCENTRATIONS AND GROWING PERIODS**

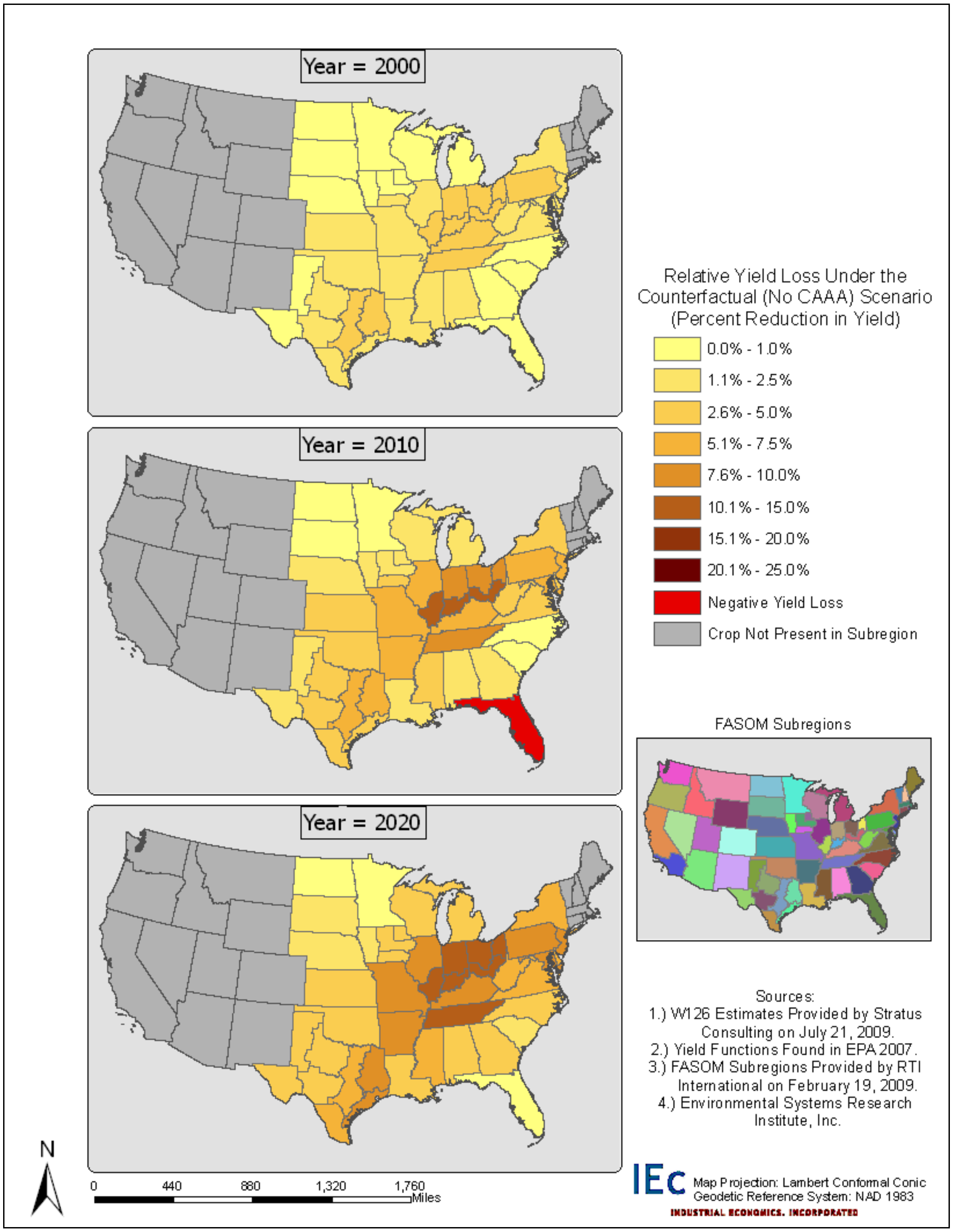


**EXHIBIT A-9 RELATIVE YIELD LOSSES IN PROCESSING TOMATOES UNDER THE COUNTERFACTUAL (NO CAAA) SCENARIO BY FASOM SUBREGION AND YEAR BASED ON SUBREGIONAL-SPECIFIC OZONE CONCENTRATIONS AND GROWING PERIODS**

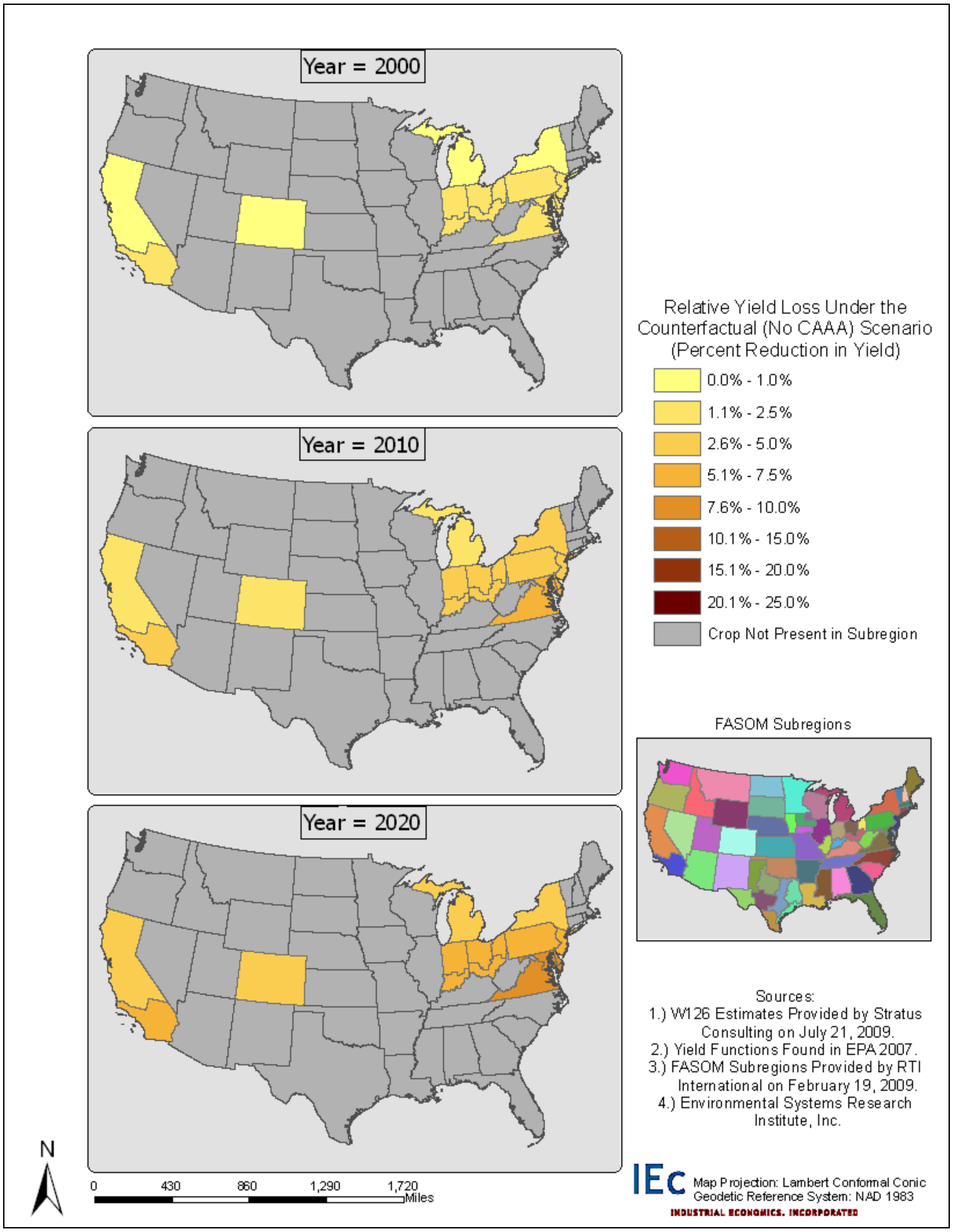


**EXHIBIT A-10 RELATIVE YIELD LOSSES IN SPRING WHEAT UNDER THE COUNTERFACTUAL (NO CAAA) SCENARIO BY FASOM SUBREGION AND YEAR BASED ON SUBREGIONAL-SPECIFIC OZONE CONCENTRATIONS AND GROWING PERIODS**

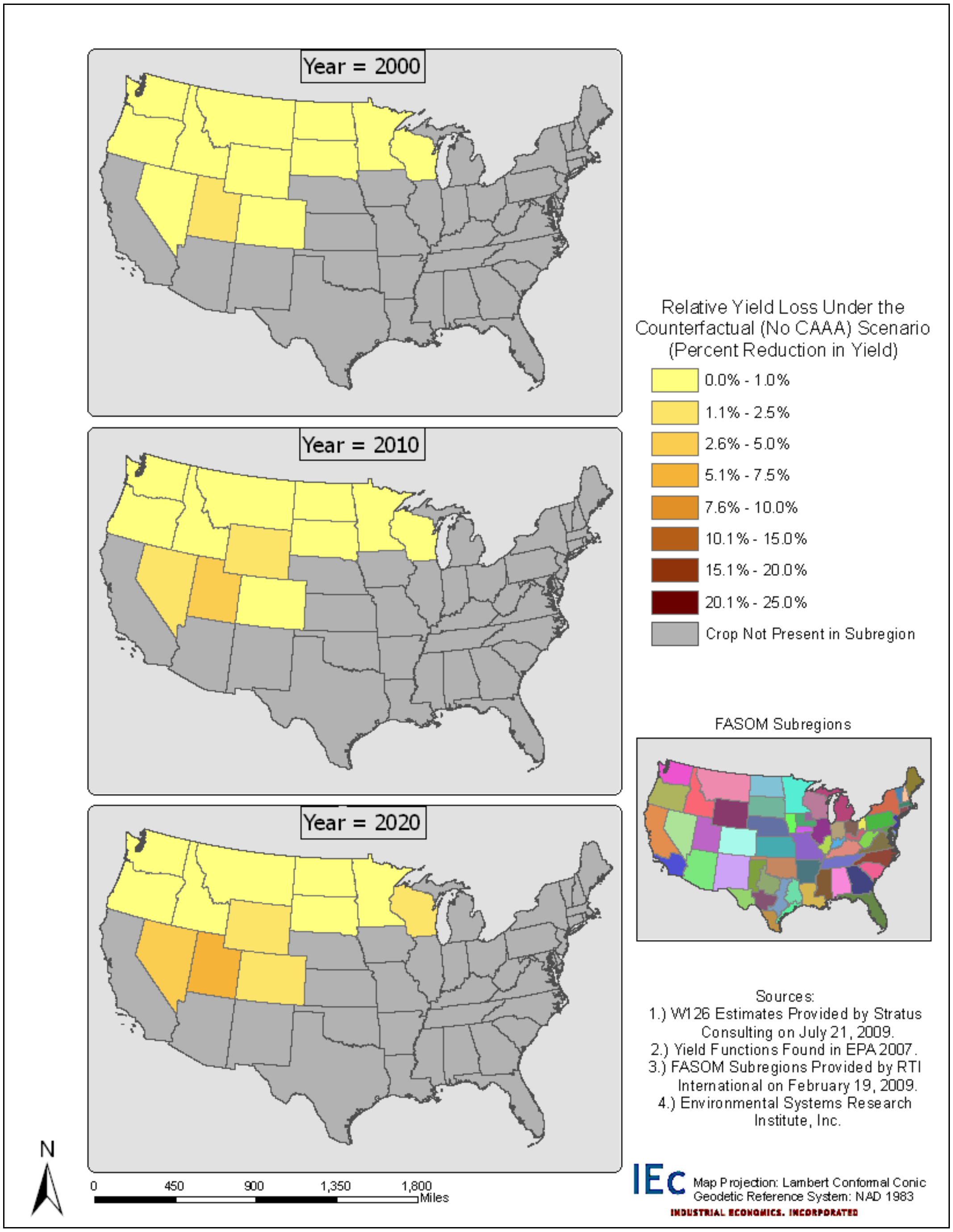


**EXHIBIT A-11 RELATIVE YIELD LOSSES IN WINTER WHEAT UNDER THE COUNTERFACTUAL (NO CAAA) SCENARIO BY FASOM SUBREGION AND YEAR BASED ON SUBREGIONAL-SPECIFIC OZONE CONCENTRATIONS AND GROWING PERIODS**

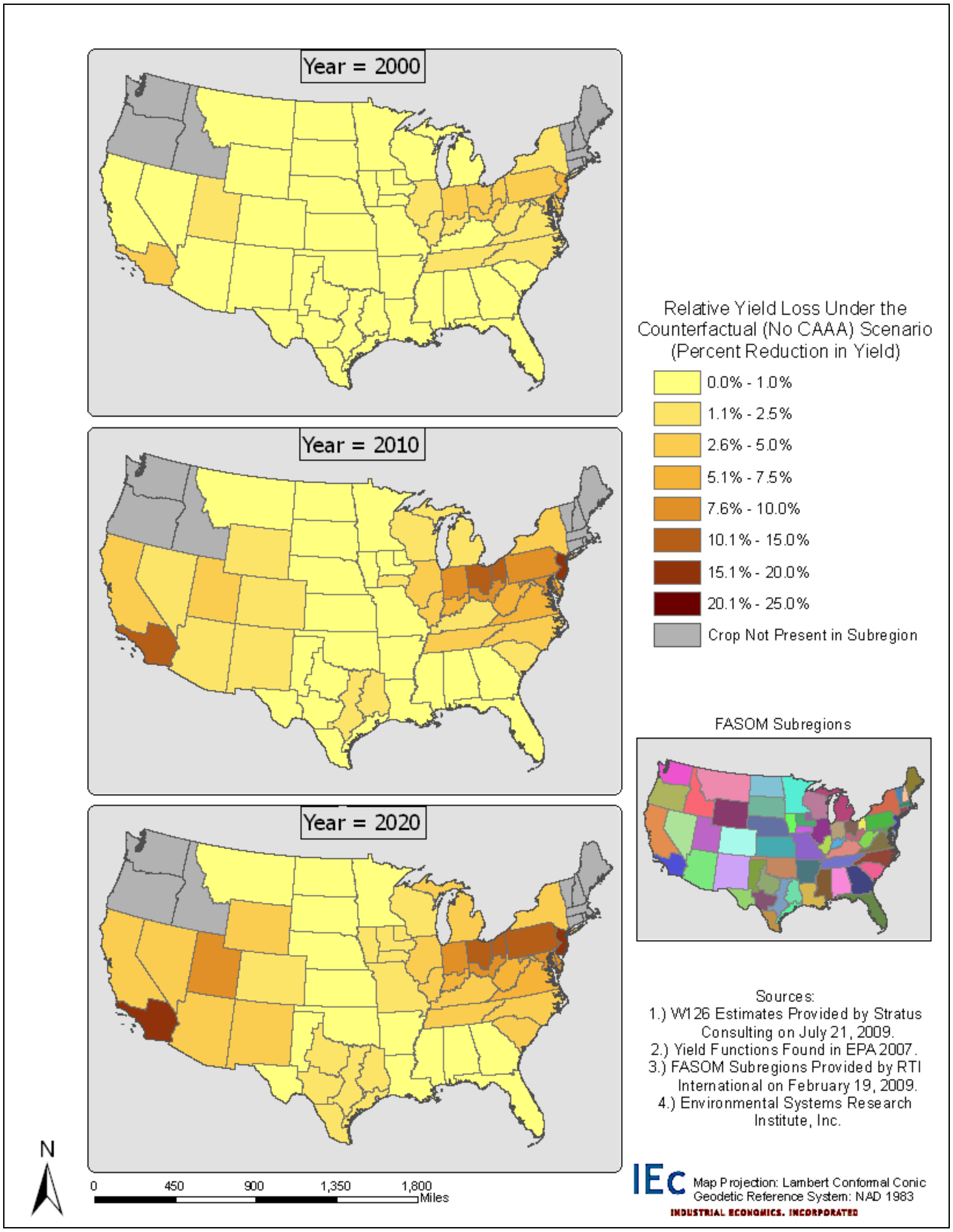


**EXHIBIT A-12 RELATIVE YIELD LOSSES IN HARDWOOD FOREST TYPES UNDER THE COUNTERFACTUAL (NO CAAA) SCENARIO BY FASOM REGION AND YEAR BASED ON REGIONAL-SPECIFIC OZONE CONCENTRATIONS AND GROWING PERIODS**

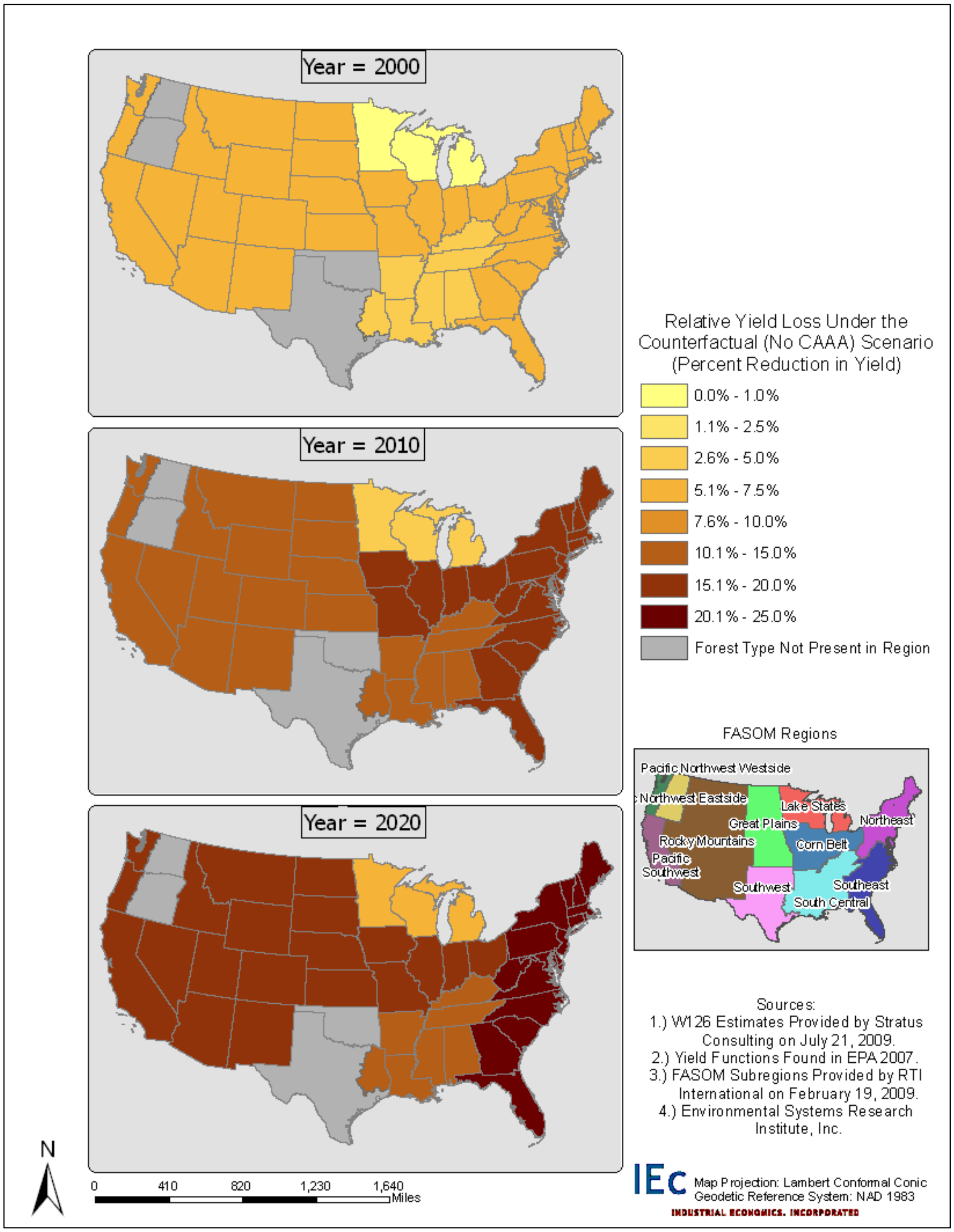
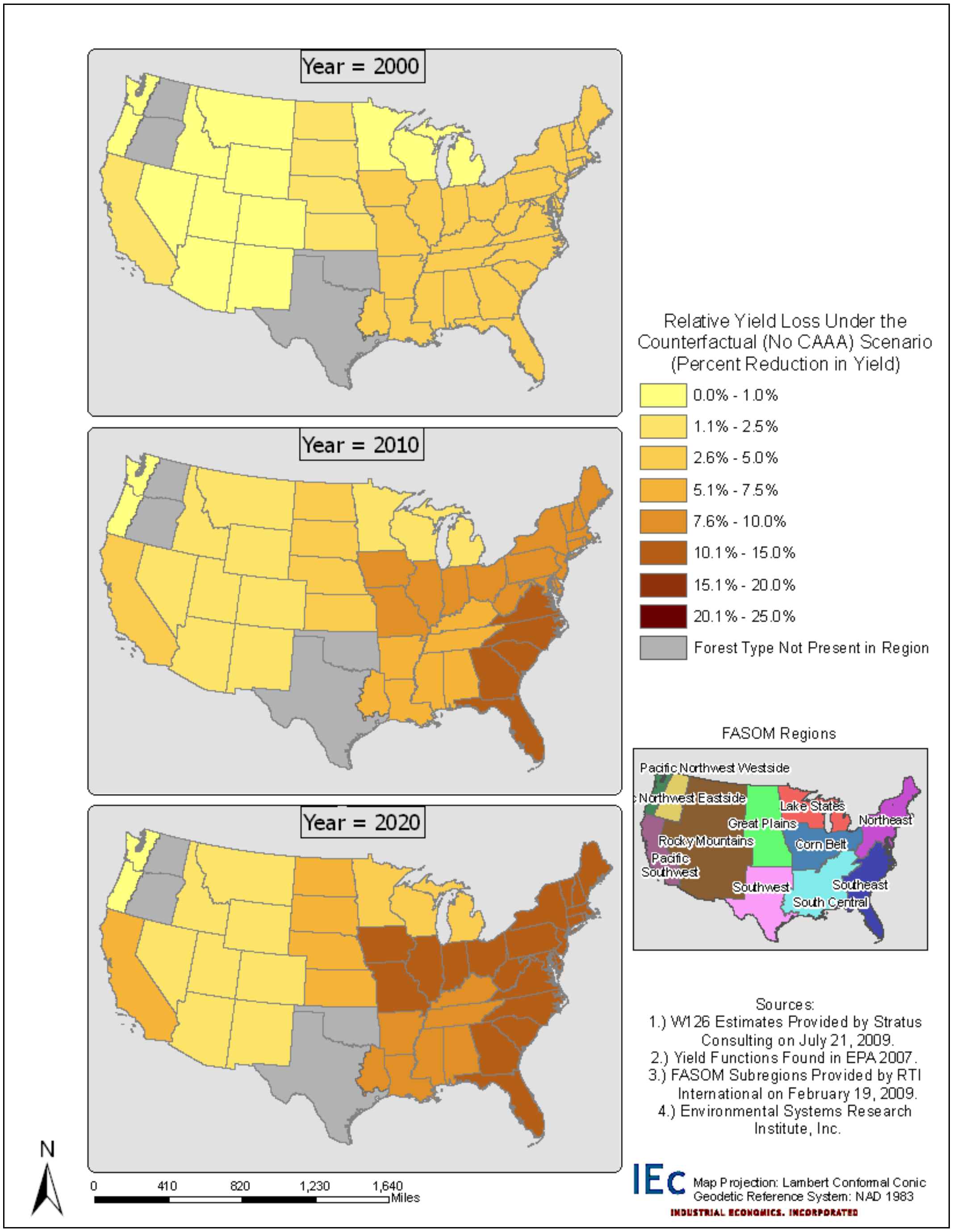


**EXHIBIT A-13 RELATIVE YIELD LOSSES IN SOFTWOOD FOREST TYPES UNDER THE COUNTERFACTUAL (NO CAAA) SCENARIO BY FASOM REGION AND YEAR BASED ON REGIONAL-SPECIFIC OZONE CONCENTRATIONS AND GROWING PERIODS**



### EXHIBIT A-14 DERIVATION OF RELATIVE YIELD LOSSES FOR BARLEY BY FASOM SUBREGION AND YEAR

| SUBREGION | X: $e^{-\left(\frac{O_3 NoCAAA}{A}\right)^B}$ | | | Y: $e^{-\left(\frac{O_3 WithCAAA}{A}\right)^B}$ | | | RYL: (X/Y) * (100%) | | |
|---|---|---|---|---|---|---|---|---|---|
| | 2000 | 2010 | 2020 | 2000 | 2010 | 2020 | 2000 | 2010 | 2020 |
| Arizona | 0.9997 | 0.9996 | 0.9995 | 0.9998 | 0.9998 | 0.9999 | 0.01% | 0.02% | 0.04% |
| Arkansas | 0.9998 | 0.9997 | 0.9997 | 0.9999 | 1.0000 | 1.0000 | 0.01% | 0.02% | 0.02% |
| California North | 0.9996 | 0.9995 | 0.9994 | 0.9997 | 0.9998 | 0.9998 | 0.01% | 0.03% | 0.05% |
| California South | 0.9994 | 0.9993 | 0.9991 | 0.9996 | 0.9997 | 0.9998 | 0.02% | 0.04% | 0.07% |
| Colorado | 0.9998 | 0.9998 | 0.9998 | 0.9999 | 0.9999 | 0.9999 | 0.00% | 0.01% | 0.02% |
| Delaware | 0.9994 | 0.9993 | 0.9992 | 0.9996 | 0.9998 | 0.9999 | 0.02% | 0.06% | 0.07% |
| Georgia | 0.9998 | 0.9997 | 0.9997 | 0.9999 | 0.9999 | 1.0000 | 0.01% | 0.02% | 0.03% |
| Idaho | 0.9999 | 0.9999 | 0.9999 | 0.9999 | 0.9999 | 0.9999 | 0.00% | 0.00% | 0.01% |
| Illinois North | 0.9997 | 0.9996 | 0.9996 | 0.9998 | 0.9999 | 0.9999 | 0.01% | 0.03% | 0.03% |
| Illinois South | 0.9996 | 0.9995 | 0.9996 | 0.9998 | 0.9999 | 1.0000 | 0.01% | 0.04% | 0.04% |
| Indiana North | 0.9995 | 0.9994 | 0.9994 | 0.9997 | 0.9999 | 0.9999 | 0.02% | 0.04% | 0.05% |
| Indiana South | 0.9996 | 0.9994 | 0.9995 | 0.9997 | 0.9999 | 0.9999 | 0.01% | 0.05% | 0.05% |
| Iowa West | 0.9999 | 0.9999 | 0.9998 | 0.9999 | 0.9999 | 1.0000 | 0.00% | 0.01% | 0.01% |
| Iowa Central | 0.9999 | 0.9999 | 0.9999 | 0.9999 | 1.0000 | 1.0000 | 0.00% | 0.01% | 0.01% |
| Iowa Northeast | 0.9999 | 0.9999 | 0.9998 | 0.9999 | 1.0000 | 1.0000 | 0.00% | 0.01% | 0.01% |
| Iowa South | 0.9999 | 0.9998 | 0.9998 | 0.9999 | 1.0000 | 1.0000 | 0.00% | 0.01% | 0.01% |
| Kansas | 1.0000 | 0.9999 | 0.9999 | 1.0000 | 1.0000 | 1.0000 | 0.00% | 0.00% | 0.00% |
| Kentucky | 0.9997 | 0.9995 | 0.9996 | 0.9998 | 0.9999 | 1.0000 | 0.01% | 0.04% | 0.04% |
| Maine | 0.9999 | 0.9999 | 0.9999 | 1.0000 | 1.0000 | 1.0000 | 0.00% | 0.00% | 0.01% |
| Maryland | 0.9993 | 0.9992 | 0.9992 | 0.9995 | 0.9998 | 0.9999 | 0.02% | 0.06% | 0.07% |
| Michigan | 0.9998 | 0.9998 | 0.9998 | 0.9999 | 0.9999 | 1.0000 | 0.00% | 0.01% | 0.02% |
| Minnesota | 0.9999 | 0.9999 | 0.9999 | 1.0000 | 1.0000 | 1.0000 | 0.00% | 0.00% | 0.00% |
| Missouri | 0.9998 | 0.9996 | 0.9997 | 0.9998 | 0.9999 | 1.0000 | 0.01% | 0.03% | 0.03% |
| Montana | 0.9999 | 0.9999 | 0.9999 | 0.9999 | 1.0000 | 1.0000 | 0.00% | 0.00% | 0.00% |
| Nebraska | 0.9999 | 0.9999 | 0.9999 | 1.0000 | 1.0000 | 1.0000 | 0.00% | 0.00% | 0.00% |
| Nevada | 0.9998 | 0.9997 | 0.9997 | 0.9998 | 0.9999 | 0.9999 | 0.00% | 0.01% | 0.02% |
| New Jersey | 0.9994 | 0.9993 | 0.9993 | 0.9995 | 0.9998 | 0.9999 | 0.02% | 0.05% | 0.07% |
| New Mexico | 0.9998 | 0.9998 | 0.9998 | 0.9999 | 0.9999 | 0.9999 | 0.00% | 0.01% | 0.02% |
| New York | 0.9997 | 0.9997 | 0.9997 | 0.9998 | 0.9999 | 1.0000 | 0.01% | 0.02% | 0.03% |
| North Carolina | 0.9995 | 0.9993 | 0.9993 | 0.9997 | 0.9999 | 1.0000 | 0.02% | 0.06% | 0.07% |
| North Dakota | 1.0000 | 1.0000 | 0.9999 | 1.0000 | 1.0000 | 1.0000 | 0.00% | 0.00% | 0.00% |
| Ohio Northwest | 0.9995 | 0.9994 | 0.9994 | 0.9996 | 0.9998 | 0.9999 | 0.01% | 0.05% | 0.06% |
| Ohio South | 0.9995 | 0.9994 | 0.9994 | 0.9997 | 0.9999 | 0.9999 | 0.01% | 0.05% | 0.05% |
| Ohio Northeast | 0.9995 | 0.9994 | 0.9994 | 0.9996 | 0.9998 | 0.9999 | 0.01% | 0.04% | 0.06% |
| Oklahoma | 0.9998 | 0.9998 | 0.9998 | 0.9999 | 0.9999 | 1.0000 | 0.00% | 0.01% | 0.02% |
| Oregon | 0.9999 | 0.9999 | 0.9999 | 1.0000 | 1.0000 | 1.0000 | 0.00% | 0.00% | 0.00% |
| Pennsylvania | 0.9995 | 0.9995 | 0.9994 | 0.9997 | 0.9999 | 0.9999 | 0.02% | 0.04% | 0.05% |
| South Carolina | 0.9996 | 0.9994 | 0.9994 | 0.9997 | 0.9999 | 1.0000 | 0.02% | 0.05% | 0.06% |
| South Dakota | 0.9999 | 0.9999 | 0.9999 | 0.9999 | 1.0000 | 1.0000 | 0.00% | 0.00% | 0.00% |
| Tennessee | 0.9996 | 0.9995 | 0.9994 | 0.9997 | 0.9999 | 1.0000 | 0.02% | 0.04% | 0.05% |
| Texas High Plains | 0.9999 | 0.9999 | 0.9999 | 0.9999 | 0.9999 | 1.0000 | 0.00% | 0.01% | 0.01% |

| SUBREGION | X: $e^{-\left(\frac{O_3 NoCAAA}{A}\right)^B}$ | | | Y: $e^{-\left(\frac{O_3 WithCAAA}{A}\right)^B}$ | | | RYL: (X/Y) * (100%) | | |
|---|---|---|---|---|---|---|---|---|---|
| | 2000 | 2010 | 2020 | 2000 | 2010 | 2020 | 2000 | 2010 | 2020 |
| Texas Rolling Plains | 0.9999 | 0.9998 | 0.9998 | 0.9999 | 0.9999 | 1.0000 | 0.00% | 0.01% | 0.02% |
| Texas Central Blacklands | 0.9998 | 0.9998 | 0.9998 | 0.9999 | 0.9999 | 1.0000 | 0.01% | 0.01% | 0.02% |
| Texas East | 0.9998 | 0.9998 | 0.9997 | 0.9999 | 1.0000 | 1.0000 | 0.01% | 0.02% | 0.02% |
| Texas Edwards Plateau | 0.9999 | 0.9999 | 0.9999 | 0.9999 | 1.0000 | 1.0000 | 0.00% | 0.01% | 0.01% |
| Texas South | 0.9999 | 0.9999 | 0.9998 | 0.9999 | 1.0000 | 1.0000 | 0.00% | 0.01% | 0.01% |
| Texas Trans Pecos | 0.9999 | 0.9999 | 0.9999 | 0.9999 | 1.0000 | 1.0000 | 0.00% | 0.01% | 0.01% |
| Utah | 0.9997 | 0.9996 | 0.9995 | 0.9998 | 0.9998 | 0.9999 | 0.01% | 0.02% | 0.03% |
| Virginia | 0.9995 | 0.9993 | 0.9993 | 0.9997 | 0.9999 | 0.9999 | 0.02% | 0.05% | 0.06% |
| Washington | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 0.00% | 0.00% | 0.00% |
| West Virginia | 0.9996 | 0.9995 | 0.9995 | 0.9998 | 0.9999 | 1.0000 | 0.01% | 0.04% | 0.04% |
| Wisconsin | 0.9999 | 0.9999 | 0.9998 | 0.9999 | 0.9999 | 1.0000 | 0.00% | 0.01% | 0.01% |
| Wyoming | 0.9998 | 0.9998 | 0.9997 | 0.9999 | 0.9999 | 0.9999 | 0.01% | 0.01% | 0.02% |

Notes:

1. Parameter values for A and B in the equations for X and Y are presented along with the appropriate ozone metric to apply by crop in Exhibit X-6.
2. Relative yield losses are only derived for subregions where the crop is present as defined in FASOM.
3. Relative yield losses are based on ozone concentrations during the growing period for each crop and forest type, not ozone concentrations for the entire May through September period. Growing periods are specific to individual crops and subregions, and to individual regions for hardwood and softwood forest types.

**EXHIBIT A-15 DERIVATION OF RELATIVE YIELD LOSSES FOR CORN BY FASOM SUBREGION AND YEAR**

| SUBREGION | X: $e^{-\left(\frac{O_3 NoCAAA}{A}\right)^B}$ | | | Y: $e^{-\left(\frac{O_3 WithCAAA}{A}\right)^B}$ | | | RYL: (X/Y) * (100%) | | |
|---|---|---|---|---|---|---|---|---|---|
| | 2000 | 2010 | 2020 | 2000 | 2010 | 2020 | 2000 | 2010 | 2020 |
| Alabama | 0.9974 | 0.9960 | 0.9946 | 0.9991 | 0.9999 | 1.0000 | 0.17% | 0.40% | 0.54% |
| Arizona | 0.9994 | 0.9989 | 0.9984 | 0.9997 | 0.9999 | 0.9999 | 0.04% | 0.10% | 0.15% |
| Arkansas | 0.9958 | 0.9914 | 0.9909 | 0.9986 | 0.9999 | 1.0000 | 0.27% | 0.85% | 0.90% |
| California North | 0.9959 | 0.9936 | 0.9927 | 0.9970 | 0.9985 | 0.9986 | 0.11% | 0.49% | 0.59% |
| California South | 0.9947 | 0.9925 | 0.9910 | 0.9973 | 0.9988 | 0.9992 | 0.26% | 0.63% | 0.82% |
| Colorado | 0.9998 | 0.9998 | 0.9997 | 0.9999 | 1.0000 | 1.0000 | 0.01% | 0.02% | 0.02% |
| Connecticut | 0.9972 | 0.9967 | 0.9960 | 0.9986 | 0.9996 | 1.0000 | 0.14% | 0.29% | 0.40% |
| Delaware | 0.9849 | 0.9779 | 0.9744 | 0.9937 | 0.9983 | 0.9999 | 0.88% | 2.04% | 2.55% |
| Florida | 0.9998 | 0.9997 | 0.9995 | 0.9999 | 1.0000 | 1.0000 | 0.01% | 0.03% | 0.05% |
| Georgia | 0.9958 | 0.9927 | 0.9905 | 0.9983 | 0.9998 | 1.0000 | 0.25% | 0.71% | 0.95% |
| Idaho | 0.9999 | 0.9999 | 0.9999 | 1.0000 | 1.0000 | 1.0000 | 0.00% | 0.00% | 0.01% |
| Illinois North | 0.9988 | 0.9985 | 0.9979 | 0.9995 | 0.9999 | 1.0000 | 0.07% | 0.14% | 0.21% |
| Illinois South | 0.9961 | 0.9954 | 0.9939 | 0.9984 | 0.9998 | 1.0000 | 0.22% | 0.44% | 0.60% |
| Indiana North | 0.9980 | 0.9976 | 0.9968 | 0.9991 | 0.9998 | 1.0000 | 0.11% | 0.22% | 0.32% |
| Indiana South | 0.9972 | 0.9968 | 0.9959 | 0.9986 | 0.9997 | 1.0000 | 0.14% | 0.30% | 0.41% |
| Iowa West | 0.9999 | 0.9999 | 0.9998 | 1.0000 | 1.0000 | 1.0000 | 0.00% | 0.01% | 0.01% |
| Iowa Central | 0.9999 | 0.9998 | 0.9997 | 0.9999 | 1.0000 | 1.0000 | 0.01% | 0.02% | 0.03% |
| Iowa Northeast | 0.9998 | 0.9998 | 0.9996 | 0.9999 | 1.0000 | 1.0000 | 0.01% | 0.02% | 0.04% |
| Iowa South | 0.9995 | 0.9993 | 0.9990 | 0.9998 | 1.0000 | 1.0000 | 0.03% | 0.07% | 0.10% |
| Kansas | 0.9990 | 0.9987 | 0.9984 | 0.9995 | 0.9999 | 0.9999 | 0.05% | 0.12% | 0.15% |
| Kentucky | 0.9895 | 0.9833 | 0.9828 | 0.9959 | 0.9995 | 0.9999 | 0.64% | 1.62% | 1.71% |
| Louisiana | 0.9990 | 0.9981 | 0.9976 | 0.9997 | 0.9999 | 1.0000 | 0.06% | 0.18% | 0.24% |
| Maine | 0.9998 | 0.9997 | 0.9997 | 0.9999 | 0.9999 | 1.0000 | 0.01% | 0.02% | 0.03% |
| Maryland | 0.9837 | 0.9775 | 0.9735 | 0.9926 | 0.9981 | 0.9999 | 0.90% | 2.06% | 2.63% |
| Massachusetts | 0.9974 | 0.9970 | 0.9964 | 0.9988 | 0.9996 | 1.0000 | 0.14% | 0.26% | 0.36% |
| Michigan | 0.9997 | 0.9996 | 0.9995 | 0.9998 | 1.0000 | 1.0000 | 0.01% | 0.03% | 0.05% |
| Minnesota | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 0.00% | 0.00% | 0.00% |
| Mississippi | 0.9987 | 0.9976 | 0.9970 | 0.9996 | 0.9999 | 1.0000 | 0.09% | 0.23% | 0.29% |
| Missouri | 0.9961 | 0.9931 | 0.9927 | 0.9985 | 0.9998 | 1.0000 | 0.24% | 0.68% | 0.73% |
| Montana | 0.9999 | 0.9999 | 0.9998 | 0.9999 | 1.0000 | 1.0000 | 0.00% | 0.01% | 0.01% |
| Nebraska | 0.9999 | 0.9999 | 0.9999 | 1.0000 | 1.0000 | 1.0000 | 0.00% | 0.01% | 0.01% |
| Nevada | 0.9994 | 0.9991 | 0.9988 | 0.9996 | 0.9998 | 0.9998 | 0.02% | 0.07% | 0.10% |
| New Hampshire | 0.9993 | 0.9992 | 0.9989 | 0.9997 | 0.9999 | 1.0000 | 0.04% | 0.07% | 0.11% |
| New Jersey | 0.9984 | 0.9981 | 0.9977 | 0.9991 | 0.9996 | 1.0000 | 0.07% | 0.15% | 0.23% |
| New Mexico | 0.9998 | 0.9997 | 0.9995 | 0.9999 | 1.0000 | 1.0000 | 0.01% | 0.03% | 0.04% |
| New York | 0.9990 | 0.9989 | 0.9986 | 0.9996 | 0.9999 | 1.0000 | 0.06% | 0.10% | 0.14% |
| North Carolina | 0.9845 | 0.9680 | 0.9654 | 0.9942 | 0.9987 | 1.0000 | 0.97% | 3.07% | 3.45% |
| North Dakota | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 0.00% | 0.00% | 0.00% |
| Ohio Northwest | 0.9969 | 0.9964 | 0.9953 | 0.9985 | 0.9997 | 1.0000 | 0.16% | 0.33% | 0.46% |
| Ohio South | 0.9966 | 0.9962 | 0.9952 | 0.9983 | 0.9997 | 1.0000 | 0.16% | 0.35% | 0.48% |
| Ohio Northeast | 0.9973 | 0.9968 | 0.9960 | 0.9986 | 0.9998 | 0.9999 | 0.13% | 0.30% | 0.39% |
| Oklahoma | 0.9968 | 0.9955 | 0.9943 | 0.9985 | 0.9997 | 0.9998 | 0.17% | 0.42% | 0.54% |
| Oregon | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 0.00% | 0.00% | 0.00% |

| SUBREGION | X: $e^{-\left(\frac{O_3 NoCAAA}{A}\right)^B}$ | | | Y: $e^{-\left(\frac{O_3 WithCAAA}{A}\right)^B}$ | | | RYL: (X/Y) * (100%) | | |
|---|---|---|---|---|---|---|---|---|---|
| | 2000 | 2010 | 2020 | 2000 | 2010 | 2020 | 2000 | 2010 | 2020 |
| Pennsylvania | 0.9978 | 0.9974 | 0.9966 | 0.9991 | 0.9998 | 1.0000 | 0.13% | 0.24% | 0.34% |
| Rhode Island | 0.9973 | 0.9968 | 0.9961 | 0.9987 | 0.9996 | 1.0000 | 0.14% | 0.28% | 0.39% |
| South Carolina | 0.9852 | 0.9709 | 0.9657 | 0.9947 | 0.9994 | 1.0000 | 0.96% | 2.85% | 3.43% |
| South Dakota | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 0.00% | 0.00% | 0.00% |
| Tennessee | 0.9825 | 0.9737 | 0.9671 | 0.9936 | 0.9992 | 1.0000 | 1.12% | 2.55% | 3.29% |
| Texas High Plains | 0.9993 | 0.9992 | 0.9986 | 0.9997 | 0.9999 | 1.0000 | 0.03% | 0.07% | 0.13% |
| Texas Rolling Plains | 0.9985 | 0.9980 | 0.9969 | 0.9993 | 0.9999 | 1.0000 | 0.08% | 0.19% | 0.31% |
| Texas Central Blacklands | 0.9978 | 0.9972 | 0.9953 | 0.9991 | 0.9998 | 1.0000 | 0.13% | 0.26% | 0.46% |
| Texas East | 0.9976 | 0.9965 | 0.9947 | 0.9992 | 0.9999 | 1.0000 | 0.16% | 0.34% | 0.53% |
| Texas Edwards Plateau | 0.9994 | 0.9993 | 0.9987 | 0.9997 | 0.9999 | 1.0000 | 0.03% | 0.07% | 0.13% |
| Texas Coastal Bend | 0.9979 | 0.9977 | 0.9959 | 0.9991 | 0.9999 | 1.0000 | 0.12% | 0.22% | 0.40% |
| Texas South | 0.9994 | 0.9994 | 0.9988 | 0.9998 | 1.0000 | 1.0000 | 0.03% | 0.06% | 0.11% |
| Texas Trans Pecos | 0.9995 | 0.9993 | 0.9988 | 0.9997 | 0.9999 | 1.0000 | 0.02% | 0.06% | 0.12% |
| Utah | 0.9993 | 0.9989 | 0.9984 | 0.9996 | 0.9998 | 0.9999 | 0.03% | 0.09% | 0.14% |
| Vermont | 0.9993 | 0.9991 | 0.9988 | 0.9997 | 0.9999 | 1.0000 | 0.05% | 0.08% | 0.12% |
| Virginia | 0.9840 | 0.9722 | 0.9691 | 0.9941 | 0.9984 | 0.9999 | 1.02% | 2.62% | 3.08% |
| Washington | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 0.00% | 0.00% | 0.00% |
| West Virginia | 0.9927 | 0.9899 | 0.9875 | 0.9972 | 0.9995 | 1.0000 | 0.45% | 0.96% | 1.24% |
| Wisconsin | 0.9998 | 0.9998 | 0.9997 | 0.9999 | 1.0000 | 1.0000 | 0.01% | 0.02% | 0.03% |
| Wyoming | 0.9998 | 0.9997 | 0.9996 | 0.9999 | 0.9999 | 0.9999 | 0.01% | 0.02% | 0.03% |

Notes:

1. Parameter values for A and B in the equations for X and Y are presented along with the appropriate ozone metric to apply by crop in Exhibit X-6.
2. Relative yield losses are only derived for subregions where the crop is present as defined in FASOM.
3. Relative yield losses are based on ozone concentrations during the growing period for each crop and forest type, not ozone concentrations for the entire May through September period. Growing periods are specific to individual crops and subregions, and to individual regions for hardwood and softwood forest types.

**EXHIBIT A-16 DERIVATION OF RELATIVE YIELD LOSSES FOR COTTON BY FASOM SUBREGION AND YEAR**

| SUBREGION | X: $e^{-\left(\frac{O_3 NoCAAA}{A}\right)^B}$ | | | Y: $e^{-\left(\frac{O_3 WithCAAA}{A}\right)^B}$ | | | RYL: (X/Y) * (100%) | | |
|---|---|---|---|---|---|---|---|---|---|
| | 2000 | 2010 | 2020 | 2000 | 2010 | 2020 | 2000 | 2010 | 2020 |
| Alabama | 0.9249 | 0.9086 | 0.8944 | 0.9544 | 0.9785 | 0.9955 | 3.08% | 7.15% | 10.16% |
| Arizona | 0.9538 | 0.9404 | 0.9238 | 0.9701 | 0.9823 | 0.9874 | 1.68% | 4.26% | 6.44% |
| Arkansas | 0.9157 | 0.8846 | 0.8783 | 0.9498 | 0.9825 | 0.9932 | 3.59% | 9.96% | 11.57% |
| California North | 0.8839 | 0.8550 | 0.8334 | 0.9022 | 0.9332 | 0.9408 | 2.04% | 8.38% | 11.42% |
| California South | 0.8554 | 0.8290 | 0.8029 | 0.8974 | 0.9335 | 0.9533 | 4.67% | 11.19% | 15.78% |
| Florida | 0.9894 | 0.9856 | 0.9818 | 0.9932 | 0.9885 | 0.9990 | 0.38% | 0.30% | 1.72% |
| Georgia | 0.9438 | 0.9261 | 0.9154 | 0.9643 | 0.9795 | 0.9965 | 2.12% | 5.45% | 8.13% |
| Illinois South | 0.8680 | 0.8130 | 0.8366 | 0.9128 | 0.9712 | 0.9869 | 4.91% | 16.29% | 15.23% |
| Kansas | 0.9605 | 0.9553 | 0.9505 | 0.9719 | 0.9857 | 0.9875 | 1.18% | 3.08% | 3.75% |
| Kentucky | 0.8629 | 0.8183 | 0.8276 | 0.9125 | 0.9695 | 0.9888 | 5.44% | 15.59% | 16.31% |
| Louisiana | 0.9522 | 0.9375 | 0.9281 | 0.9719 | 0.9767 | 0.9944 | 2.03% | 4.02% | 6.67% |
| Mississippi | 0.9551 | 0.9416 | 0.9344 | 0.9734 | 0.9856 | 0.9972 | 1.88% | 4.46% | 6.30% |
| Missouri | 0.9051 | 0.8590 | 0.8731 | 0.9390 | 0.9783 | 0.9890 | 3.61% | 12.19% | 11.71% |
| Nevada | 0.9657 | 0.9573 | 0.9487 | 0.9719 | 0.9796 | 0.9836 | 0.64% | 2.27% | 3.54% |
| New Mexico | 0.9827 | 0.9787 | 0.9749 | 0.9886 | 0.9929 | 0.9931 | 0.59% | 1.43% | 1.84% |
| North Carolina | 0.8783 | 0.8314 | 0.8231 | 0.9236 | 0.9581 | 0.9932 | 4.91% | 13.23% | 17.13% |
| Oklahoma | 0.9503 | 0.9428 | 0.9371 | 0.9664 | 0.9859 | 0.9837 | 1.66% | 4.37% | 4.73% |
| South Carolina | 0.9078 | 0.8744 | 0.8614 | 0.9442 | 0.9682 | 0.9948 | 3.86% | 9.69% | 13.41% |
| Tennessee | 0.8425 | 0.8050 | 0.7900 | 0.9021 | 0.9660 | 0.9914 | 6.60% | 16.67% | 20.31% |
| Texas High Plains | 0.9726 | 0.9686 | 0.9656 | 0.9808 | 0.9902 | 0.9887 | 0.84% | 2.18% | 2.33% |
| Texas Rolling Plains | 0.9507 | 0.9434 | 0.9397 | 0.9672 | 0.9860 | 0.9821 | 1.71% | 4.32% | 4.32% |
| Texas Central Blacklands | 0.9336 | 0.9255 | 0.9131 | 0.9578 | 0.9800 | 0.9844 | 2.53% | 5.56% | 7.24% |
| Texas East | 0.9400 | 0.9290 | 0.9142 | 0.9656 | 0.9805 | 0.9929 | 2.64% | 5.25% | 7.93% |
| Texas Edwards Plateau | 0.9640 | 0.9588 | 0.9499 | 0.9773 | 0.9876 | 0.9920 | 1.36% | 2.92% | 4.24% |
| Texas Coastal Bend | 0.9381 | 0.9330 | 0.9156 | 0.9589 | 0.9800 | 0.9912 | 2.17% | 4.79% | 7.63% |
| Texas South | 0.9611 | 0.9564 | 0.9433 | 0.9757 | 0.9847 | 0.9951 | 1.49% | 2.88% | 5.20% |
| Texas Trans Pecos | 0.9726 | 0.9678 | 0.9641 | 0.9805 | 0.9898 | 0.9884 | 0.81% | 2.22% | 2.46% |
| Virginia | 0.9025 | 0.8786 | 0.8665 | 0.9398 | 0.9655 | 0.9928 | 3.97% | 9.00% | 12.72% |

Notes:
1. Parameter values for A and B in the equations for X and Y are presented along with the appropriate ozone metric to apply by crop in Exhibit X-6.
2. Relative yield losses are only derived for subregions where the crop is present as defined in FASOM.
3. Relative yield losses are based on ozone concentrations during the growing period for each crop and forest type, not ozone concentrations for the entire May through September period. Growing periods are specific to individual crops and subregions, and to individual regions for hardwood and softwood forest types.

EXHIBIT A-17 DERIVATION OF RELATIVE YIELD LOSSES FOR ORANGES BY FASOM SUBREGION AND YEAR

| SUBREGION | X: $A-(B*O_3NoCAAA)$ | | | Y: $A-(B*O_3WithCAAA)$ | | | RYL: (X/Y) * (100%) | | |
|---|---|---|---|---|---|---|---|---|---|
| | 2000 | 2010 | 2020 | 2000 | 2010 | 2020 | 2000 | 2010 | 2020 |
| Arizona | 39.55 | 39.24 | 38.76 | 40.06 | 40.61 | 41.24 | 1.28% | 3.37% | 6.02% |
| California North | 40.12 | 39.76 | 39.33 | 40.39 | 40.85 | 41.25 | 0.68% | 2.69% | 4.67% |
| California South | 38.23 | 37.81 | 37.19 | 38.99 | 39.67 | 40.37 | 1.95% | 4.68% | 7.87% |
| Florida | 44.06 | 43.88 | 43.60 | 44.36 | 45.10 | 45.63 | 0.67% | 2.71% | 4.44% |
| Texas South | 42.56 | 42.40 | 42.13 | 42.92 | 43.54 | 43.93 | 0.85% | 2.60% | 4.10% |

Notes:
1. Parameter values for A and B in the equations for X and Y are presented along with the appropriate ozone metric to apply by crop in Exhibit X-6.
2. Relative yield losses are only derived for subregions where the crop is present as defined in FASOM.
3. Relative yield losses are based on ozone concentrations during the growing period for each crop and forest type, not ozone concentrations for the entire May through September period. Growing periods are specific to individual crops and subregions, and to individual regions for hardwood and softwood forest types.

## EXHIBIT A-18 DERIVATION OF RELATIVE YIELD LOSSES FOR POTATOES BY FASOM SUBREGION AND YEAR

| SUBREGION | X: $e^{-\left(\frac{O_3 NoCAAA}{A}\right)^B}$ | | | Y: $e^{-\left(\frac{O_3 WithCAAA}{A}\right)^B}$ | | | RYL: (X/Y) * (100%) | | |
|---|---|---|---|---|---|---|---|---|---|
| | 2000 | 2010 | 2020 | 2000 | 2010 | 2020 | 2000 | 2010 | 2020 |
| Alabama | 0.9396 | 0.9308 | 0.9187 | 0.9606 | 0.9881 | 0.9947 | 2.18% | 5.79% | 7.65% |
| Arizona | 0.9106 | 0.8945 | 0.8673 | 0.9325 | 0.9513 | 0.9684 | 2.35% | 5.98% | 10.44% |
| California North | 0.8840 | 0.8594 | 0.8330 | 0.9002 | 0.9287 | 0.9488 | 1.80% | 7.46% | 12.21% |
| California South | 0.8267 | 0.8028 | 0.7669 | 0.8686 | 0.9067 | 0.9425 | 4.82% | 11.46% | 18.63% |
| Colorado | 0.9385 | 0.9324 | 0.9192 | 0.9538 | 0.9630 | 0.9715 | 1.61% | 3.18% | 5.39% |
| Connecticut | 0.8738 | 0.8665 | 0.8564 | 0.9050 | 0.9607 | 0.9877 | 3.44% | 9.80% | 13.30% |
| Delaware | 0.8136 | 0.7811 | 0.7739 | 0.8672 | 0.9472 | 0.9770 | 6.17% | 17.54% | 20.79% |
| Florida | 0.9749 | 0.9694 | 0.9611 | 0.9815 | 0.9915 | 0.9937 | 0.68% | 2.22% | 3.28% |
| Idaho | 0.9656 | 0.9609 | 0.9528 | 0.9702 | 0.9753 | 0.9796 | 0.48% | 1.48% | 2.74% |
| Illinois North | 0.8933 | 0.8645 | 0.8706 | 0.9207 | 0.9624 | 0.9784 | 2.99% | 10.17% | 11.01% |
| Indiana North | 0.8392 | 0.8097 | 0.8081 | 0.8825 | 0.9469 | 0.9728 | 4.91% | 14.49% | 16.93% |
| Iowa Northeast | 0.9564 | 0.9520 | 0.9392 | 0.9684 | 0.9838 | 0.9906 | 1.24% | 3.23% | 5.19% |
| Kansas | 0.9554 | 0.9496 | 0.9415 | 0.9665 | 0.9804 | 0.9874 | 1.16% | 3.14% | 4.64% |
| Louisiana | 0.9563 | 0.9456 | 0.9383 | 0.9724 | 0.9867 | 0.9934 | 1.66% | 4.17% | 5.55% |
| Maine | 0.9681 | 0.9660 | 0.9628 | 0.9785 | 0.9897 | 0.9960 | 1.06% | 2.39% | 3.33% |
| Maryland | 0.8061 | 0.7753 | 0.7687 | 0.8569 | 0.9379 | 0.9706 | 5.93% | 17.33% | 20.80% |
| Massachusetts | 0.8865 | 0.8718 | 0.8711 | 0.9158 | 0.9625 | 0.9844 | 3.20% | 9.42% | 11.51% |
| Michigan | 0.9311 | 0.9314 | 0.9167 | 0.9458 | 0.9700 | 0.9819 | 1.55% | 3.98% | 6.64% |
| Minnesota | 0.9785 | 0.9759 | 0.9731 | 0.9828 | 0.9888 | 0.9926 | 0.43% | 1.31% | 1.97% |
| Missouri | 0.9156 | 0.8706 | 0.8921 | 0.9421 | 0.9754 | 0.9869 | 2.81% | 10.74% | 9.61% |
| Montana | 0.9749 | 0.9734 | 0.9700 | 0.9788 | 0.9816 | 0.9844 | 0.39% | 0.83% | 1.46% |
| Nebraska | 0.9697 | 0.9673 | 0.9620 | 0.9768 | 0.9852 | 0.9897 | 0.73% | 1.81% | 2.79% |
| Nevada | 0.9319 | 0.9195 | 0.9008 | 0.9422 | 0.9557 | 0.9675 | 1.09% | 3.78% | 6.90% |
| New Jersey | 0.8067 | 0.7785 | 0.7781 | 0.8509 | 0.9328 | 0.9725 | 5.19% | 16.54% | 19.99% |
| New Mexico | 0.9482 | 0.9398 | 0.9250 | 0.9611 | 0.9710 | 0.9787 | 1.34% | 3.21% | 5.48% |
| New York | 0.9016 | 0.8890 | 0.8862 | 0.9286 | 0.9667 | 0.9841 | 2.90% | 8.04% | 9.95% |
| North Carolina | 0.8485 | 0.7968 | 0.7962 | 0.8955 | 0.9642 | 0.9850 | 5.25% | 17.36% | 19.17% |
| North Dakota | 0.9867 | 0.9858 | 0.9844 | 0.9894 | 0.9922 | 0.9943 | 0.27% | 0.64% | 1.00% |
| Ohio Northwest | 0.8321 | 0.8088 | 0.8026 | 0.8733 | 0.9429 | 0.9715 | 4.71% | 14.22% | 17.38% |
| Oregon | 0.9810 | 0.9775 | 0.9728 | 0.9829 | 0.9860 | 0.9881 | 0.20% | 0.86% | 1.55% |
| Pennsylvania | 0.8488 | 0.8367 | 0.8207 | 0.8937 | 0.9588 | 0.9801 | 5.03% | 12.73% | 16.26% |
| Rhode Island | 0.8670 | 0.8506 | 0.8483 | 0.8988 | 0.9583 | 0.9861 | 3.54% | 11.25% | 13.97% |
| South Dakota | 0.9717 | 0.9726 | 0.9658 | 0.9772 | 0.9858 | 0.9878 | 0.56% | 1.34% | 2.23% |
| Tennessee | 0.8613 | 0.8286 | 0.8220 | 0.9083 | 0.9711 | 0.9891 | 5.17% | 14.68% | 16.89% |
| Texas High Plains | 0.9653 | 0.9611 | 0.9531 | 0.9743 | 0.9853 | 0.9872 | 0.92% | 2.45% | 3.45% |
| Texas Rolling Plains | 0.9433 | 0.9363 | 0.9421 | 0.9596 | 0.9803 | 0.9902 | 1.70% | 4.49% | 4.86% |
| Texas East | 0.9324 | 0.9221 | 0.9083 | 0.9577 | 0.9762 | 0.9893 | 2.64% | 5.54% | 8.19% |
| Texas Coastal Bend | 0.9323 | 0.9277 | 0.9119 | 0.9522 | 0.9751 | 0.9871 | 2.09% | 4.87% | 7.61% |
| Texas South | 0.9570 | 0.9439 | 0.9410 | 0.9710 | 0.9760 | 0.9923 | 1.44% | 3.28% | 5.17% |
| Utah | 0.9000 | 0.8853 | 0.8595 | 0.9213 | 0.9390 | 0.9568 | 2.31% | 5.72% | 10.17% |
| Virginia | 0.8482 | 0.8038 | 0.8051 | 0.8976 | 0.9628 | 0.9832 | 5.50% | 16.51% | 18.11% |
| Washington | 0.9911 | 0.9897 | 0.9877 | 0.9919 | 0.9936 | 0.9950 | 0.09% | 0.40% | 0.73% |
| West Virginia | 0.8826 | 0.8585 | 0.8548 | 0.9212 | 0.9756 | 0.9880 | 4.19% | 12.00% | 13.47% |

| SUBREGION | X: $e^{-\left(\frac{O_3NoCAAA}{A}\right)^B}$ | | | Y: $e^{-\left(\frac{O_3WithCAAA}{A}\right)^B}$ | | | RYL: (X/Y) * (100%) | | |
|---|---|---|---|---|---|---|---|---|---|
| | 2000 | 2010 | 2020 | 2000 | 2010 | 2020 | 2000 | 2010 | 2020 |
| Wisconsin | 0.9472 | 0.9446 | 0.9318 | 0.9598 | 0.9778 | 0.9866 | 1.31% | 3.39% | 5.56% |
| Wyoming | 0.9326 | 0.9261 | 0.9131 | 0.9489 | 0.9578 | 0.9670 | 1.72% | 3.31% | 5.58% |

Notes:

1. Parameter values for A and B in the equations for X and Y are presented along with the appropriate ozone metric to apply by crop in Exhibit X-6.
2. Relative yield losses are only derived for subregions where the crop is present as defined in FASOM.
3. Relative yield losses are based on ozone concentrations during the growing period for each crop and forest type, not ozone concentrations for the entire May through September period. Growing periods are specific to individual crops and subregions, and to individual regions for hardwood and softwood forest types.

**EXHIBIT A-19 DERIVATION OF RELATIVE YIELD LOSSES FOR RICE BY FASOM SUBREGION AND YEAR**

| SUBREGION | X: $e^{-\left(\frac{O_3 NoCAAA}{A}\right)^B}$ | | | Y: $e^{-\left(\frac{O_3 WithCAAA}{A}\right)^B}$ | | | RYL: (X/Y) * (100%) | | |
|---|---|---|---|---|---|---|---|---|---|
| | 2000 | 2010 | 2020 | 2000 | 2010 | 2020 | 2000 | 2010 | 2020 |
| Arkansas | 0.9696 | 0.9681 | 0.9653 | 0.9700 | 0.9775 | 0.9814 | 0.04% | 0.97% | 1.64% |
| California North | 0.9625 | 0.9589 | 0.9567 | 0.9623 | 0.9655 | 0.9681 | -0.02% | 0.68% | 1.18% |
| California South | 0.9597 | 0.9538 | 0.9524 | 0.9589 | 0.9637 | 0.9684 | -0.08% | 1.03% | 1.66% |
| Louisiana | 0.9772 | 0.9763 | 0.9744 | 0.9779 | 0.9819 | 0.9844 | 0.07% | 0.57% | 1.02% |
| Mississippi | 0.9761 | 0.9749 | 0.9727 | 0.9762 | 0.9823 | 0.9858 | 0.00% | 0.75% | 1.33% |
| Missouri | 0.9671 | 0.9659 | 0.9636 | 0.9674 | 0.9745 | 0.9787 | 0.03% | 0.89% | 1.54% |
| Texas Central Blacklands | 0.9787 | 0.9773 | 0.9761 | 0.9787 | 0.9824 | 0.9846 | 0.01% | 0.53% | 0.86% |
| Texas East | 0.9752 | 0.9740 | 0.9721 | 0.9763 | 0.9813 | 0.9839 | 0.11% | 0.74% | 1.20% |
| Texas Coastal Bend | 0.9801 | 0.9796 | 0.9784 | 0.9815 | 0.9841 | 0.9856 | 0.14% | 0.46% | 0.73% |

Notes:

1. Parameter values for A and B in the equations for X and Y are presented along with the appropriate ozone metric to apply by crop in Exhibit X-6.
2. Relative yield losses are only derived for subregions where the crop is present as defined in FASOM.
3. Relative yield losses are based on ozone concentrations during the growing period for each crop and forest type, not ozone concentrations for the entire May through September period. Growing periods are specific to individual crops and subregions, and to individual regions for hardwood and softwood forest types.

### EXHIBIT A-20 DERIVATION OF RELATIVE YIELD LOSSES FOR SORGHUM BY FASOM SUBREGION AND YEAR

| SUBREGION | X: $e^{-\left(\frac{O_3NoCAAA}{A}\right)^B}$ | | | Y: $e^{-\left(\frac{O_3WithCAAA}{A}\right)^B}$ | | | RYL: (X/Y) * (100%) | | |
|---|---|---|---|---|---|---|---|---|---|
| | 2000 | 2010 | 2020 | 2000 | 2010 | 2020 | 2000 | 2010 | 2020 |
| Alabama | 0.9966 | 0.9957 | 0.9945 | 0.9983 | 0.9992 | 0.9999 | 0.17% | 0.35% | 0.54% |
| Arizona | 0.9990 | 0.9985 | 0.9982 | 0.9994 | 0.9997 | 0.9997 | 0.05% | 0.12% | 0.15% |
| Arkansas | 0.9932 | 0.9892 | 0.9887 | 0.9967 | 0.9993 | 0.9998 | 0.35% | 1.01% | 1.11% |
| California North | 0.9900 | 0.9863 | 0.9839 | 0.9920 | 0.9952 | 0.9957 | 0.21% | 0.89% | 1.18% |
| California South | 0.9870 | 0.9835 | 0.9803 | 0.9918 | 0.9954 | 0.9969 | 0.49% | 1.20% | 1.67% |
| Colorado | 0.9992 | 0.9990 | 0.9989 | 0.9995 | 0.9997 | 0.9997 | 0.03% | 0.06% | 0.08% |
| Delaware | 0.9876 | 0.9843 | 0.9824 | 0.9930 | 0.9969 | 0.9996 | 0.54% | 1.26% | 1.72% |
| Georgia | 0.9952 | 0.9930 | 0.9915 | 0.9974 | 0.9988 | 0.9999 | 0.22% | 0.58% | 0.83% |
| Illinois North | 0.9973 | 0.9970 | 0.9962 | 0.9985 | 0.9996 | 0.9998 | 0.11% | 0.26% | 0.36% |
| Illinois South | 0.9943 | 0.9936 | 0.9923 | 0.9968 | 0.9993 | 0.9997 | 0.25% | 0.57% | 0.74% |
| Indiana North | 0.9929 | 0.9917 | 0.9903 | 0.9959 | 0.9987 | 0.9996 | 0.30% | 0.70% | 0.93% |
| Indiana South | 0.9912 | 0.9894 | 0.9886 | 0.9944 | 0.9983 | 0.9995 | 0.33% | 0.89% | 1.09% |
| Iowa West | 0.9994 | 0.9993 | 0.9992 | 0.9996 | 0.9998 | 0.9999 | 0.02% | 0.04% | 0.07% |
| Iowa Central | 0.9993 | 0.9991 | 0.9988 | 0.9996 | 0.9998 | 0.9999 | 0.03% | 0.06% | 0.11% |
| Iowa Northeast | 0.9992 | 0.9990 | 0.9986 | 0.9996 | 0.9997 | 0.9999 | 0.04% | 0.07% | 0.13% |
| Iowa South | 0.9983 | 0.9978 | 0.9974 | 0.9991 | 0.9997 | 0.9999 | 0.08% | 0.19% | 0.25% |
| Kansas | 0.9984 | 0.9982 | 0.9979 | 0.9990 | 0.9996 | 0.9996 | 0.06% | 0.15% | 0.17% |
| Kentucky | 0.9933 | 0.9924 | 0.9907 | 0.9963 | 0.9990 | 0.9998 | 0.31% | 0.66% | 0.91% |
| Louisiana | 0.9974 | 0.9961 | 0.9954 | 0.9987 | 0.9995 | 0.9998 | 0.13% | 0.34% | 0.45% |
| Maryland | 0.9848 | 0.9812 | 0.9790 | 0.9910 | 0.9963 | 0.9993 | 0.63% | 1.52% | 2.03% |
| Mississippi | 0.9971 | 0.9957 | 0.9950 | 0.9986 | 0.9996 | 0.9999 | 0.15% | 0.39% | 0.49% |
| Missouri | 0.9942 | 0.9917 | 0.9913 | 0.9969 | 0.9993 | 0.9997 | 0.27% | 0.75% | 0.84% |
| Nebraska | 0.9994 | 0.9993 | 0.9992 | 0.9996 | 0.9998 | 0.9998 | 0.02% | 0.05% | 0.06% |
| New Mexico | 0.9995 | 0.9993 | 0.9993 | 0.9997 | 0.9999 | 0.9998 | 0.02% | 0.05% | 0.06% |
| North Carolina | 0.9908 | 0.9865 | 0.9842 | 0.9952 | 0.9974 | 0.9998 | 0.44% | 1.08% | 1.56% |
| Oklahoma | 0.9974 | 0.9968 | 0.9966 | 0.9985 | 0.9995 | 0.9993 | 0.11% | 0.27% | 0.27% |
| Pennsylvania | 0.9883 | 0.9868 | 0.9844 | 0.9935 | 0.9980 | 0.9996 | 0.53% | 1.13% | 1.52% |
| South Carolina | 0.9912 | 0.9866 | 0.9844 | 0.9956 | 0.9978 | 0.9998 | 0.44% | 1.12% | 1.55% |
| South Dakota | 0.9996 | 0.9996 | 0.9995 | 0.9997 | 0.9999 | 0.9999 | 0.01% | 0.03% | 0.04% |
| Tennessee | 0.9824 | 0.9762 | 0.9732 | 0.9910 | 0.9979 | 0.9997 | 0.87% | 2.17% | 2.65% |
| Texas High Plains | 0.9981 | 0.9977 | 0.9968 | 0.9987 | 0.9994 | 0.9997 | 0.07% | 0.17% | 0.28% |
| Texas Rolling Plains | 0.9966 | 0.9960 | 0.9945 | 0.9980 | 0.9993 | 0.9997 | 0.13% | 0.33% | 0.51% |
| Texas Central Blacklands | 0.9956 | 0.9949 | 0.9929 | 0.9976 | 0.9992 | 0.9997 | 0.20% | 0.43% | 0.68% |
| Texas East | 0.9956 | 0.9942 | 0.9924 | 0.9979 | 0.9995 | 0.9998 | 0.24% | 0.52% | 0.74% |
| Texas Edwards Plateau | 0.9982 | 0.9979 | 0.9968 | 0.9989 | 0.9996 | 0.9998 | 0.08% | 0.17% | 0.30% |
| Texas Coastal Bend | 0.9959 | 0.9955 | 0.9936 | 0.9976 | 0.9993 | 0.9997 | 0.18% | 0.38% | 0.61% |
| Texas South | 0.9982 | 0.9980 | 0.9971 | 0.9990 | 0.9997 | 0.9998 | 0.08% | 0.17% | 0.28% |
| Texas Trans Pecos | 0.9984 | 0.9980 | 0.9972 | 0.9989 | 0.9995 | 0.9997 | 0.05% | 0.14% | 0.25% |
| Virginia | 0.9863 | 0.9805 | 0.9788 | 0.9929 | 0.9969 | 0.9996 | 0.67% | 1.65% | 2.08% |

Notes:
1. Parameter values for A and B in the equations for X and Y are presented along with the appropriate ozone metric to apply by crop in Exhibit X-6.
2. Relative yield losses are only derived for subregions where the crop is present as defined in FASOM.
3. Relative yield losses are based on ozone concentrations during the growing period for each crop and forest type, not ozone concentrations for the entire May through September period. Growing periods are specific to individual crops and subregions, and to individual regions for hardwood and softwood forest types.

## EXHIBIT A-21 DERIVATION OF RELATIVE YIELD LOSSES FOR SOYBEANS BY FASOM SUBREGION AND YEAR

| SUBREGION | X: $e^{-\left(\frac{O_3 NoCAAA}{A}\right)^B}$ | | | Y: $e^{-\left(\frac{O_3 WithCAAA}{A}\right)^B}$ | | | RYL: (X/Y) * (100%) | | |
|---|---|---|---|---|---|---|---|---|---|
| | 2000 | 2010 | 2020 | 2000 | 2010 | 2020 | 2000 | 2010 | 2020 |
| Alabama | 0.9710 | 0.9670 | 0.9605 | 0.9814 | 0.9864 | 0.9978 | 1.06% | 1.96% | 3.74% |
| Arkansas | 0.9418 | 0.9309 | 0.9176 | 0.9644 | 0.9863 | 0.9946 | 2.34% | 5.62% | 7.75% |
| Delaware | 0.9397 | 0.9329 | 0.9227 | 0.9589 | 0.9707 | 0.9939 | 2.01% | 3.89% | 7.16% |
| Florida | 0.9958 | 0.9948 | 0.9931 | 0.9972 | 0.9894 | 0.9995 | 0.13% | -0.55% | 0.64% |
| Georgia | 0.9763 | 0.9720 | 0.9656 | 0.9842 | 0.9858 | 0.9979 | 0.80% | 1.40% | 3.24% |
| Illinois North | 0.9306 | 0.9125 | 0.9124 | 0.9511 | 0.9799 | 0.9886 | 2.16% | 6.88% | 7.71% |
| Illinois South | 0.8951 | 0.8601 | 0.8721 | 0.9285 | 0.9743 | 0.9875 | 3.60% | 11.73% | 11.68% |
| Indiana North | 0.8940 | 0.8765 | 0.8705 | 0.9259 | 0.9665 | 0.9853 | 3.45% | 9.31% | 11.65% |
| Indiana South | 0.8865 | 0.8569 | 0.8658 | 0.9166 | 0.9633 | 0.9842 | 3.29% | 11.05% | 12.02% |
| Iowa West | 0.9766 | 0.9749 | 0.9708 | 0.9827 | 0.9888 | 0.9928 | 0.62% | 1.41% | 2.21% |
| Iowa Central | 0.9762 | 0.9733 | 0.9670 | 0.9837 | 0.9901 | 0.9958 | 0.75% | 1.69% | 2.89% |
| Iowa Northeast | 0.9753 | 0.9722 | 0.9634 | 0.9834 | 0.9887 | 0.9957 | 0.82% | 1.67% | 3.25% |
| Iowa South | 0.9602 | 0.9457 | 0.9460 | 0.9737 | 0.9884 | 0.9938 | 1.38% | 4.32% | 4.81% |
| Kansas | 0.9640 | 0.9599 | 0.9560 | 0.9738 | 0.9860 | 0.9871 | 1.00% | 2.65% | 3.15% |
| Kentucky | 0.9225 | 0.9140 | 0.9033 | 0.9485 | 0.9792 | 0.9923 | 2.74% | 6.66% | 8.96% |
| Louisiana | 0.9652 | 0.9575 | 0.9497 | 0.9789 | 0.9796 | 0.9956 | 1.39% | 2.26% | 4.61% |
| Maryland | 0.9219 | 0.9138 | 0.9024 | 0.9451 | 0.9665 | 0.9905 | 2.46% | 5.45% | 8.90% |
| Michigan | 0.9635 | 0.9618 | 0.9542 | 0.9727 | 0.9862 | 0.9921 | 0.95% | 2.47% | 3.82% |
| Minnesota | 0.9910 | 0.9898 | 0.9883 | 0.9932 | 0.9941 | 0.9973 | 0.23% | 0.43% | 0.90% |
| Mississippi | 0.9543 | 0.9420 | 0.9353 | 0.9718 | 0.9836 | 0.9965 | 1.80% | 4.23% | 6.14% |
| Missouri | 0.9348 | 0.9163 | 0.9142 | 0.9570 | 0.9838 | 0.9912 | 2.32% | 6.87% | 7.77% |
| Nebraska | 0.9784 | 0.9765 | 0.9735 | 0.9840 | 0.9901 | 0.9918 | 0.57% | 1.38% | 1.85% |
| New Jersey | 0.9212 | 0.9140 | 0.9069 | 0.9404 | 0.9647 | 0.9900 | 2.04% | 5.25% | 8.39% |
| New York | 0.9461 | 0.9418 | 0.9356 | 0.9633 | 0.9807 | 0.9927 | 1.78% | 3.96% | 5.75% |
| North Carolina | 0.9752 | 0.9708 | 0.9643 | 0.9841 | 0.9776 | 0.9980 | 0.91% | 0.69% | 3.38% |
| North Dakota | 0.9908 | 0.9902 | 0.9893 | 0.9928 | 0.9947 | 0.9958 | 0.20% | 0.46% | 0.65% |
| Ohio Northwest | 0.8814 | 0.8660 | 0.8575 | 0.9139 | 0.9612 | 0.9827 | 3.55% | 9.90% | 12.74% |
| Ohio South | 0.8819 | 0.8628 | 0.8610 | 0.9129 | 0.9636 | 0.9843 | 3.39% | 10.45% | 12.53% |
| Ohio Northeast | 0.8813 | 0.8670 | 0.8611 | 0.9106 | 0.9618 | 0.9791 | 3.22% | 9.85% | 12.05% |
| Oklahoma | 0.9499 | 0.9432 | 0.9380 | 0.9650 | 0.9843 | 0.9816 | 1.57% | 4.17% | 4.44% |
| Pennsylvania | 0.9271 | 0.9209 | 0.9116 | 0.9512 | 0.9768 | 0.9924 | 2.54% | 5.73% | 8.14% |
| South Carolina | 0.9822 | 0.9787 | 0.9738 | 0.9888 | 0.9832 | 0.9985 | 0.67% | 0.46% | 2.47% |
| South Dakota | 0.9846 | 0.9833 | 0.9814 | 0.9882 | 0.9920 | 0.9933 | 0.37% | 0.87% | 1.20% |
| Tennessee | 0.9085 | 0.8976 | 0.8790 | 0.9410 | 0.9749 | 0.9938 | 3.45% | 7.93% | 11.55% |
| Texas High Plains | 0.9675 | 0.9632 | 0.9598 | 0.9765 | 0.9872 | 0.9857 | 0.92% | 2.43% | 2.63% |
| Texas Rolling Plains | 0.9458 | 0.9386 | 0.9348 | 0.9626 | 0.9828 | 0.9789 | 1.74% | 4.50% | 4.51% |
| Texas Central Blacklands | 0.9293 | 0.9216 | 0.9094 | 0.9533 | 0.9764 | 0.9813 | 2.51% | 5.61% | 7.33% |
| Texas East | 0.9346 | 0.9233 | 0.9091 | 0.9607 | 0.9769 | 0.9907 | 2.71% | 5.49% | 8.24% |
| Texas Edwards Plateau | 0.9600 | 0.9550 | 0.9458 | 0.9738 | 0.9850 | 0.9899 | 1.41% | 3.05% | 4.46% |
| Texas Coastal Bend | 0.9335 | 0.9291 | 0.9117 | 0.9543 | 0.9764 | 0.9888 | 2.18% | 4.85% | 7.80% |
| Texas South | 0.9574 | 0.9530 | 0.9398 | 0.9723 | 0.9818 | 0.9935 | 1.53% | 2.94% | 5.40% |
| Texas Trans Pecos | 0.9676 | 0.9625 | 0.9582 | 0.9763 | 0.9868 | 0.9855 | 0.89% | 2.47% | 2.77% |
| Virginia | 0.9466 | 0.9392 | 0.9279 | 0.9660 | 0.9731 | 0.9950 | 2.01% | 3.48% | 6.74% |

| SUBREGION | X: $e^{-\left(\frac{O_3NoCAAA}{A}\right)^B}$ | | | Y: $e^{-\left(\frac{O_3WithCAAA}{A}\right)^B}$ | | | RYL: (X/Y) * (100%) | | |
|---|---|---|---|---|---|---|---|---|---|
| | 2000 | 2010 | 2020 | 2000 | 2010 | 2020 | 2000 | 2010 | 2020 |
| West Virginia | 0.9373 | 0.9313 | 0.9200 | 0.9588 | 0.9785 | 0.9941 | 2.24% | 4.82% | 7.45% |
| Wisconsin | 0.9766 | 0.9745 | 0.9687 | 0.9833 | 0.9889 | 0.9953 | 0.68% | 1.46% | 2.67% |

Notes:

1. Parameter values for A and B in the equations for X and Y are presented along with the appropriate ozone metric to apply by crop in Exhibit X-6.
2. Relative yield losses are only derived for subregions where the crop is present as defined in FASOM.
3. Relative yield losses are based on ozone concentrations during the growing period for each crop and forest type, not ozone concentrations for the entire May through September period. Growing periods are specific to individual crops and subregions, and to individual regions for hardwood and softwood forest types.

## EXHIBIT A-22 DERIVATION OF RELATIVE YIELD LOSSES FOR PROCESSING TOMATOES BY FASOM SUBREGION AND YEAR

| SUBREGION | X: $A-(B*O_3NoCAAA)$ | | | Y: $A-(B*O_3WithCAAA)$ | | | RYL: (X/Y) * (100%) | | |
|---|---|---|---|---|---|---|---|---|---|
| | 2000 | 2010 | 2020 | 2000 | 2010 | 2020 | 2000 | 2010 | 2020 |
| California North | 7,290.13 | 7,232.09 | 7,164.21 | 7,332.20 | 7,406.13 | 7,469.18 | 0.57% | 2.35% | 4.08% |
| California South | 7,096.73 | 7,032.19 | 6,938.08 | 7,209.71 | 7,313.33 | 7,431.04 | 1.57% | 3.84% | 6.63% |
| Colorado | 7,415.28 | 7,390.86 | 7,344.74 | 7,478.11 | 7,532.51 | 7,591.02 | 0.84% | 1.88% | 3.24% |
| Delaware | 7,054.53 | 7,034.34 | 6,984.21 | 7,177.10 | 7,423.04 | 7,584.43 | 1.71% | 5.24% | 7.91% |
| Indiana North | 7,167.08 | 7,138.69 | 7,094.80 | 7,269.14 | 7,456.14 | 7,585.62 | 1.40% | 4.26% | 6.47% |
| Indiana South | 7,188.07 | 7,161.13 | 7,114.87 | 7,294.13 | 7,506.79 | 7,644.14 | 1.45% | 4.60% | 6.92% |
| Maryland | 7,022.28 | 6,982.46 | 6,933.75 | 7,152.79 | 7,392.19 | 7,553.57 | 1.82% | 5.54% | 8.21% |
| Michigan | 7,522.37 | 7,546.02 | 7,528.65 | 7,560.12 | 7,690.92 | 7,769.18 | 0.50% | 1.88% | 3.10% |
| New Jersey | 7,067.04 | 7,029.99 | 7,003.71 | 7,160.55 | 7,356.54 | 7,533.69 | 1.31% | 4.44% | 7.03% |
| New York | 7,398.89 | 7,382.07 | 7,385.19 | 7,465.67 | 7,594.68 | 7,718.73 | 0.89% | 2.80% | 4.32% |
| Ohio Northwest | 7,110.99 | 7,083.27 | 7,045.09 | 7,211.10 | 7,408.55 | 7,548.21 | 1.39% | 4.39% | 6.67% |
| Ohio South | 7,159.61 | 7,134.65 | 7,091.84 | 7,256.56 | 7,489.78 | 7,622.76 | 1.34% | 4.74% | 6.97% |
| Ohio Northeast | 7,097.34 | 7,073.26 | 7,045.48 | 7,190.71 | 7,390.46 | 7,531.13 | 1.30% | 4.29% | 6.45% |
| Pennsylvania | 7,201.80 | 7,176.27 | 7,150.19 | 7,308.58 | 7,518.60 | 7,656.11 | 1.46% | 4.55% | 6.61% |
| Virginia | 7,143.70 | 7,102.29 | 7,047.07 | 7,267.16 | 7,510.62 | 7,653.34 | 1.70% | 5.44% | 7.92% |

Notes:
1. Parameter values for A and B in the equations for X and Y are presented along with the appropriate ozone metric to apply by crop in Exhibit X-6.
2. Relative yield losses are only derived for subregions where the crop is present as defined in FASOM.
3. Relative yield losses are based on ozone concentrations during the growing period for each crop and forest type, not ozone concentrations for the entire May through September period. Growing periods are specific to individual crops and subregions, and to individual regions for hardwood and softwood forest types.

**EXHIBIT A-23 DERIVATION OF RELATIVE YIELD LOSSES FOR SPRING WHEAT BY FASOM SUBREGION AND YEAR**

| SUBREGION | X: $e^{-\left(\frac{O_3 NoCAAA}{A}\right)^B}$ | | | Y: $e^{-\left(\frac{O_3 WithCAAA}{A}\right)^B}$ | | | RYL: (X/Y) * (100%) | | |
|---|---|---|---|---|---|---|---|---|---|
| | 2000 | 2010 | 2020 | 2000 | 2010 | 2020 | 2000 | 2010 | 2020 |
| Colorado | 0.9893 | 0.9868 | 0.9802 | 0.9944 | 0.9967 | 0.9982 | 0.51% | 0.99% | 1.80% |
| Idaho | 0.9962 | 0.9950 | 0.9925 | 0.9972 | 0.9982 | 0.9988 | 0.09% | 0.31% | 0.63% |
| Minnesota | 0.9992 | 0.9990 | 0.9988 | 0.9995 | 0.9998 | 0.9999 | 0.03% | 0.08% | 0.12% |
| Montana | 0.9980 | 0.9977 | 0.9970 | 0.9986 | 0.9990 | 0.9993 | 0.06% | 0.13% | 0.23% |
| Nevada | 0.9833 | 0.9762 | 0.9631 | 0.9882 | 0.9933 | 0.9965 | 0.50% | 1.71% | 3.35% |
| North Dakota | 0.9990 | 0.9989 | 0.9986 | 0.9993 | 0.9996 | 0.9998 | 0.03% | 0.07% | 0.12% |
| Oregon | 0.9982 | 0.9975 | 0.9965 | 0.9985 | 0.9990 | 0.9993 | 0.03% | 0.15% | 0.28% |
| South Dakota | 0.9958 | 0.9953 | 0.9940 | 0.9972 | 0.9984 | 0.9991 | 0.14% | 0.31% | 0.50% |
| Utah | 0.9639 | 0.9514 | 0.9246 | 0.9785 | 0.9876 | 0.9940 | 1.50% | 3.67% | 6.98% |
| Washington | 0.9996 | 0.9995 | 0.9993 | 0.9997 | 0.9998 | 0.9999 | 0.01% | 0.03% | 0.06% |
| Wisconsin | 0.9906 | 0.9899 | 0.9840 | 0.9945 | 0.9983 | 0.9994 | 0.39% | 0.85% | 1.54% |
| Wyoming | 0.9857 | 0.9824 | 0.9747 | 0.9922 | 0.9950 | 0.9971 | 0.66% | 1.26% | 2.25% |

Notes:

1. Parameter values for A and B in the equations for X and Y are presented along with the appropriate ozone metric to apply by crop in Exhibit X-6.
2. Relative yield losses are only derived for subregions where the crop is present as defined in FASOM.
3. Relative yield losses are based on ozone concentrations during the growing period for each crop and forest type, not ozone concentrations for the entire May through September period. Growing periods are specific to individual crops and subregions, and to individual regions for hardwood and softwood forest types.

### EXHIBIT A-24 DERIVATION OF RELATIVE YIELD LOSSES FOR WINTER WHEAT BY FASOM SUBREGION AND YEAR

| SUBREGION | X: $e^{-\left(\frac{O_3NoCAAA}{A}\right)^B}$ | | | Y: $e^{-\left(\frac{O_3WithCAAA}{A}\right)^B}$ | | | RYL: (X/Y) * (100%) | | |
|---|---|---|---|---|---|---|---|---|---|
| | 2000 | 2010 | 2020 | 2000 | 2010 | 2020 | 2000 | 2010 | 2020 |
| Alabama | 0.9960 | 0.9951 | 0.9934 | 0.9979 | 0.9995 | 0.9998 | 0.19% | 0.44% | 0.64% |
| Arizona | 0.9816 | 0.9772 | 0.9690 | 0.9873 | 0.9916 | 0.9952 | 0.58% | 1.45% | 2.63% |
| Arkansas | 0.9948 | 0.9935 | 0.9903 | 0.9973 | 0.9992 | 0.9997 | 0.25% | 0.57% | 0.94% |
| California North | 0.9716 | 0.9612 | 0.9442 | 0.9783 | 0.9874 | 0.9918 | 0.68% | 2.64% | 4.80% |
| California South | 0.8857 | 0.8583 | 0.8109 | 0.9284 | 0.9586 | 0.9797 | 4.60% | 10.47% | 17.24% |
| Colorado | 0.9839 | 0.9810 | 0.9741 | 0.9900 | 0.9931 | 0.9955 | 0.62% | 1.22% | 2.16% |
| Delaware | 0.9425 | 0.9313 | 0.9166 | 0.9681 | 0.9923 | 0.9977 | 2.64% | 6.14% | 8.13% |
| Florida | 0.9994 | 0.9992 | 0.9989 | 0.9996 | 0.9999 | 0.9999 | 0.02% | 0.06% | 0.10% |
| Georgia | 0.9963 | 0.9954 | 0.9937 | 0.9979 | 0.9994 | 0.9998 | 0.15% | 0.40% | 0.61% |
| Illinois North | 0.9758 | 0.9703 | 0.9661 | 0.9858 | 0.9959 | 0.9983 | 1.02% | 2.57% | 3.23% |
| Illinois South | 0.9746 | 0.9660 | 0.9628 | 0.9865 | 0.9968 | 0.9989 | 1.21% | 3.09% | 3.61% |
| Indiana North | 0.9326 | 0.9155 | 0.9062 | 0.9626 | 0.9905 | 0.9970 | 3.12% | 7.58% | 9.10% |
| Indiana South | 0.9520 | 0.9294 | 0.9327 | 0.9734 | 0.9939 | 0.9982 | 2.20% | 6.49% | 6.57% |
| Iowa West | 0.9908 | 0.9896 | 0.9863 | 0.9943 | 0.9976 | 0.9990 | 0.34% | 0.80% | 1.27% |
| Iowa Central | 0.9919 | 0.9903 | 0.9868 | 0.9953 | 0.9985 | 0.9994 | 0.34% | 0.82% | 1.26% |
| Iowa Northeast | 0.9918 | 0.9900 | 0.9856 | 0.9953 | 0.9985 | 0.9994 | 0.35% | 0.85% | 1.38% |
| Iowa South | 0.9922 | 0.9870 | 0.9869 | 0.9960 | 0.9989 | 0.9996 | 0.38% | 1.19% | 1.27% |
| Kansas | 0.9953 | 0.9946 | 0.9924 | 0.9972 | 0.9988 | 0.9994 | 0.19% | 0.42% | 0.70% |
| Kentucky | 0.9824 | 0.9790 | 0.9725 | 0.9911 | 0.9980 | 0.9993 | 0.87% | 1.91% | 2.68% |
| Louisiana | 0.9976 | 0.9973 | 0.9963 | 0.9986 | 0.9994 | 0.9997 | 0.10% | 0.21% | 0.33% |
| Maryland | 0.9266 | 0.9113 | 0.8967 | 0.9570 | 0.9887 | 0.9964 | 3.18% | 7.82% | 10.00% |
| Michigan | 0.9804 | 0.9799 | 0.9722 | 0.9875 | 0.9958 | 0.9983 | 0.72% | 1.59% | 2.62% |
| Minnesota | 0.9983 | 0.9979 | 0.9974 | 0.9989 | 0.9996 | 0.9998 | 0.06% | 0.16% | 0.24% |
| Mississippi | 0.9966 | 0.9959 | 0.9942 | 0.9981 | 0.9994 | 0.9998 | 0.15% | 0.36% | 0.55% |
| Missouri | 0.9911 | 0.9893 | 0.9857 | 0.9951 | 0.9985 | 0.9994 | 0.40% | 0.91% | 1.37% |
| Montana | 0.9976 | 0.9972 | 0.9964 | 0.9983 | 0.9987 | 0.9991 | 0.07% | 0.15% | 0.26% |
| Nebraska | 0.9971 | 0.9967 | 0.9957 | 0.9982 | 0.9991 | 0.9995 | 0.11% | 0.24% | 0.38% |
| Nevada | 0.9812 | 0.9737 | 0.9599 | 0.9866 | 0.9921 | 0.9958 | 0.54% | 1.86% | 3.61% |
| New Jersey | 0.8505 | 0.8020 | 0.8048 | 0.9100 | 0.9808 | 0.9964 | 6.53% | 18.23% | 19.23% |
| New Mexico | 0.9823 | 0.9779 | 0.9695 | 0.9884 | 0.9923 | 0.9952 | 0.61% | 1.44% | 2.58% |
| New York | 0.9643 | 0.9549 | 0.9534 | 0.9797 | 0.9947 | 0.9985 | 1.58% | 3.99% | 4.51% |
| North Carolina | 0.9695 | 0.9617 | 0.9500 | 0.9827 | 0.9957 | 0.9986 | 1.35% | 3.42% | 4.87% |
| North Dakota | 0.9986 | 0.9985 | 0.9984 | 0.9989 | 0.9992 | 0.9995 | 0.03% | 0.07% | 0.11% |
| Ohio Northwest | 0.9087 | 0.8864 | 0.8751 | 0.9468 | 0.9877 | 0.9965 | 4.03% | 10.25% | 12.18% |
| Ohio South | 0.9327 | 0.9083 | 0.9080 | 0.9614 | 0.9931 | 0.9979 | 2.99% | 8.54% | 9.01% |
| Ohio Northeast | 0.9033 | 0.8827 | 0.8755 | 0.9403 | 0.9854 | 0.9952 | 3.94% | 10.42% | 12.02% |
| Oklahoma | 0.9940 | 0.9929 | 0.9899 | 0.9964 | 0.9985 | 0.9993 | 0.24% | 0.57% | 0.95% |
| Pennsylvania | 0.9199 | 0.9090 | 0.8908 | 0.9585 | 0.9931 | 0.9982 | 4.03% | 8.47% | 10.75% |
| South Carolina | 0.9845 | 0.9800 | 0.9733 | 0.9919 | 0.9979 | 0.9993 | 0.74% | 1.79% | 2.61% |
| South Dakota | 0.9961 | 0.9957 | 0.9947 | 0.9973 | 0.9984 | 0.9990 | 0.12% | 0.27% | 0.43% |
| Tennessee | 0.9753 | 0.9699 | 0.9596 | 0.9872 | 0.9974 | 0.9992 | 1.20% | 2.75% | 3.96% |
| Texas High Plains | 0.9951 | 0.9943 | 0.9923 | 0.9966 | 0.9981 | 0.9988 | 0.15% | 0.37% | 0.65% |
| Texas Rolling Plains | 0.9930 | 0.9917 | 0.9885 | 0.9957 | 0.9981 | 0.9990 | 0.27% | 0.65% | 1.06% |

| SUBREGION | X: $e^{-\left(\frac{O_3NoCAAA}{A}\right)^B}$ | | | Y: $e^{-\left(\frac{O_3WithCAAA}{A}\right)^B}$ | | | RYL: (X/Y) * (100%) | | |
|---|---|---|---|---|---|---|---|---|---|
| | 2000 | 2010 | 2020 | 2000 | 2010 | 2020 | 2000 | 2010 | 2020 |
| Texas Central Blacklands | 0.9868 | 0.9843 | 0.9782 | 0.9928 | 0.9973 | 0.9987 | 0.60% | 1.31% | 2.05% |
| Texas East | 0.9895 | 0.9875 | 0.9816 | 0.9950 | 0.9984 | 0.9992 | 0.55% | 1.09% | 1.76% |
| Texas Edwards Plateau | 0.9934 | 0.9919 | 0.9887 | 0.9958 | 0.9982 | 0.9991 | 0.24% | 0.62% | 1.04% |
| Texas Coastal Bend | 0.9896 | 0.9879 | 0.9839 | 0.9939 | 0.9977 | 0.9988 | 0.43% | 0.98% | 1.50% |
| Texas South | 0.9906 | 0.9887 | 0.9845 | 0.9944 | 0.9976 | 0.9987 | 0.38% | 0.90% | 1.42% |
| Texas Trans Pecos | 0.9979 | 0.9975 | 0.9966 | 0.9984 | 0.9989 | 0.9993 | 0.05% | 0.14% | 0.27% |
| Utah | 0.9562 | 0.9426 | 0.9140 | 0.9730 | 0.9837 | 0.9917 | 1.72% | 4.18% | 7.84% |
| Virginia | 0.9539 | 0.9407 | 0.9274 | 0.9756 | 0.9947 | 0.9981 | 2.23% | 5.43% | 7.09% |
| West Virginia | 0.9525 | 0.9355 | 0.9300 | 0.9764 | 0.9970 | 0.9991 | 2.45% | 6.17% | 6.92% |
| Wisconsin | 0.9882 | 0.9873 | 0.9804 | 0.9931 | 0.9978 | 0.9992 | 0.49% | 1.06% | 1.88% |
| Wyoming | 0.9801 | 0.9762 | 0.9671 | 0.9886 | 0.9922 | 0.9952 | 0.86% | 1.61% | 2.82% |

Notes:

1. Parameter values for A and B in the equations for X and Y are presented along with the appropriate ozone metric to apply by crop in Exhibit X-6.
2. Relative yield losses are only derived for subregions where the crop is present as defined in FASOM.
3. Relative yield losses are based on ozone concentrations during the growing period for each crop and forest type, not ozone concentrations for the entire May through September period. Growing periods are specific to individual crops and subregions, and to individual regions for hardwood and softwood forest types.

**EXHIBIT A-25 DERIVATION OF AVERAGE RELATIVE YIELD LOSSES FOR HARDWOOD AND SOFTWOOD FOREST TYPES IN THE NORTHEAST FASOM REGION**

| FOREST TYPE | SPECIES | X: $e^{-\left(\frac{O_3NoCAAA}{A}\right)^B}$ | | | Y: $e^{-\left(\frac{O_3WithCAAA}{A}\right)^B}$ | | | RYL: (X/Y) * (100%) | | | AVERAGE RYL | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 2000 | 2010 | 2020 | 2000 | 2010 | 2020 | 2000 | 2010 | 2020 | 2000 | 2010 | 2020 |
| Hardwoods | Black Cherry | 0.5345 | 0.5059 | 0.4873 | 0.6227 | 0.7968 | 0.8837 | 14.17% | 36.51% | 44.86% | 7.16% | 17.13% | 21.24% |
| | Tulip Poplar | 0.8113 | 0.7791 | 0.7562 | 0.8904 | 0.9756 | 0.9932 | 8.88% | 20.14% | 23.86% | | | |
| | Sugar Maple | 0.9100 | 0.8574 | 0.8103 | 0.9817 | 0.9997 | 1.0000 | 7.30% | 14.24% | 18.97% | | | |
| | Red Maple | 0.9714 | 0.9679 | 0.9654 | 0.9805 | 0.9929 | 0.9969 | 0.93% | 2.52% | 3.16% | | | |
| | Aspen | 0.8532 | 0.8386 | 0.8286 | 0.8935 | 0.9554 | 0.9786 | 4.51% | 12.23% | 15.34% | | | |
| Softwoods | Eastern White Pine | 0.8149 | 0.7902 | 0.7729 | 0.8796 | 0.9631 | 0.9865 | 7.36% | 17.96% | 21.66% | 3.85% | 9.49% | 11.50% |
| | Virginia Pine | 0.9859 | 0.9847 | 0.9839 | 0.9894 | 0.9949 | 0.9972 | 0.35% | 1.03% | 1.34% | | | |

Notes:

1. Parameter values for A and B in the equations for X and Y are presented along with the appropriate ozone metric to apply by tree species in Exhibit X-6.
2. Relative yield losses are only derived for tree species present in the region as defined in FASOM.
3. Relative yield losses are based on ozone concentrations during the growing period for each crop and forest type, not ozone concentrations for the entire May through September period. Growing periods are specific to individual crops and subregions, and to individual regions for hardwood and softwood forest types.
4. Average relative yield losses for hardwood and softwood forest types are estimated by taking the arithmetic average of relative yield losses for all hardwood or softwood species present in the region.
5. If no hardwood or softwood species, for which relative yield losses are estimated, are present in the region, the average relative yield loss of hardwoods or softwoods from all other regions is applied as a proxy estimate of average relative yield losses.

## EXHIBIT A-26 DERIVATION OF AVERAGE RELATIVE YIELD LOSSES FOR HARDWOOD AND SOFTWOOD FOREST TYPES IN THE SOUTHEAST FASOM REGION

| FOREST TYPE | SPECIES | X: $e^{-\left(\frac{O_3NoCAAA}{A}\right)^B}$ | | | Y: $e^{-\left(\frac{O_3WithCAAA}{A}\right)^B}$ | | | RYL: (X/Y) * (100%) | | | AVERAGE RYL | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 2000 | 2010 | 2020 | 2000 | 2010 | 2020 | 2000 | 2010 | 2020 | 2000 | 2010 | 2020 |
| Hardwoods | Black Cherry | 0.5648 | 0.4961 | 0.4765 | 0.6601 | 0.8326 | 0.9097 | 14.44% | 40.41% | 47.62% | 6.49% | 19.12% | 23.04% |
| | Tulip Poplar | 0.8418 | 0.7673 | 0.7423 | 0.9157 | 0.9844 | 0.9961 | 8.08% | 22.06% | 25.48% | | | |
| | Sugar Maple | 0.9463 | 0.8340 | 0.7777 | 0.9914 | 0.9999 | 1.0000 | 4.55% | 16.59% | 22.23% | | | |
| | Red Maple | 0.9747 | 0.9666 | 0.9640 | 0.9837 | 0.9947 | 0.9979 | 0.91% | 2.83% | 3.40% | | | |
| | Aspen | 0.8678 | 0.8334 | 0.8226 | 0.9086 | 0.9656 | 0.9846 | 4.49% | 13.69% | 16.45% | | | |
| Softwoods | Eastern White Pine | 0.8391 | 0.7812 | 0.7625 | 0.9021 | 0.9741 | 0.9913 | 6.99% | 19.81% | 23.08% | 3.67% | 10.49% | 12.27% |
| | Virginia Pine | 0.9872 | 0.9843 | 0.9834 | 0.9907 | 0.9959 | 0.9979 | 0.35% | 1.17% | 1.46% | | | |

Notes:

1. Parameter values for A and B in the equations for X and Y are presented along with the appropriate ozone metric to apply by tree species in Exhibit X-6.
2. Relative yield losses are only derived for tree species present in the region as defined in FASOM.
3. Relative yield losses are based on ozone concentrations during the growing period for each crop and forest type, not ozone concentrations for the entire May through September period. Growing periods are specific to individual crops and subregions, and to individual regions for hardwood and softwood forest types.
4. Average relative yield losses for hardwood and softwood forest types are estimated by taking the arithmetic average of relative yield losses for all hardwood or softwood species present in the region.
5. If no hardwood or softwood species, for which relative yield losses are estimated, are present in the region, the average relative yield loss of hardwoods or softwoods from all other regions is applied as a proxy estimate of average relative yield losses.

### EXHIBIT A-27 DERIVATION OF AVERAGE RELATIVE YIELD LOSSES FOR HARDWOOD AND SOFTWOOD FOREST TYPES IN THE LAKE STATES FASOM REGION

| FOREST TYPE | SPECIES | X: $e^{-\left(\frac{O_3NoCAAA}{A}\right)^B}$ | | | Y: $e^{-\left(\frac{O_3WithCAAA}{A}\right)^B}$ | | | RYL: (X/Y) * (100%) | | | AVERAGE RYL | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 2000 | 2010 | 2020 | 2000 | 2010 | 2020 | 2000 | 2010 | 2020 | 2000 | 2010 | 2020 |
| Hardwoods | Black Cherry | 0.7571 | 0.7493 | 0.7164 | 0.7975 | 0.8677 | 0.9094 | 5.06% | 13.64% | 21.23% | 1.60% | 4.20% | 6.61% |
| | Tulip Poplar | 0.9628 | 0.9599 | 0.9460 | 0.9758 | 0.9909 | 0.9961 | 1.33% | 3.12% | 5.02% | | | |
| | Sugar Maple | 0.9992 | 0.9990 | 0.9976 | 0.9997 | 1.0000 | 1.0000 | 0.06% | 0.10% | 0.24% | | | |
| | Red Maple | 0.9906 | 0.9901 | 0.9879 | 0.9929 | 0.9963 | 0.9979 | 0.23% | 0.62% | 1.00% | | | |
| | Aspen | 0.9431 | 0.9406 | 0.9295 | 0.9556 | 0.9748 | 0.9845 | 1.31% | 3.50% | 5.59% | | | |
| Softwoods | Eastern White Pine | 0.9487 | 0.9455 | 0.9311 | 0.9634 | 0.9830 | 0.9913 | 1.53% | 3.82% | 6.07% | 0.82% | 2.07% | 3.30% |
| | Virginia Pine | 0.9938 | 0.9935 | 0.9925 | 0.9949 | 0.9968 | 0.9979 | 0.12% | 0.33% | 0.54% | | | |

Notes:
1. Parameter values for A and B in the equations for X and Y are presented along with the appropriate ozone metric to apply by tree species in Exhibit X-6.
2. Relative yield losses are only derived for tree species present in the region as defined in FASOM.
3. Relative yield losses are based on ozone concentrations during the growing period for each crop and forest type, not ozone concentrations for the entire May through September period. Growing periods are specific to individual crops and subregions, and to individual regions for hardwood and softwood forest types.
4. Average relative yield losses for hardwood and softwood forest types are estimated by taking the arithmetic average of relative yield losses for all hardwood or softwood species present in the region.
5. If no hardwood or softwood species, for which relative yield losses are estimated, are present in the region, the average relative yield loss of hardwoods or softwoods from all other regions is applied as a proxy estimate of average relative yield losses.

**EXHIBIT A-28 DERIVATION OF AVERAGE RELATIVE YIELD LOSSES FOR HARDWOOD AND SOFTWOOD FOREST TYPES IN THE CORN BELT FASOM REGION**

| FOREST TYPE | SPECIES | X: $e^{-\left(\frac{O_3NoCAAA}{A}\right)^B}$ | | | Y: $e^{-\left(\frac{O_3WithCAAA}{A}\right)^B}$ | | | RYL: (X/Y) * (100%) | | | AVERAGE RYL | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 2000 | 2010 | 2020 | 2000 | 2010 | 2020 | 2000 | 2010 | 2020 | 2000 | 2010 | 2020 |
| Hardwoods | Black Cherry | 0.5734 | 0.5111 | 0.5165 | 0.6540 | 0.8035 | 0.8773 | 12.33% | 36.39% | 41.13% | 5.48% | 16.76% | 17.96% |
| | Tulip Poplar | 0.8498 | 0.7853 | 0.7914 | 0.9119 | 0.9774 | 0.9923 | 6.82% | 19.66% | 20.24% | | | |
| | Sugar Maple | 0.9539 | 0.8686 | 0.8793 | 0.9903 | 0.9998 | 1.0000 | 3.67% | 13.12% | 12.07% | | | |
| | Red Maple | 0.9757 | 0.9685 | 0.9692 | 0.9832 | 0.9933 | 0.9967 | 0.77% | 2.49% | 2.76% | | | |
| | Aspen | 0.8718 | 0.8413 | 0.8441 | 0.9063 | 0.9574 | 0.9771 | 3.80% | 12.12% | 13.62% | | | |
| Softwoods | Eastern White Pine | 0.8455 | 0.7948 | 0.7995 | 0.8987 | 0.9653 | 0.9852 | 5.91% | 17.66% | 18.84% | 3.11% | 9.34% | 10.02% |
| | Virginia Pine | 0.9875 | 0.9849 | 0.9852 | 0.9905 | 0.9951 | 0.9971 | 0.30% | 1.02% | 1.20% | | | |

Notes:

1. Parameter values for A and B in the equations for X and Y are presented along with the appropriate ozone metric to apply by tree species in Exhibit X-6.
2. Relative yield losses are only derived for tree species present in the region as defined in FASOM.
3. Relative yield losses are based on ozone concentrations during the growing period for each crop and forest type, not ozone concentrations for the entire May through September period. Growing periods are specific to individual crops and subregions, and to individual regions for hardwood and softwood forest types.
4. Average relative yield losses for hardwood and softwood forest types are estimated by taking the arithmetic average of relative yield losses for all hardwood or softwood species present in the region.
5. If no hardwood or softwood species, for which relative yield losses are estimated, are present in the region, the average relative yield loss of hardwoods or softwoods from all other regions is applied as a proxy estimate of average relative yield losses.

**EXHIBIT A-29 DERIVATION OF AVERAGE RELATIVE YIELD LOSSES FOR HARDWOOD AND SOFTWOOD FOREST TYPES IN THE SOUTH CENTRAL FASOM REGION**

| FOREST TYPE | SPECIES | X: $e^{-\left(\frac{O_3NoCAAA}{A}\right)^B}$ | | | Y: $e^{-\left(\frac{O_3WithCAAA}{A}\right)^B}$ | | | RYL: (X/Y) * (100%) | | | AVERAGE RYL | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 2000 | 2010 | 2020 | 2000 | 2010 | 2020 | 2000 | 2010 | 2020 | 2000 | 2010 | 2020 |
| Hardwoods | Black Cherry | 0.6403 | 0.5900 | 0.5698 | 0.7302 | 0.8722 | 0.9265 | 12.32% | 32.36% | 38.50% | 4.58% | 12.08% | 14.56% |
| | Tulip Poplar | 0.9029 | 0.8644 | 0.8465 | 0.9522 | 0.9916 | 0.9975 | 5.18% | 12.82% | 15.14% | | | |
| | Sugar Maple | 0.9871 | 0.9659 | 0.9509 | 0.9983 | 1.0000 | 1.0000 | 1.13% | 3.41% | 4.91% | | | |
| | Red Maple | 0.9820 | 0.9774 | 0.9753 | 0.9889 | 0.9965 | 0.9984 | 0.69% | 1.92% | 2.32% | | | |
| | Aspen | 0.9008 | 0.8793 | 0.8701 | 0.9342 | 0.9759 | 0.9881 | 3.58% | 9.89% | 11.94% | | | |
| Softwoods | Eastern White Pine | 0.8905 | 0.8576 | 0.8429 | 0.9374 | 0.9841 | 0.9940 | 5.00% | 12.85% | 15.20% | 2.65% | 6.87% | 8.15% |
| | Virginia Pine | 0.9900 | 0.9882 | 0.9874 | 0.9930 | 0.9969 | 0.9983 | 0.30% | 0.88% | 1.10% | | | |

Notes:
1. Parameter values for A and B in the equations for X and Y are presented along with the appropriate ozone metric to apply by tree species in Exhibit X-6.
2. Relative yield losses are only derived for tree species present in the region as defined in FASOM.
3. Relative yield losses are based on ozone concentrations during the growing period for each crop and forest type, not ozone concentrations for the entire May through September period. Growing periods are specific to individual crops and subregions, and to individual regions for hardwood and softwood forest types.
4. Average relative yield losses for hardwood and softwood forest types are estimated by taking the arithmetic average of relative yield losses for all hardwood or softwood species present in the region.
5. If no hardwood or softwood species, for which relative yield losses are estimated, are present in the region, the average relative yield loss of hardwoods or softwoods from all other regions is applied as a proxy estimate of average relative yield losses.

**EXHIBIT A-30 DERIVATION OF AVERAGE RELATIVE YIELD LOSSES FOR HARDWOOD AND SOFTWOOD FOREST TYPES IN THE ROCKY MOUNTAINS FASOM REGION**

| FOREST TYPE | SPECIES | X: $e^{-\left(\frac{O_3NoCAAA}{A}\right)^B}$ | | | Y: $e^{-\left(\frac{O_3WithCAAA}{A}\right)^B}$ | | | RYL: (X/Y) * (100%) | | | AVERAGE RYL | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 2000 | 2010 | 2020 | 2000 | 2010 | 2020 | 2000 | 2010 | 2020 | 2000 | 2010 | 2020 |
| Softwoods | Ponderosa Pine | 0.9488 | 0.9415 | 0.9288 | 0.9595 | 0.9683 | 0.9764 | 1.11% | 2.77% | 4.88% | 0.56% | 1.38% | 2.44% |
| | Douglas Fir | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 0.00% | 0.00% | 0.00% | | | |

Notes:

1. Parameter values for A and B in the equations for X and Y are presented along with the appropriate ozone metric to apply by tree species in Exhibit X-6.
2. Relative yield losses are only derived for tree species present in the region as defined in FASOM.
3. Relative yield losses are based on ozone concentrations during the growing period for each crop and forest type, not ozone concentrations for the entire May through September period. Growing periods are specific to individual crops and subregions, and to individual regions for hardwood and softwood forest types.
4. Average relative yield losses for hardwood and softwood forest types are estimated by taking the arithmetic average of relative yield losses for all hardwood or softwood species present in the region.
5. If no hardwood or softwood species, for which relative yield losses are estimated, are present in the region, the average relative yield loss of hardwoods or softwoods from all other regions is applied as a proxy estimate of average relative yield losses.

**EXHIBIT A-31 DERIVATION OF AVERAGE RELATIVE YIELD LOSSES FOR HARDWOOD AND SOFTWOOD FOREST TYPES IN THE PACIFIC NORTHWEST-WESTSIDE FASOM REGION**

| FOREST TYPE | SPECIES | X: $e^{-\left(\frac{O_3 NoCAAA}{A}\right)^B}$ | | | Y: $e^{-\left(\frac{O_3 WithCAAA}{A}\right)^B}$ | | | RYL: (X/Y) * (100%) | | | AVERAGE RYL | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 2000 | 2010 | 2020 | 2000 | 2010 | 2020 | 2000 | 2010 | 2020 | 2000 | 2010 | 2020 |
| Softwoods | Ponderosa Pine | 0.9892 | 0.9873 | 0.9852 | 0.9907 | 0.9922 | 0.9936 | 0.15% | 0.49% | 0.85% | 0.07% | 0.25% | 0.42% |
| | Douglas Fir | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 0.00% | 0.00% | 0.00% | | | |

Notes:
1. Parameter values for A and B in the equations for X and Y are presented along with the appropriate ozone metric to apply by tree species in Exhibit X-6.
2. Relative yield losses are only derived for tree species present in the region as defined in FASOM.
3. Relative yield losses are based on ozone concentrations during the growing period for each crop and forest type, not ozone concentrations for the entire May through September period. Growing periods are specific to individual crops and subregions, and to individual regions for hardwood and softwood forest types.
4. Average relative yield losses for hardwood and softwood forest types are estimated by taking the arithmetic average of relative yield losses for all hardwood or softwood species present in the region.
5. If no hardwood or softwood species, for which relative yield losses are estimated, are present in the region, the average relative yield loss of hardwoods or softwoods from all other regions is applied as a proxy estimate of average relative yield losses.

EXHIBIT A-32 DERIVATION OF AVERAGE RELATIVE YIELD LOSSES FOR HARDWOOD AND SOFTWOOD FOREST TYPES IN THE PACIFIC SOUTHWEST FASOM REGION

| FOREST TYPE | SPECIES | X: $e^{-\left(\frac{O_3 NoCAAA}{A}\right)^B}$ | | | Y: $e^{-\left(\frac{O_3 WithCAAA}{A}\right)^B}$ | | | RYL: (X/Y) * (100%) | | | AVERAGE RYL | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 2000 | 2010 | 2020 | 2000 | 2010 | 2020 | 2000 | 2010 | 2020 | 2000 | 2010 | 2020 |
| Softwoods | Ponderosa Pine | 0.8803 | 0.8595 | 0.8312 | 0.9006 | 0.9280 | 0.9485 | 2.25% | 7.38% | 12.37% | 1.14% | 3.73% | 6.30% |
| | Douglas Fir | 0.9996 | 0.9991 | 0.9977 | 0.9999 | 1.0000 | 1.0000 | 0.02% | 0.08% | 0.23% | | | |

Notes:
1. Parameter values for A and B in the equations for X and Y are presented along with the appropriate ozone metric to apply by tree species in Exhibit X-6.
2. Relative yield losses are only derived for tree species present in the region as defined in FASOM.
3. Relative yield losses are based on ozone concentrations during the growing period for each crop and forest type, not ozone concentrations for the entire May through September period. Growing periods are specific to individual crops and subregions, and to individual regions for hardwood and softwood forest types.
4. Average relative yield losses for hardwood and softwood forest types are estimated by taking the arithmetic average of relative yield losses for all hardwood or softwood species present in the region.
5. If no hardwood or softwood species, for which relative yield losses are estimated, are present in the region, the average relative yield loss of hardwoods or softwoods from all other regions is applied as a proxy estimate of average relative yield losses.