SULPHUR DIOXIDE FUMIGATION OF WHEAT WITH SPECIAL REFERENCE TO ITS EFFECT ON YIELD

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(WITH SIX FIGURES)

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Introduction

Early investigators of the effect of sulphur dioxide from industrial plants on crops theorized that the leaves of a plant represented its manufacturing power. They reasoned that each plant type was endowed with a standard number of leaves with which to produce a crop and if this standard was reduced by the action of SO_2 the production would be reduced proportionately. This theory was known as the "measured basis for damage computation." Experimentation was necessary to prove or disprove the theory. This is the purpose of the experimental work reported herein.

The experiments were conducted over a five-year period at Hereford, in the San Pedro Valley, a smoke free district, 35 miles air line from the smelter at Douglas, Arizona. Early in the work it became evident that the yield loss resulting from the sulphur dioxide treatment varied noticeably with the weather in different years. Since experimental work dealing with growing plants in the field is subject to many variable factors which are beyond the control of the investigator, many repetitions were necessary. In all, 278 separate tests were made. After treating such crops as beans, potatoes, peppers, onions, wheat, etc. for several years, it became apparent that loss of yield differed with each crop. Vegetative, fructifying and root crops react somewhat differently and there was even certain evidence that varieties within the species were differently affected. Evidently each plant type should be considered separately.

The principal effect of sulphur dioxide on wheat is on the leaves and leaf sheaths because the stomata are most numerous in these organs. In certain very severe treatments however, the glume, awn and even the green stem above the terminal leaf showed the injury. The effect on the yield of marketable produce is a direct result of foliage reduction. Plants may be affected in any stage of growth even before flowering or fruit formation has started. To determine the effect of defoliation caused by SO_2 on the quality and quantity of the produce, the authors devised a method of measuring the per cent. of foliage destroyed. By use of this method and the resultant effect on the yield, as shown in the accompanying graphs, it is possible to predict with reasonable accuracy the per cent. of yield reduction which will follow any given per cent. of foliage reduction.

Historical review

Previous work of this type is lacking, either in published works or in manuscripts in the hands of educational institutions, government agencies or investigators employed in private industry.

The earliest work in this country tending to shed light on the effect of sulphur dioxide on grain was conducted by a Commission whose findings were published in the Selby Report (**1**). Apparatus was devised whereby plants could be treated with the gas under field conditions, but the experimental emphasis was solely on determining the susceptibility factor of certain species, including barley, and the resultant effect on the leaves.

Somewhat later P. J. O'Gara of the American Smelting and Refining Company conducted field experiments, on a limited scale, with wheat, barley and oats. His experiments (unpublished) supplied quantitative information regarding the necessary SO_2 concentrations, time factor, humidity, heat and light values necessary to produce injury to the leaves. O'Gara also recorded resultant yields, but only evaluated the severity of injury to the leaves in such general terms as light, medium and heavy.

M. D. Thomas and George R. Hill, also of the American Smelting and Refining Company, developed apparatus designed to measure continuously and automatically the carbon dioxide exchange and transpiration of plants growing under normal conditions and when treated experimentally with sulphur dioxide. Their experiments covering alfalfa and wheat are published (**2, 3**).

In 1932, Robert E. Swain and Arthur B. Johnson conducted experiments at Stanford University, using wheat plants grown in nutrient solutions in two cabinets under duplicate conditions of temperature, light intensity, humidity and circulating air volume. Sulphur dioxide in regulated amounts was added daily to the air stream passing through one of the cabinets for periods up to six hours each day in such small concentrations that there was no visible effect on the leaves. They found that no reduction in yield occurred unless there was visible foliar injury (**4**).

Between 1927 and 1937 the Canadian National Research Council performed experiments to show the effect on the chemical composition of wheat plants when treated with sulphur dioxide (**5**).

General experimental procedure

Size and arrangement of plots.—The plots were six feet square and arranged as shown in figure 1. The letter "F" indicates fumigated plots and "C" check plots. The ten-foot aisles and two-foot spaces furnish working room. The purpose of this arrangement was to equalize possible irregularities in the soil, cultivation and irrigation. Furthermore, each fumigated plot, with the exception of those at the ends of the rows, had three adjacent check plots, any one of which, or the average of three, could be used as a standard for determining the effect of fumigation. Figure 2 shows the wheat plots in the year 1941.

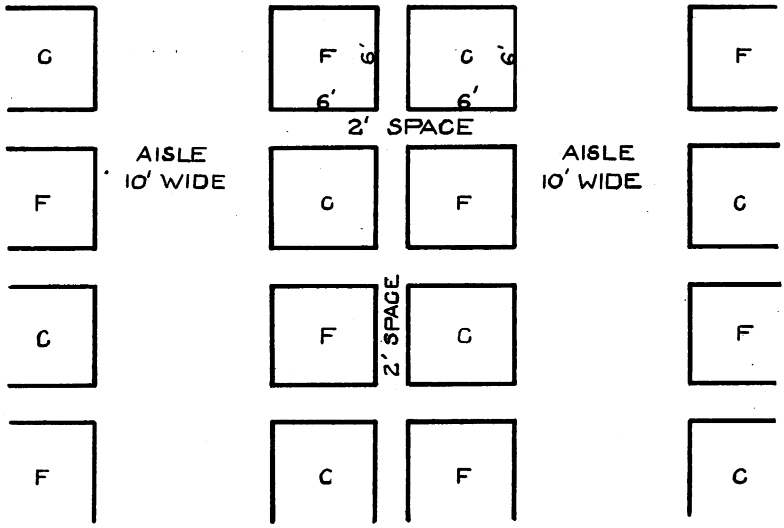

FIG. 1. Planting arrangement of the wheat plots to equalize possible irregularities in soil, cultivation and irrigation. The letter F indicates fumigated plots and C the check or untreated plots.

FUMIGATION EQUIPMENT.—The apparatus used was substantially the same as that developed by P. J. O'Gara. Briefly, it was composed of a closed cabinet of light wood framework covered on sides and top with transparent cellulose acetate sheets. The cabinet was four and one-half feet tall and covered a ground surface of six feet square. The delivery pipe was located at the center top of the cabinet with baffles to distribute the air stream uniformly over the plants within the cabinet. The exit stream was expelled into the ten-foot aisle through holes under the baseboard. To secure the proper air delivery into the cabinet, an electric blower was used having a capacity of 10,000 liters of air per minute when operated on 110-volt direct current. Sulphur dioxide gas was delivered into this air stream in known quantities by means of a calibrated capillary flow-meter.

Two identical cabinets were used and most of the fumigations were made on a half-hourly, instead of an hourly basis as was the practice in most of the O'Gara experiments. In this way a larger number of tests could be made during suitable weather.

APPEARANCE OF SULPHUR DIOXIDE INJURY ON WHEAT FOLIAGE.—There are two types of injury shown in figure 3, acute and chlorotic. The pattern of the injury is difficult to describe and is best indicated by a study of the illustration. Acute injury is most common. The rate at which the affected areas of the leaves dry to a light tan color depends on the humidity of the air. Generally the desiccation becomes complete within two to four days. At this stage the markings can readily be recognized by persons experienced in SO_2 injury diagnosis. Frequently the area immediately adjacent to the midrib is more resistant to the gas action and remains un-

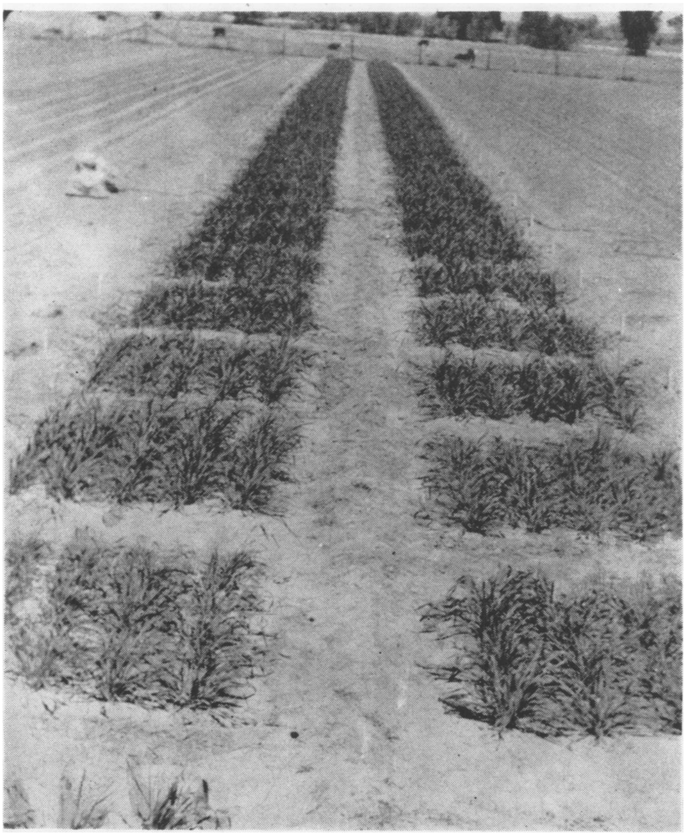

FIG. 2. Wheat plots grown in the year 1941. Plots were six feet square and contained 25 plants each. Half were later treated with sulphur dioxide and half served as checks.

injured. When the dosage is heavy or long continued, the whole leaf blade may be destroyed. Banding occurs from contact with nearby leaves which form a protective covering over a portion of the leaf. If the dosage is mild, a period of four to six days may elapse before the injury manifests itself as a yellowing of the affected areas due to the loss of chlorophyll. This is known as chlorotic injury and is different in appearance from the acute type which is caused by the breakdown and collapse of the leaf cells. The fully developed, highly functional leaves are the first to show injury, and the young, undeveloped blades are quite resistant.

PRELIMINARY TESTS.—The first year that wheat was grown, experimental procedures were standardized, pure varieties developed and methods of determining the per cent. of foliage destroyed were devised. The best locally grown seed available of two varieties of wheat, Baart and Sonora, was used and 32 plots of each variety were planted in the arrangement shown in figure 1. Seed was drilled in rows and later the plants were thinned to exactly 25 plants per plot, allowing each plant one square foot of ground on

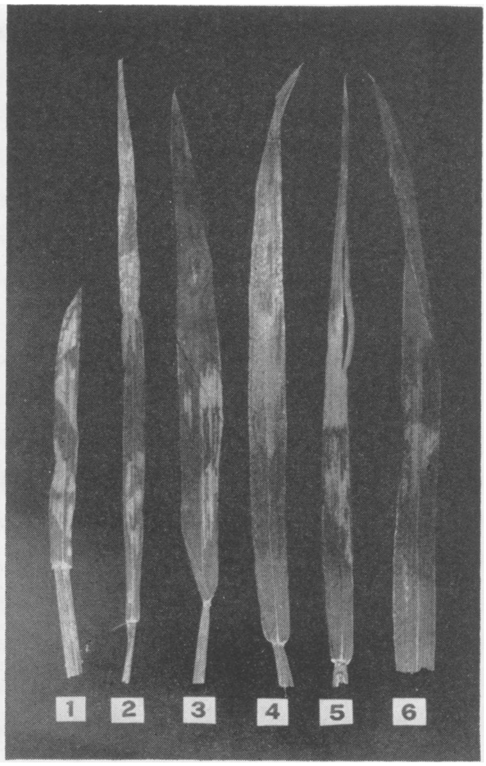

FIG. 3. Illustrating the pattern of sulphur dioxide marking on wheat leaves. (1) Banding due to contact with nearby leaves. (3) Typical acute markings. (4) Typical chlorotic margins. (2, 5, 6) Other manifestations.

which to grow. At the season's end, 6.6% of the plants were discarded because they were not true to type. Seed was selected from plants of perfect Baart and Sonora type for planting in subsequent years.

A number of irregularities appeared the first year. Counting the number of leaves destroyed by the treatments and expressing them as a per cent. of the total number produced on the check plants proved unsatisfactory because of the extreme variation in leaf size. Furthermore, wheat blades may elongate and continue to increase in size after being injured by the gas. For example, at time of treatment one-half the area of a leaf might be destroyed but four days later, because of subsequent growth, only one-tenth of the leaf was destroyed. This reduction of area, when expressed as part of the whole continued to decrease until the leaf became full grown. Obviously it was necessary to obtain the leaf area rather than the number of leaves destroyed by the treatment. The average mature leaf which developed each week on the check plants was traced on cross section paper and the area destroyed, in square centimeters, was expressed as a per cent. of the total area of this leaf. This entailed a determination of the number of square centimeters of leaf tissue produced on the untreated plants each year, because the leaf area of normal plants varied from an average of 4703 sq. cm. per plant in 1941 to 2662 sq. cm. in 1944.

It further became apparent that when plants received several very severe treatments they produced fewer leaves during the season than did the checks. Wheat plants treated once a week throughout their entire growth period, judging by visual observation, appeared to have 90% of the green tissue destroyed. Actual measurements of the foliage area destroyed, when expressed as a per cent. of the foliage area of untreated plants, often gave a figure of no more than 30%. In order to correct this difficulty it became necessary to determine, not only the area destroyed by treatment, but also the area inhibited. To a combination of these two values the term "area lost by treatment" is used in this paper. It was impossible to measure the total leaf area produced on every treated plant (a total of 3350 plants were grown in 1944). However, it was possible to count the num-

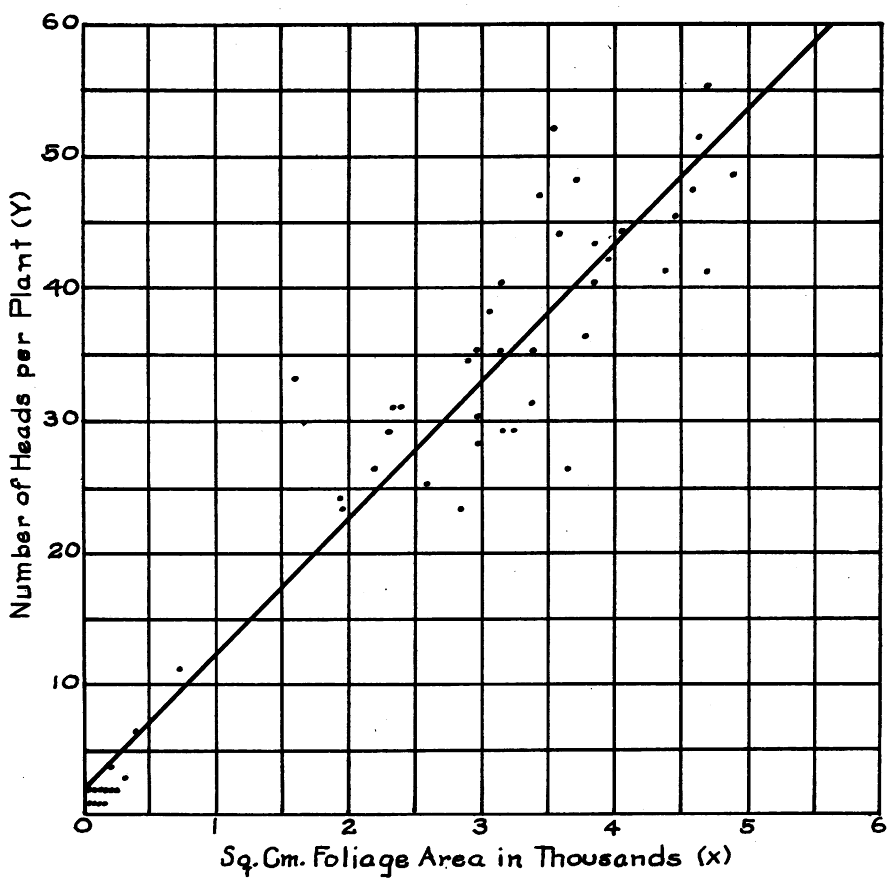

FIG. 4. Correlation between the number of heads and the foliage area of wheat plants. Individual tests, numbering 51, were made during a three-year period. The correlation coefficient has a value of +0.953.

ber of heads produced on each plant at the time of harvest. Because of the growth habit of wheat plant the foliage area is predetermined.

Figure 4 shows a graph based on measurements of the total leaf area of 51 individual, untreated plants made during a three-year period. It will be noted that the greater the number of heads per plant the larger the foliage area per head. The correlation coefficient of the graph, $r = +0.953$ is high and by use of the null hypothesis a highly significant correlation was shown between the leaf areas and the number of heads in the 51 individual determinations, involving plants having from 1 to 55 heads each. The graph may be used with a high degree of accuracy to determine the average leaf area per plant when the number of heads per plant is known.

The difference between the total leaf area of each fumigated plant (as determined by the area-head graph, figure 4) and the leaf area of the average check plant gives the area inhibited because of treatment. To arrive at the total area lost by treatment this figure is added to the measured area actually destroyed by sulphur dioxide.

Complications arising from the operation of natural agencies

In the preliminary phases of the work it was found that a rather wide range of factors entered into the attempt to determine the effect of SO_2 on the yield of wheat plants. If one plant or even a few heads were missing from either the test or check plot the reduction in yield constituted a noticeable experimental error. The outstanding plant disease of the region, affecting wheat, is smut. This was completely controlled by disinfecting the seed the first year. Injuries due to birds, insects and rodents were combatted by every possible means before severe damage occurred. The injury caused by winds was not equally distributed and plants set out where meadow larks killed an occasional seedling did not grow as well as the undisturbed plants. They did, however, serve to limit the growth of adjacent plants which would have become larger than normal had the spaces not been filled. The yield of these transplants could not be included in the yield of the plot. Instead, they were assigned the average yield of the normal plants. An area of wheat seeded adjacent to the plots tended to minimize the bird and insect damage until these pests could be brought under control. It was found necessary to drive stakes at the corners of each plot and surround the growth with a string to prevent lodging of the border plants after heading. The larger the number of plots allotted to any test, the smaller was the error resulting from these adverse factors. It seemed desirable to use at least 50 plots before drawing definite conclusions.

Table I shows the variation in the yield of the check plots in the four years since the preliminary work. Probably much of the yearly variation in yield was due to weather. In the year of lowest yield there was a correspondingly low wheat production on farms growing that crop.

TABLE I

YEARLY VARIATION IN YIELD OF CHECK PLOTS

YEAR	NUMBER OF PLOTS	YIELD IN OUNCES	
		TOTAL	AVERAGE
1941	36	1980.19	55.10
1942	35	1680.00	48.00
1943	41	1407.79	34.34
1944	134	5503.24	41.07

Plan of fumigation treatments

In carrying out the tests an attempt was made to subject the experimental plants to treatments such as may be received under actual field conditions on farms near smelters. We have tried to attain this end, on the one hand by giving some plants single treatments with different concentrations of sulphur dioxide at various stages of plant growth, and on the other hand, by giving others repeated treatments at many stages throughout the growing period.

Table II shows the year in which the tests were made, the number of plots treated, the stage of treatment and the frequency of fumigations. It will be noted that in the year 1944, 130 plots were fumigated once. In order to subject the plants to treatments in every stage of their growth, 10 plots were treated each week for 13 weeks. This covered the entire span of the growth period, from the time the plants had made two blades until ripening had begun.

TABLE II

NUMBER OF PLOTS TREATED

YEAR	ONE FUMIGATION			TWO FUMIGATIONS	THREE FUMIGATIONS	MULTIPLE FUMIGATIONS	
	EARLY STAGE	BLOOM STAGE	LATE STAGE	BLOOM STAGE LATE STAGE	EARLY STAGE BLOOM STAGE LATE STAGE	WEEKLY	BI-MONTHLY
1940	9	9	9	1	1	1	2
1941	......	12	......	12	12	......	......
1942	......	......	......	14	15	4	2
1943	......	......	......	19	18	2	2
1944	......	130	......	......	......	2	2

Correlation between foliage area destroyed by SO_2 (a measure of leaves destroyed) and yield

SINGLE FUMIGATIONS.—In 1944 the experimental emphasis was on single fumigations. In that year 10 plots were treated each week for 13 weeks, 130 plots in all. In this way plants were treated in every stage of growth from the time they had only two leaves until they were nearly mature.

The only other single fumigations used in making the graph, figure 5, were made in 1941 when 12 plots were treated in the bloom stage. The single fumigations made in 1940 could not be used because the method of leaf area measurement had not been fully developed and standardized until the year 1941.

The leaf area destroyed by the treatments was determined in square centimeters for each of the 25 plants in every plot and the average number of square centimeters destroyed per plant was computed. The normal foliage area was determined on eleven average plants from the check plots

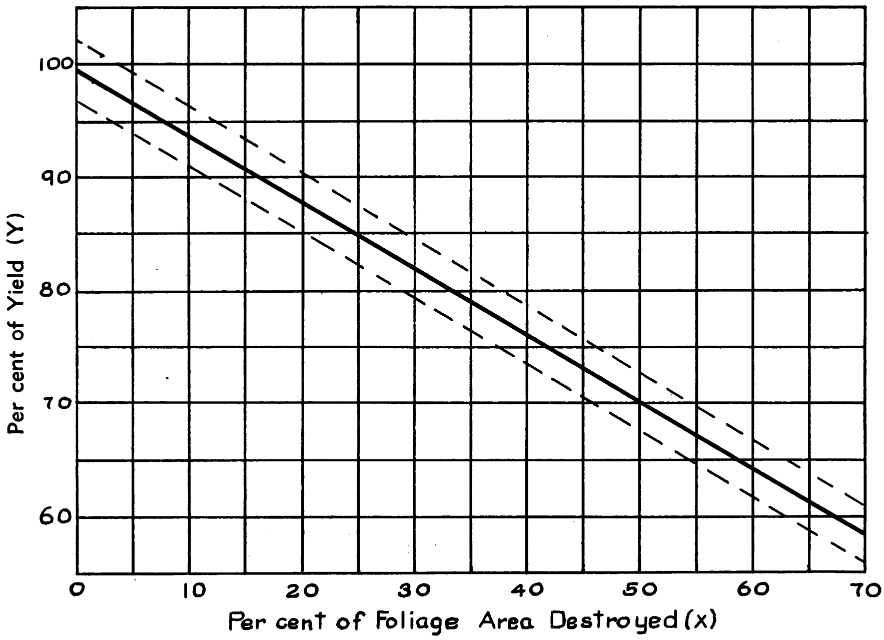

FIG. 5. Correlation between the per cent. of foliage area destroyed and the per cent. of yield when 142 wheat plots were fumigated once during growth. The formula for the regression line is Y = 99.58 − .558X. The standard deviation is 2.694 and the correlation coefficient + 0.928. The result of each test is given in table III.

and the per cent. of area destroyed for each of the 142 fumigated plots was determined. When the wheat was fully matured, the plots were harvested and threshed separately and the per cent. of yield computed, using the check plot as the standard. With these two variables, per cent. of area destroyed X, and per cent. of yield Y, the regression line shown in figure 5 was calculated by using the method of least squares. The equation for this regression line is Y = 99.58 − .588X.

The large number of tests and the overlapping of the points in the region where Y = 98% to 101% and X = 0% to 3% made it impractical to spot each of the individual 142 determinations on the graph. The figures, however, are supplied in detail in table III.

The standard deviation (Sy) of the individual plot yields from the regression line is 2.69%. When the independent variate (per cent. of area destroyed) is known the dependent variate (per cent. of yield) may be determined from the graph within the limits of the standard deviation band.

In order to determine the weight that may be attached to this experimental evidence, the correlation coefficient (r) was determined. This

TABLE III

SINGLE FUMIGATIONS OF WHEAT

	Year 1941 Yield in ounces			
Plot No.	Fumigated	Check	% Area Destroyed	% of Crop
279	45.27	52.71	32.0	85.89
280	51.15	55.75	30.7	91.75
281	50.23	54.88	22.6	91.53
282	45.63	51.45	24.5	88.69
283	50.72	55.43	24.9	91.50
284	50.47	55.57	28.8	90.82
285	53.41	55.15	13.2	96.84
286	47.34	51.63	21.2	91.69
287	49.05	53.70	15.2	91.34
288	44.53	50.25	12.7	88.62
289	49.73	52.01	10.7	95.62
290	46.56	50.96	12.9	91.37
	Average		20.73	91.34

	Year 1944 Yield in ounces			
Plot No.	Fumigated	Check	% Area Destroyed	% of Crop
127	40.25	40.47	.03	99.46
128	39.75	39.75	.08	100.00
129	35.77	35.85	.14	99.78
130	33.15	32.00	.11	103.59
131	36.55	36.66	.02	99.70
132	34.38	33.00	.04	104.18
133	40.00	40.25	.00	99.38
134	36.00	36.50	.00	98.63
135	38.44	38.75	.00	99.20
136	41.01	41.25	.00	99.42
117	39.20	39.50	.22	99.24
118	38.06	38.08	.16	99.95
119	45.25	44.75	.13	101.12
120	38.76	39.00	.11	99.38
121	38.42	38.92	.11	98.72
122	40.25	40.50	.07	99.38
123	39.51	39.66	.10	99.62
124	39.75	39.75	.02	100.00
125	42.31	42.25	.00	100.14
126	43.00	43.25	.00	99.42
107	39.24	39.75	1.54	98.72
108	39.75	40.25	1.06	98.76
109	35.15	35.00	.88	100.43
110	34.25	33.50	.88	102.24
111	35.35	35.50	.89	99.58
112	35.76	36.38	.54	98.30

	Year 1944 Yield in ounces			
Plot No.	Fumigated	Check	% Area Destroyed	% of Crop
113	35.25	35.15	.78	100.28
114	37.81	38.00	.46	99.50
115	39.16	39.21	.11	99.87
116	35.02	33.76	.02	103.73
66	39.50	40.00	1.11	98.75
67	40.15	41.00	1.69	97.93
68	37.25	37.78	1.40	98.60
69	39.25	40.20	2.06	97.64
101	28.25	31.45	1.20	89.83
102	34.75	33.81	1.24	102.78
103	31.69	32.00	.66	99.03
104	35.77	36.61	1.61	97.71
105	36.72	37.75	2.41	97.27
106	42.25	42.25	.00	100.00
70	40.75	41.00	.00	99.39
71	42.62	42.89	.23	99.37
72	44.25	44.25	.78	100.00
73	49.50	48.50	.59	102.06
74	46.25	46.75	4.33	98.93
75	42.25	43.00	1.76	98.26
76	40.53	40.75	.13	99.46
77	47.33	46.79	2.51	101.15
78	41.51	42.00	2.29	98.83
79	39.48	40.75	3.35	96.88
80	44.75	44.50	.00	100.56
81	42.50	42.67	.33	99.60
82	41.85	43.00	3.12	97.33
83	42.00	44.00	5.46	95.45
84	44.00	44.35	2.19	99.21
85	38.22	39.61	4.34	96.49
86	43.25	44.25	3.54	97.74
87	45.25	46.25	6.32	97.84
88	41.21	43.50	6.26	94.74
89	37.35	39.25	6.40	95.16
90	41.19	41.32	.00	99.69
91	40.11	40.28	.00	99.58
92	42.83	44.24	4.78	96.81
93	38.82	41.45	7.96	93.66
94	39.87	43.75	10.71	91.13
95	31.45	33.21	11.36	94.70
96	40.06	43.25	9.08	92.62
97	33.22	36.50	10.73	91.01
98	36.50	40.25	11.49	90.68
99	32.78	37.80	17.46	86.72
56	35.36	41.37	18.89	85.47

TABLE III (*Continued*)

SINGLE FUMIGATIONS OF WHEAT

	Year 1941 Yield in ounces					Year 1944 Yield in ounces			
Plot no.	Fumigated	Check	% Area destroyed	% of crop	Plot no.	Fumigated	Check	% Area destroyed	% of crop
57	36.50	44.62	24.55	81.80	4	39.00	39.55	1.57	98.61
58	36.23	42.00	18.32	86.26	5	35.75	36.25	.29	98.62
59	42.54	50.75	19.30	83.82	6	36.75	36.68	.76	100.19
60	38.75	42.50	11.63	91.18	7	41.75	42.00	.39	99.40
61	40.75	44.75	12.43	91.06	8	41.25	41.50	.63	99.40
62	40.25	42.50	6.95	94.71	9	38.78	39.00	.84	99.44
63	41.50	44.01	7.67	94.30	10	38.00	38.49	.40	98.73
64	39.78	39.78	.00	100.00	11	42.75	43.50	.98	98.28
65	38.75	39.50	1.80	98.10	12	44.50	45.50	4.00	97.80
46	38.00	42.50	13.92	89.41	13	47.75	46.75	.00	102.14
47	46.00	45.75	.87	100.55	14	45.75	46.00	3.80	99.46
48	41.50	52.50	22.23	79.05	15	41.75	43.99	5.89	94.91
49	44.50	45.00	3.38	98.89	16	41.25	43.50	5.94	94.83
50	41.25	42.53	4.06	96.99	17	40.75	43.75	8.04	93.14
51	40.14	41.50	4.12	96.72	18	36.50	38.75	6.62	94.19
52	38.54	39.24	2.25	98.22	19	42.25	47.25	18.05	90.48
53	35.25	34.50	.21	102.17	20	35.75	39.41	11.87	90.71
54	28.05	30.75	.05	91.22	21	37.75	41.99	12.47	89.90
55	40.95	41.07	.00	99.71	22	41.50	48.25	20.53	86.01
1	35.38	42.25	21.87	83.74	23	39.25	39.25	.00	100.00
2	37.75	44.05	19.19	85.70	24	39.25	40.38	2.90	97.20
33	31.00	46.00	43.99	67.39	25	36.50	38.52	6.37	94.76
34	32.50	32.81	5.30	99.06	26	35.50	36.75	5.83	96.60
35	33.00	41.25	25.77	80.00	27	36.50	38.50	6.27	94.81
36	33.09	37.90	16.88	87.31	28	38.00	40.75	7.97	93.25
37	38.00	44.06	18.69	86.25	29	34.78	37.75	9.07	92.13
38	41.00	43.95	8.12	93.29	30	36.75	42.00	16.63	87.50
39	46.50	47.25	5.90	98.41	31	39.75	55.25	60.05	71.95
40	45.75	45.00	.00	101.67	32	29.75	54.00	66.91	55.09
3	37.25	37.38	.04	99.65		Average		6.02	95.32

In the year 1944 the first 10 plots (127 to 136, inclusive) were fumigated in the first week of growth, the next 10 plots in the second week of growth, this system being continued up to 13 weeks.

measures the degree to which the average relationship holds in practice. In this case the value of r is + 0.928 which is beyond the 1% level of significance, calculated by the null hypothesis. This high value of r indicates that the correlation between the individual tests is highly significant.

The data were further correlated using the variates per cent. of area lost (area destroyed plus area inhibited) already defined on page 671, and per cent. of yield. In this case the regression line equation became $Y = 101.40 - .60X$. This line is nearly parallel to the regression line shown in figure 5 and the origin of the line on the Y axis would be only 1.82% higher. Thus it is shown that with single fumigations the area inhibited is not particularly important. Statistically, however, it serves to explain why the origin of the regression line, figure 5, falls below 100% of crop.

Of the total foliage which a wheat plant develops during its life, no more than 60% is green and functioning at any stage. Many of the plots showed as high as 95% destruction of the foliage present at the time of treatment, but when expressed in per cent. of the total foliage area made by the plant during the season, this generally fell below 30%.

In 1941 the 12 plots fumigated once in the bloom stage were insufficient in number to warrant any very definite conclusion, yet it is interesting to note by the average given in table III that there was less crop damage for each per cent. of leaf area destroyed than in the tests made during the year 1944. In 1944 the check plants averaged only 2662 sq. cm. foliage area while in 1941, a year of high yield, the average plant made 4703 sq. cm. Thus it is tentatively assumed that the more thrifty the crop the less damage is sustained by the action of SO_2.

Summation of the tests given in table III by groups of various stages of plant growth at the time of fumigation showed no distinct trend that would indicate a critical stage at which the yield might be more severely affected. At the two extremes of the growth period there may be some evidence of a change in the amount of damage for each per cent. of area destroyed, a slight increase at the earliest stage of growth and a decrease when the plants are near maturity. This trend is not at all conclusive as it falls well within the standard deviation band.

Correlation between foliage area lost (area destroyed plus area inhibited) and yield

DOUBLE AND TRIPLE FUMIGATIONS.—During the years 1941 to 1943, inclusive, wheat in 45 plots was fumigated twice. The first treatment was at the male anthesis after the fertile tillers had expanded the terminal blades and the second treatment when the plants were nearing maturity. An additional 45 plots were treated three times. The first treatment was in the vegetative stage, the second at male anthesis and the third in the early dough stage before the plant showed signs of maturity.

When wheat plants are treated more than once during growth, the leaf area inhibited by the treatments is important; therefore, to arrive at the foliage area lost because of the treatment it is necessary to add the area inhibited to the area destroyed and to compare this total with the average foliage area of the check plants to determine the per cent. of foliage area lost.

The area destroyed was determined in the same manner as already explained under single fumigations, but in order to arrive at the area inhibited it was necessary to count the number of heads made by both the fumigated and check plants at the time of harvest. This has been fully discussed under the heading Preliminary Tests. Because the area inhibited was determined by using the average leaf area produced on representative check plants, it was necessary to express the independent variate (area lost) as a deviation from the mean as shown in figure 6. It seems somewhat ambiguous to indicate a minus per cent. of area lost, but it should be remembered that this is simply the result of an average figure being used

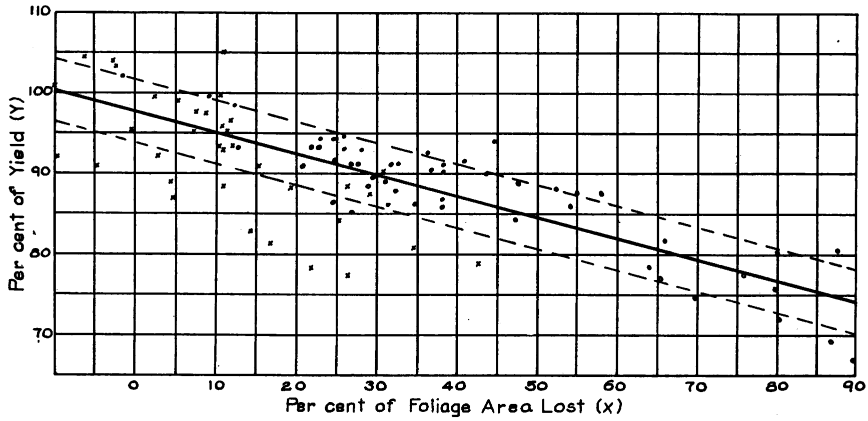

FIG. 6. Correlation between the per cent. of foliage area lost (area destroyed plus area inhibited) and the per cent. of yield when 90 wheat plots were fumigated with sulphur dioxide two or three times during growth. The formula for the regression line is $Y = 97.617 - .263X$. The standard deviation is 4.05 and the correlation coefficient is X0.843.

Legend—(●) Tests made during 1941. (o) Tests made during 1942. (x) Tests made during 1943.

as a basis for computing percentages. Because of individual plant variations, there were eight plots out of the 90 which had unusual thrift and vigor, so that even though there was a reduction of foliage due to treatment these eight plots still produced a larger foliage area than the average check plot.

The result of treating each plot is spotted on the graph, figure 6, using different kinds of points, as indicated in the legend, for the years in which the respective treatments were made. The equation for the regression line as worked out by the method of least squares is $Y = 97.62 - .26X$ and the standard deviation is 4.05. The high value of the correlation coefficient (+ 0.843) indicates that the correlation between the individual tests is highly significant. The origin of the regression line at 97.62% of yield instead of 100% is not significant as it falls well within the standard deviation band. However, in searching for an explanation for this occurrence, the following point seems worthy of consideration. In the process of determining the number of square centimeters of foliage area destroyed, it was necessary to handle every leaf of the fumigated plants after each treatment. Experience has shown that handling alone may damage the plants and lower the yield. The check plants were not exposed to this type of treatment, therefore this constitutes an experimental error which we were unable to eliminate even by extremely careful work. Very probably this error would amount to at least the 2.38% necessary to place the origin of the regression line at 100% of yield.

Observing the tests indicated by years on the graph, it will be noted that the greatest loss of yield, per per cent. of area lost, was in the year

1943, and the least in 1941. Comparing this with the average foliage area (a measure of thrift) produced by the check plants in these same years,

4703 sq. cm. in 1941
3951 " " " 1942
3642 " " " 1943

we observe a distinct correlation between thrift of plants and damage to yield from sulphur dioxide treatment.

A further comparison can be made between the regression line for single treatments and the regression line for double and triple treatments. Comparing the graphs in figures 5 and 6 it is noted that the slope of the line, which indicates the degree of damage, is greater in the case of single fumigations. It is a reasonable assumption that at least part of this difference is due to the recovery of plants between treatments. It is a greater shock to the plant's vital processes to remove 30% of its foliage at one treatment than to remove 15% at two different treatments, allowing several weeks between for recovery. Another probable reason for the difference in slope is due to the fact that no double and triple fumigations were made during 1944, the year of poorest plant growth when the average

TABLE IV

MULTIPLE FUMIGATIONS OF WHEAT

Plot no.	Yield in ounces: Fumigated	Yield in ounces: Check	% area lost	% of crop
Year 1942				
152	31.25	48.00	97.6	65.1
153	31.00	47.00	93.8	66.0
154	22.00	42.00	99.0	52.4
155	24.00	43.00	94.7	55.8
156	33.30	51.00	95.2	65.3
157	32.00	48.00	96.1	66.7
Year 1943				
352	32.01	36.07	26.6	88.7
353	33.63	42.70	34.8	78.8
354	19.07	23.48	43.0	81.2
355	19.82	29.49	43.8	67.2
Year 1944				
41	34.50	42.50	27.8	81.2
42	38.25	46.75	23.1	81.8
43	33.47	47.25	40.4	70.8
45	33.75	50.75	43.4	66.5

foliage area of the check plants was only 2662 sq. cm. In that year the emphasis was on single fumigations, the double and triple fumigations being omitted.

MULTIPLE FUMIGATIONS.—During the years 1942 to 1944 inclusive, eight wheat plots were treated once a week from the time the seedlings had made three leaves until the plants were nearly mature, thus making a total of 13 weekly treatments. Every leaf that the plants had produced showed at least some degree of damage. Another six plots were treated every two weeks during their growth. The main purpose of these frequent treatments was to discover whether the yield could be reduced to zero. A second purpose was to show that severe fumigations are not to be considered comparable to a blight which prevents fructification or even kills the plants outright. These tests indicate that severe and repeated fumigations resemble severe prunings, in that the plants continue to grow and to develop their fruiting organs, though the crop may be much reduced and may mature ten days late depending somewhat on the severity of the test. For the detail of the resultant effect on the yield of these 14 tests refer to table IV.

DAY VERSUS NIGHT FUMIGATIONS.—A concentration of SO_2 sufficient to damage wheat plants in 30 minutes, viz. 15 p.p.m., was applied to four wheat plots, beginning two and a half hours before sunset, for a period of one hour each. Plants in the first two plots, fumigated in full sunlight were severely damaged. The third plot, fumigated partly in sunshine and partly in the dusk was only mildly affected. The fourth plot, fumigated in very dim light or complete darkness was not marked at all, the plants showing no effect whatever from the treatment.

Summary

Three methods of correlation were used as a basis for determining production loss when wheat was subjected to sulphur dioxide injury, namely, correlation between per cent. of leaves destroyed and yield, per cent. of foliage area destroyed and yield and per cent. of foliage area lost and yield. The first, per cent. of leaves destroyed and yield, has been used in smelter districts since 1923 as a means of determining the amount of damage sustained by a crop. The method was not sufficiently accurate for experimental procedures there being great variation in the size of the leaves produced on individual wheat plants. Obviously the measure of the manufacturing power of the plant was the foliage area, rather than the number of leaves which it produced.

Graphs are given, based on four years' work involving 278 separate tests. These provide a guide whereby the per cent. of yield loss may be determined, within the narrow limits of the standard deviation band, when wheat plants are subjected to: (a) only one treatment with SO_2 gas when the foliage area destroyed is known, and (b) double and triple treatments when the foliage area lost is known.

Tests conducted in years of good plant growth showed distinctly less damage for each per cent. of foliage area destroyed than in years of poor growth. The more thrifty the plants the less damage was occasioned by the SO_2 markings.

In no correlation, involving several tests, did the per cent. of crop loss ever reach the per cent. of foliage area destroyed or the per cent. of foliage area lost. Generally it ranged between .26% and .62% of crop reduction for each 1% foliage reduction, depending on the thrift of the plant and the frequency of treatments.

Wheat plants sustained less damage by having 15% of their foliage destroyed twice during the season, with an interval for recovery, than when 30% of the foliage was destroyed by one treatment.

Wheat treated at night showed no effect from SO_2 concentrations sufficient to produce severe foliage injury in sunlight.

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