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Estimating Agricultural Production and its Response to SO_2 in the Pacific Northwest

October 1976

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ESTIMATING AGRICULTURAL PRODUCTION
AND ITS RESPONSE TO SO₂ IN
THE PACIFIC NORTHWEST

R. H. SAUER

OCTOBER 1976

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CONTENTS

SUMMARY	iii
INTRODUCTION	1
AGRICULTURAL PRODUCTION	1
EFFECTS OF SO ₂	2
CONCLUSIONS	7
ACKNOWLEDGMENTS	8
LITERATURE CITED	9

SUMMARY

Agricultural production and its response ^{to} of SO_2 fumigation are parameters of the Regional Assessment Program's simulation model. It was hoped sufficient data would be available to develop a generic submodel of agricultural production that would consist of regression equations for each crop grown in the Pacific Northwest. These equations were to be based on annual production data for each county of interest and annual weather summaries (mean temperature, total rainfall, frost-free days, etc.) characteristic of a county. To date, only data on a county basis, but at five-year intervals, or annual data on a state-wide total has been found. However, the search for adequate data continues. For the present time, agricultural estimates of low confidence are based on the five-year interval data.

A literature review on the effect of SO_2 on crop yield brought out significant facts. Crop species and sulfur balance appear to be the principle variables determining the extent of SO_2 damage. Further, levels of SO_2 below .1 ppm ($262 \mu\text{g}/\text{m}^3$) are probably beneficial, particularly to unfertilized crops. SO_2 levels above .1 ppm ($262 \mu\text{g}/\text{m}^3$), particularly if chronic, are probably damaging as they supply sulfur in excess of the needs of the plant. Two mathematical models that calculate the effect of SO_2 on plants have been identified and may prove useful here.

Data and mathematical relationships are needed to quantitatively relate species, exposure concentration and duration, plant and soil sulfur content, plant growth stage, and microenvironment.

ESTIMATING AGRICULTURAL PRODUCTION AND THE EFFECT OF SO₂ IN THE PACIFIC NORTHWEST

INTRODUCTION

The construction and operation of a coal-fired power plant and associated support facilities (mines, roads, towns, tracks) present a significant impact on the natural and man-made ecosystems in the surrounding area. The major sources of impact are changes in the land area available for agriculture, changes in crops cultivated in the remaining area, and the effects of stack effluents on plant growth and production. This paper describes a potentially useful means of estimating agricultural production on a county-by-county basis, and reviews some pertinent literature on the effect of SO₂ and other pollutants on plant growth and production.

AGRICULTURAL PRODUCTION

Initially, for each county a regression equation was to be developed to estimate agricultural yield based on county soil and meteorological data (see equation 1).

$$(1) \quad Y_i = C_1 X_1 + C_2 X_2 + \dots + C_n X_n$$

where,

Y_i = yield per unit area for crop i

$X_{1 \rightarrow n}$ = independent variables such as available
soil nitrogen, mean annual temperature,
etc.

$C_{1 \rightarrow n}$ = regression coefficients.

This equation would then predict, on a per-unit-area basis, production in the counties or county of interest. As crop type and acreage changed with construction of a coal-fired power plant, changes in agricultural productivity could be estimated.

While annual data on a county-by-county basis may be available, the data located to date are inadequate in space or time. The Bureau of the Census publishes a detailed county-by-county report of

agricultural production, but only at five-year intervals. Annual data are available in the USDA Agricultural Statistics only on a statewide basis. These reports are summaries and the needed data are probably collected but not published.

A rough estimate of agricultural production can be obtained by making tables of agricultural commodities by county and five-year intervals. Such a table has been prepared for the counties of the Powder River Basin, Montana. The most recent (1969) available data are dated; still, production of most crops is rather constant for the available years. Hence, prediction to the present and near future may be warranted. It should be emphasized that data for 3 years out of 15 does not represent an adequate sample, and ultimately, better agricultural data will be needed. For the model under development in the PNW Regional Assessment Program, agricultural production is estimated as in Table 1. Combining these commodities would result in the estimate of agricultural productivity per unit area being somewhat meaningless.

Agricultural production models frequently rely heavily on detailed data of the region in question, data that are not always available. If generic models of agricultural production or more detailed annual production data are located, the estimate of agricultural production can be improved.

EFFECTS OF SO₂

In the literature on the effect of SO₂ on plants, both positive and negative responses to SO₂ pollution are documented.

Sulfur is an essential mineral nutrient in that, on the average, there should be 1 sulfur atom for ca. 1500 carbon atoms (Grennard and Ross, 1974). This nutritional requirement for sulfur is not considered when setting standards for effluents from coal-fired power plants. Grennard and Ross (1974) emphasize the lack of data and understanding, and probable lack of a real SO₂ problem.

Native species seem less sensitive to SO₂ than greenhouse grown plants, even when the natives are sensitized by supplying them with

TABLE 1. POWDER RIVER COUNTY, MONTANA

Land area, acres	2102400
Crop land, acres	874050
Pasture, acres	1422325
Irrigated land, acres	13215
Fertilized land, acres	8890
tons	243
\$	21920
Fuel costs (\$)	391367

LIVESTOCK

Cattle, calves	
number	73842
sales	39888
\$	3426945
Hogs, pigs	
number	471
sales	471
\$	16094
Sheep, lambs	
number	53122
sales	35389
\$	510147
Wool, pounds	492051

CROPS

		<u>% Total</u>	<u>Production/ Acre</u>
Corn silage			
acres	852	1	5.1
tons	4339	8	
Wheat			
acres	22607	30	16.1
bu	364104	19	
sales bu	349904		
Oats			
acres	1452	2	27.1
bu	39391	1	
sales, bu	2986		
Barley			
acres	4521	6	21.1
bu	95307	4	
sales, bu	24405		
Rye			
acres	117	0	20.8
bu	2430	0	
sales, bu	230		

TABLE 1. (CONT.)

<u>CROPS (Cont.)</u>		<u>% Total</u>	<u>Production/ Acre</u>
Alfalfa			
acres	26651	36	1.0
tons	27242	48	
sales, tons	818		
Clover hay			
acres	1084	1	0.8
tons	919	2	
sales, tons	80		
Hay, small grains			
acres	2341	3	0.9
tons	2204	4	
sales, ton	94		
Wild hay			
acres	5788	8	0.9
tons	5243	9	
sales, tons	125		
Other hay			
acres	3080	4	0.9
tons	2748	5	
sales, tons	40		
Alfalfa seed			
acres	5808	8	98.4
pounds	571498		
Crested wheat grass seed			
acres	163	0	61.3
pounds	10000	0	
Total			
acres	74464		1528.1
pounds	113785066		
Cropland %		42%	
Grazing land %		68%	
Irrigated land %		1%	
Electrical requirement for irrigation 2.5 HP/acre			24646 KW during growing season

adequate water. Hill et al. (1974) exposed 87 species native to the Arizona Desert in their natural habitat to 2-hour fumigations of .5 to 10 ppm SO₂ and found that concentrations over 2 ppm SO₂ were needed to cause damage to all but a few of the species. Only one species was quite sensitive and was damaged by .5 ppm SO₂. Many of the species were highly resistant to injury. Perhaps the lack of injury was a result of the species having relatively little S in the soil and the short fumigation time.

Chronic fumigation seems to be more damaging, for a given concentration, than a pulse of a few hours. Near Billings, Montana, SO₂ in the range of .01 ppm and fluoride in the range of 1 ppb (parts per billion) caused tip burn in pines (Gordon, 1975). However, it may be that the fluoride, not the low concentration of SO₂, is the principal damage-causing agent (Trlica, 1976).

Chronic exposure of fertilized tobacco, alfalfa, and radish in a growth chamber to .05 ppm SO₂ and/or a .05 ppm ozone for 40 hours in one week reduced the growth of these plants (Tingey and Reinert, 1976). Growth of soybeans similarly cultured was reduced with chronic (40 hours per week) fumigations of .05 ppm O₃ mixed with .05 ppm SO₂, but data analyses showed that most damage could be attributed to the O₃ alone (Tingey et al., 1973a). Foliar injury, however, was found on 11 species when exposed to .05 to .1 ppm O₃ and/or .25 to 1 ppm SO₂, concentrations found in urban areas (Tingey et al., 1973b). Chronic SO₂ fumigation in the vicinity of a sulphite pulp and paper mill damaged surrounding vegetation. The recorded concentrations varied between .46 and 1.35 ppm SO₂, but the recorder was just outside the slightly damaged zone of vegetation, so the actual damaging values were greater than recorded (Linzon et al., 1973). Montana rangeland was fumigated for approximately the later two-thirds of the growing season with 0, .02, .05, and .1 ppm SO₂ and showed no effect of the SO₂ on plant phenology, production, and above- and belowground arthropod populations (Heitschmidt et al., 1975; Kunar et al., 1976; Laurenroth et al., 1976; Letham et al., 1976).

A vast majority of plant species requires a narrow range of soil pH to grow normally. The pH of soil as far as 200 miles downwind of a source was found to decrease from .05 to .10 pH units per year in the top 15 cm of soil. Production of acid-sensitive crops was expected to decrease in 10 to 15 years (Nyberg and Bently, 1976).

Foliage damage and growth reduction are manifestations of disruptions in the plant's metabolism. Sulfur dioxide at aqueous concentrations of 100 and 500 ppm (divide by 1000 for rough equivalent to air concentrations) caused more damage to older pine (Pinus contorta) needles than to younger, metabolically more active tissues (Malhotra, 1975). Root growth was depressed with fumigations of ozone or SO_2 . Root growth in radish was depressed with .4 ppm ozone for 1.5 hours. The effect was almost temperature independent and did not depend on previous treatments (Tingey et al., 1973c). These and other data suggest that the shoot systems of plants move only what they don't need to the roots (Tingey, 1974). Thus, some pollution-caused damage may be invisible and limited to inadequate root growth. Carbon dioxide fixation was reduced 50% at 3×10^{-3} M and 85% by 3×10^{-2} M sulfite on the reaction sites of ribulose-1, 5-diphosphate carboxylase from alfalfa (Tanaka et al., 1974), suggesting this enzyme is a principal target of SO_2 damage.

In their review of the SO_2 problems, Malhotra and Hecking (1975) concluded: "Injurious effects result when sulfur dioxide is taken up in excess of the capacity of the tissue to incorporate sulfur into the normal metabolic activities. The ubiquitous presence of small amounts of SO_2 and the subtle and varied nature of its biochemical effects suggest the crop losses to SO_2 pollution may be more widespread and serious than generally suspected." Variability seems to be the key word in the extent of damage, though. For example, two of the three species were unaffected by an acid rain of pH 3.0 (Ferenbaugh, 1976).

Simulation modeling has been used to better understand the SO_2 problem and predict consequences of given levels of fumigation. Gaud et al. (1973, 1974) has developed a model of the effect of SO_2 on

the vegetation around the Navajo and Kaiparowits Power Plants in Arizona. While few details on the model are given, it is interesting to note the model simulated an increase in plant growth at SO_2 concentrations below .1 ppm, as well as reductions in growth above this value. A listing of the model is necessary to determine if this result is real or an artifact of the model formulation.

Another model has been developed to estimate the concentration of air pollutants that will cause a given percent of foliar damage (Larsen and Heck, 1976). The equation is:

$$C = M_g S_g^{zT^p}$$

where

C = concentration

M_g = geometric mean concentration for 1 hour

z = the number of standard errors that the percentage of leaf injury is from the median

S_g = standard geometric deviation

T = exposure time in hours

p = slope of line on log paper.

It may be possible to turn this model around and predict the percent damage from concentration. However, it still remains to relate the percent damage to reduction in productivity.

Mudd and Kozlowski (1975) have compiled the physiological, biochemical, and source characteristics of major air pollutants in a book. While this book is detailed in the subject areas it covers, it does not address the effect of air pollution on production.

An extensive review of the SO_2 problem has recently been published (Middle and Longterm Energy Policies and Alternatives, Part 4, 1976) which covers in some detail levels of SO_2 fumigation needed to cause damage to vegetation. In general, yield is proportional to undamaged leaf tissue, but there are enough exceptions that a generalization is not useful. Some species are damaged by as little as .015 ppm, while others are resistant up to 8 ppm. In this regard,

this report stresses the need for mathematical relationships between species, level and duration of fumigation, and other plant and environmental variables.

CONCLUSIONS

More effort is needed to quantify the relationships between plant growth and production, SO_2 levels, other S supplies available to the plant, plant age, weather, exposure time, and species. There is too much variability between species, regions, and SO_2 concentrations to make a general statement on the effect of SO_2 . However, it appears that levels below .1 ppm SO_2 are not harmful to most plants and may well be beneficial if a sulfur shortage exists in the plant. Concentrations over .1 ppm may or may not be harmful in chronic fumigations. Concentrations over 2 ppm are probably harmful, particularly if the fumigation is chronic and the plants are well-irrigated and fertilized crop species. In short, qualitative but not quantitative estimates of SO_2 damage can be made at this time.

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