THE ABSORPTION OF INORGANIC NUTRIENTS BY PLANTS TREATED WITH SULPHUR DIOXIDE

by

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THE ABSORPTION OF INORGANIC NUTRIENTS BY PLANTS TREATED WITH SULPHUR DIOXIDE.

I

The effect upon vegetation of the gaseous wastes from industrial enterprises, particularly smelters, has received considerable attention in this century both from the legal and from the scientific points of view.

It was soon agreed that this effect was caused by the presence of gaseous sulphur dioxide in the atmosphere. For a summary of investigations upon this subject prior to 1915 the reader is referred to the 528 pages published by the Selby Smelter Commission (1).

Such scientific investigations have shown that the conditions under which injury to vegetation from sulphur dioxide takes place are determined primarily by the concentration of the gas, the duration of the exposure, and the humidity of the air. Secondary factors are the characteristic susceptibility of the species, the light conditions, and other environmental conditions of atmosphere and soil. On these conditions a large amount of data has been compiled. It is not the purpose of this paper to disprove any of these findings.

However, it has been the purpose of these experiments to determine the absorption of inorganic nutrients by treated plants, and to see what conclusions might be made regarding the metabolism of the plants from this point of view.

II

The plant environment is so complex, with so many variable factors entering that it would be impossible to get data on all combinations in a problem of this kind. The method followed has been the usual relative study employing controls. In all factors excepting sulphur dioxide in the atmosphere, the control plants were developing in an environment identical with that of the experimental plants.

During treatments with the gas, air was supplied in continuous flow to the plants in specially constructed air-tight cabinets by blowers ("Sirocco" blowers, driven by General Electric motors, 1/20 H.P., 110 Volts, 1.3 Amps., 1140 R.P.M.). The air flow delivered by such blowers may be conveniently regulated by adjusting a sliding panel over the aperature in a galvanized iron box connected to the blower intake. To determine the volume of the air flow and to maintain equality between control and fumigated cabinets a calibrated anemometer (Short & Mason, Ltd., London, "Biram's No. 3132") was introduced into the air supply pipe through an air-tight sliding panel. The linear velocity was then determined for an interval of time measured by a stopwatch. This linear velocity multiplied by the cross-section of the supply pipe gave the volume of air supplied.

The air furnished to the experimental cabinet was passed through a "mixing chamber", a large galvanized iron box with baffle plates in it. A tube leading to the air entry end of this chamber carried the sulphur dioxide gas for intimate mixture in the concentrations desired.

The sulphur dioxide for the treatments was obtained in small cylinders from the manufacturers, Ansul Chemical Company, Marinette, Wisconsin, through the Central Scientific Company. These 6 lb. cylinders contain liquid sulphur dioxide of extreme purity, no trace of sulphur trioxide being found. They are equipped with a needle valve for regulating the flow of gas from the cylinders.

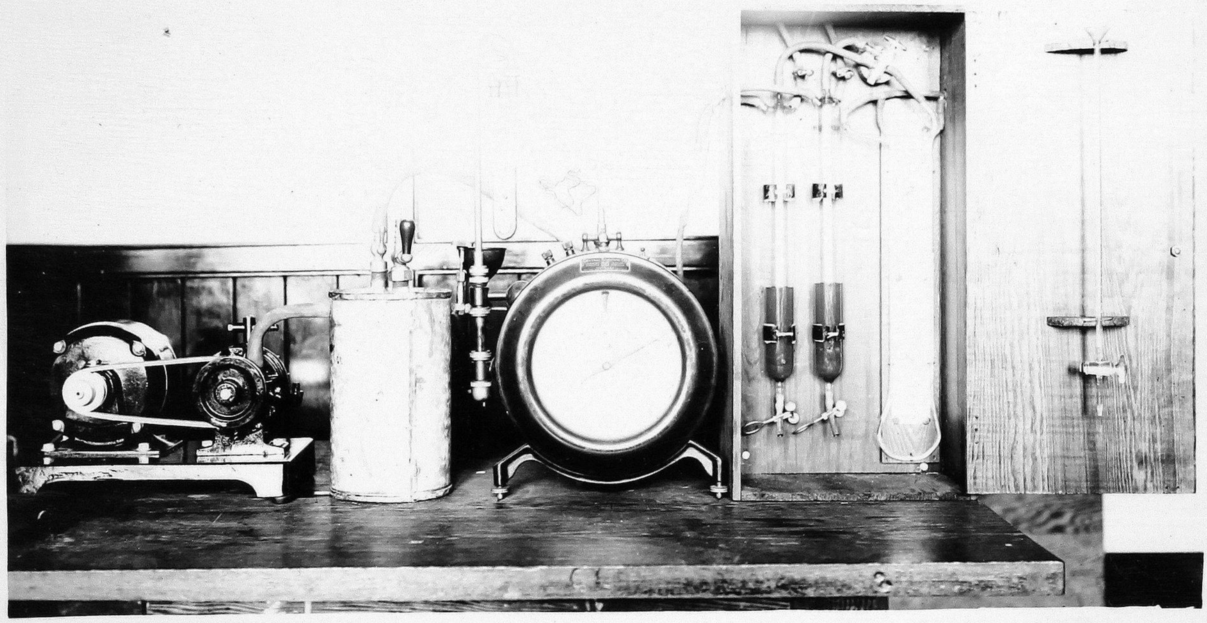
To measure the flow of gas through a needle valve, a meter of the type described by Benton (2) may be used. This article discusses the theoretical and practical considerations which lead to the application of Poiseuille's formula (for the flow of liquids) to the flow of gases through capillary tubing, and calculation of volume from the pressure difference. In this way a U-manometer of the inclined gauge type with a sealed-in capillary tube between the arms has been used. The manometer was filled with liquid petrolatum. For low concentrations it has been found more convenient to use capillary tubing leading from the cylinder outlet into a reservoir of petrolatum with the outlet above the surface of the liquid. Counts of gas-bubble rates of flow up through the petrolatum correlated with concentration determinations gave a useful empirical method of adjusting the concentration to the desired amount.

A constant pressure from the cylinder was maintained by temperature control. A lined gas-metering box was constructed. It contained the cylinder almost immersed in a water-bath; the capillary U-manometer; and a thermo-regulator (Cenco De Khotinsky) governing a 100 Watt lamp connected to supply heat when needed.

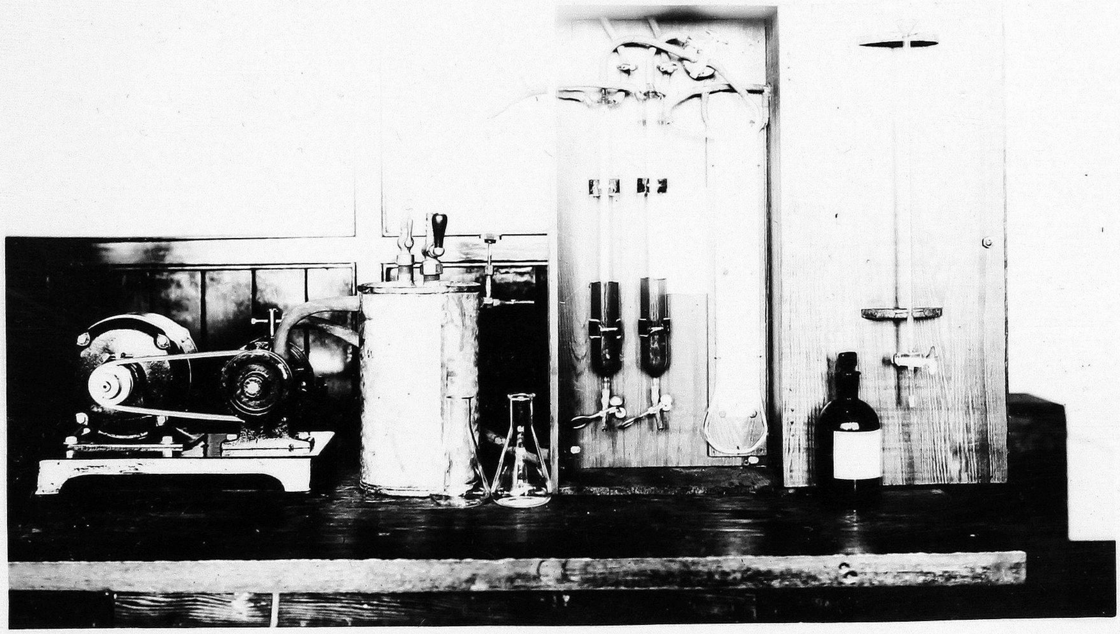
To ensure purity of air supply and to guard against any possible accident, the gas-meter box was kept in an adjoining room and the outlet passed through the wall to the mixing box.

The frequent and accurate determination of the sulphur dioxide content in the atmosphere during any treatment is essential. The most reliable method yet devised is the sampling system of Thomas and Abersold (3). In this method the gas is oxidized in absorbers by dilute hydrogen peroxide and sulphuric acid solution, and the changing conductivity is measured upon a Leeds and Northrup recording Wheatstone bridge. The special apparatus for this method was not available for these experiments. But determinations of low concentrations of sulphur dioxide using the method described by Griffin and Skinner (4) are accurate, and the necessary apparatus is easily assembled. This latter method was used throughout.

The apparatus consisted of two absorbers, an air flowmeter of the U-manometer type, a suction pump, and small pressure-equalizing tank. The air flowmeter was calibrated by means of a wet meter which in turn had been checked against a standard "prover". The manometer readings were determined for a wide range on either side of the optimum flow, which is about 1 gram-molecular volume of gas in 3 minutes. The arrangement for calibrating the flow rate is illustrated in the accompanying photograph.



The absorbers contain 100 c.c. of an iodine-potassium iodide-starch solution about 0.00003 N in iodine. Through one absorber containing this solution a metered volume of air is drawn as a "blank" using a soda-lime tower. Through the other absorber the same volume of air is drawn from the experimental cabinet. The solutions are then drained into flasks and titrated to the same light-blue end-point with a standard sodium thiosulphate solution, 0.0010 N to 0.0015 N. The titration is made by the use of a small precise buret which may be read to 0.02 c.c. The difference between the two titrations represents the equivalent of the sulphur dioxide absorbed. The concentration in parts per million may be calculated directly, since 1 c.c. of 0.002 N sodium thiosulphate solution is equivalent to 1 part per million of sulphur dioxide in 1 gram-molecular volume of air. The arrangement of the apparatus for a determination is shown in the accompanying photograph.



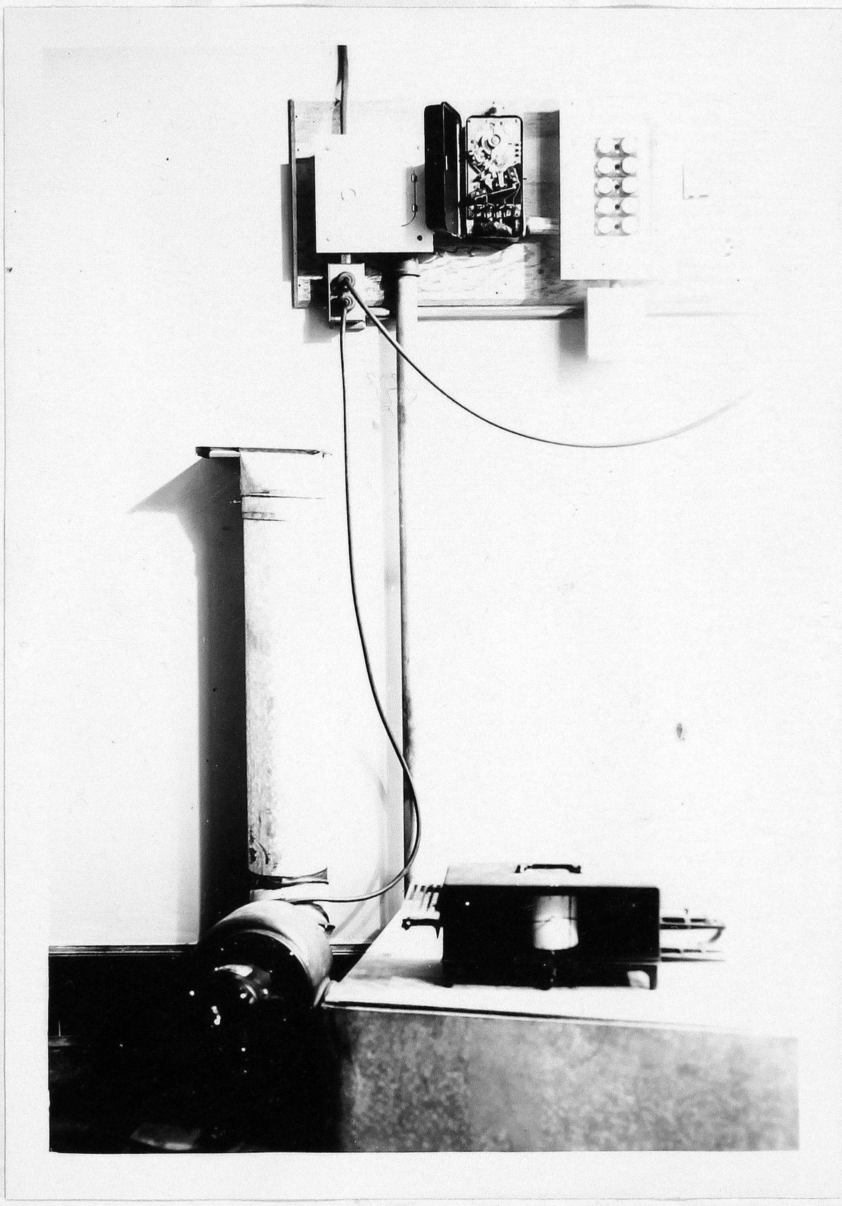
As has been mentioned, the other atmospheric condition of primary importance in gas treatments is the humidity. This is a very difficult factor to control. In all treatments a record of the relative humidity has been kept.

Temperature of the atmosphere has also been recorded.

The light factor was variable during two experiments. The plants in these experiments were grown in the greenhouse under the solar illumination received by this part of the Pacific coast in the late fall. There is a wide variation of light from day to day: clear bright sunlight, diffuse light on foggy days, or very little light in cloudy weather. The other experiments were carried out under "artificial" illumination in specially constructed cabinets. Excepting for the gradual decrease in intensity of the radiation from the bulbs, the light factor was similar for each 24-hour period.

The construction of the cabinets in which the light factor was controlled followed the general plan of Davis and Hoagland (5). One of the modifications adopted by Swain and Johnson (6) was introduced, however: the lights were placed directly over the plants. Each cabinet followed the same pattern: a counterpoised lift piece (6 ft. long x 2 ft. wide x 5 ft. high), rested upon a fixed base (6 ft. long x 2 ft. wide x 2 ft. high). The entire construction was air-tight. The top, sides, and ends of each lift piece were of fairly heavy high-grade glass. Lights were seated in 52 cm. reflectors and fixed in position 2 feet above the cabinet top.

The lights were controlled by a time switch. Air circulation was provided for through an intake in the base and outlets at the cabinet top. Some of the details are illustrated in the accompanying photographs.



The plants were grown in water culture solution. The nutrient solution used was the "Rubidoux" solution described by Eaton (7). The constituents of this solution and their concentration are as follows:

Constituent	Millimoles per liter.	Grams per 100 liters.
Calcium nitrate, $Ca(NO_3)_2.4H_2O$	4	94
Potassium nitrate, KNO_3	3	30
Ammonium sulphate, $(NH_4)_2SO_4$	2	27
Magnesium sulphate, $MgSO_4.7H_2O$	2	49
Potassium acid phosphate, KH_2PO_4	0.2	3
Boric acid, H_3BO_3	----	0.6
Manganese chloride, $MnCl_2.4H_2O$	----	0.1
Zinc sulphate, $ZnSO_4.7H_2O$	----	0.04

Iron was made available to the plants by addition of the tartrate (freshly prepared 0.5 percent solution) in small amounts at frequent intervals as required. The concentration was maintained by replacement of nutrients as these were absorbed, and by changing the whole solution. The hydrogen ion concentration varied from pH 6.0 to 6.5.

This solution has been used in preference to the older widely-used Hoagland's solution because it seems to possess the advantages described by the author. The supply of some of the nitrogen as ammonium tends to maintain a better ion balance, the low level of phosphate makes it easier to maintain available iron.

The solution containers were wide-mouth glass jars of

1.75 liter volume (2-quart Mason). The tops were closed by corks with 5 holes for plants and an opening for additions of water. Five cereal seedlings were grown in each jar, and enough jars were used to make a total of 110 plants for both control and treated in each experiment.

The plant stock used in these experiments was barley. Barley has been widely used in experimental work of this kind because it grows with vigor in balanced nutrient solutions of pH 5.5 - 7.0. The variety grown for experiment was Duck-bill, the purest line seed obtainable from the Department of Agronomy, University of British Columbia. The importance of homogeneous stock in experimental work has been rightly stressed by many investigators.

The seed was soaked for 24 hours in culture solution at 20.5°C. It was then placed on mesh screen over culture solution to germinate in a medium light intensity. When the seedlings were 9 cm. in length, a uniform selection was transplanted to the culture jars.

The importance of guarding against plant diseases such as rusts and smuts has been recognized, and the plants were free from infection. Measures were taken to prevent infestation by plant parasites such as aphids.

III

The conditions under which treatments took place, and the environmental factors are recorded in the following pages.

Experiment 1.

Sulphur Dioxide Records:-

First Treatment:	27 days after dry seed was soaked.
	Healthy plants with 3-4 leaves.
Duration:	6 hours gas history.
	Treatments on 2 successive days.
	Each treatment of 3 hours duration.
	Time of day: morning.
Concentration:	Average - 0.40 p.p.m.
	Maximum - 0.50 p.p.m.
	Minimum - 0.30 p.p.m.
Humidity:	Very high, 90-100% relative humidity.
Temperature:	65-75^{o} F.
Visible Injury:	30% of the total leaf area.

Environment Records:-

Light:	Sunlight in late fall.

Light:	Plants were grown in a greenhouse.
Temperature:	Average ----
	Maximum - 105° F.
	Minimum - 55° F.
Humidity:	Average ---- (high)
	Maximum - 100% relative humidity.
	Minimum - 70% relative humidity.

The experiment was discontinued 56 days after the dry seed was soaked.

Experiment 2.

Sulphur Dioxide Records:-

First Treatment:	27 days after dry seed was soaked.
	Healthy plants with 3-4 leaves.
Duration:	12 hours gas history.
	3 treatments at 10-day intervals.
	Time of day: morning.
Concentration:	Average - 0.30 p.p.m.
	Maximum - 0.33 p.p.m.
	Minimum - 0.27 p.p.m.
Humidity:	Very high, 90-100% relative humidity.
Temperature:	65-80° F.
Visible Injury:	5% of the total leaf area.

Environment Records:-

Light:	Sunlight in late fall.
	Plants were grown in a greenhouse.
Temperature:	Average ----
	Maximum - 105° F.

Temperature: Minimum - 55° F.

Humidity: Average ----

Maximum - 100% relative humidity.

Minimum - 70% relative humidity.

The experiment was discontinued 56 days after the dry seed was soaked.

Experiment 3.

Sulphur Dioxide Records:-

First Treatment: 15 days after dry seed was soaked. Healthy plants with 3-4 leaves.

Duration: 480 hours gas history.

Continuous treatment.

24 hours each day.

Concentration: Average - 0.27 p.p.m.

Maximum - 0.41 p.p.m.

Minimum - 0.18 p.p.m.

Humidity: Fairly low. Usually a maximum of 60-62% relative humidity before the illumination, then a decrease to a minimum of about 40% at the end of the illumination period.

Temperature: Fairly high. Usually a minimum of about 67-68° F before illumination, then an increase to a maximum of about 90-94° F at the end of the illumination period.

Visible Injury: None. Leaf colour of the experimental plants was a lighter green than that of the control plants.

Environment Records:-

Light: Plants were grown in cabinets. Illumination from four 1000-Watt gas filled bulbs seated in 52 cm. reflectors at a distance of 7 feet. 16 hours illumination each day.

Temperature: Average - 84° F.
Maximum - 98° F.
Minimum - 66° F.

Humidity: Average - 49% relative humidity.
Maximum - 66% relative humidity.
Minimum - 37% relative humidity.

The experiment was discontinued 35 days after the dry seed was soaked.

Experiment 4.

Sulphur Dioxide Records:-

First Treatment: 15 days after dry seed was soaked. Healthy plants with 3-4 leaves.

Duration: 51 hours gas history.
Treatments on 17 consecutive days.
Each treatment of 3 hours duration.
Treatment began 1 hour after the illumination had commenced.

Concentration:	Average - 0.36 p.p.m.
	Maximum - 0.58 p.p.m.
	Minimum - 0.25 p.p.m.
Humidity:	Medium - 55-70% relative humidity.
Temperature:	75-85° F.
Visible Injury:	None.

Environment Records:-

Light:	Plants were grown in cabinets. Illumination from three 1000-Watt gas filled bulbs seated in 52 cm. reflectors at a distance of 7 feet. 16 hours illumination each day.
Temperature:	Average - 78° F.
	Maximum - 90° F.
	Minimum - 70° F.
Humidity:	Average - 59% relative humidity.
	Maximum - 77% relative humidity.
	Minimum - 47% relative humidity.

The experiment was discontinued 32 days after the dry seed was soaked.

IV

The results of the experiments have been recorded as yield data and as analyses. These records are grouped in tables in the following pages.

The plants in experiment 4 had the least final green and dry weights. It seemed of interest to show the size of these plants. The accompanying picture was taken 12 days after fumigation commenced, or 5 days before the experiment was discontinued.

Table No. 1.

Yield Data.

	Tillers per Plant.	Green Weights (Grams per 100 Plants)	Moisture (as %)	Dry Weights (Grams per 100 Plants)
Experiment 1.				
Control	1.61			
Leaves		230	91.1	20.5
Stems		119	92.0	9.5
Roots		71	93.4	4.7
Total		420	91.8	34.7
Treated	1.51			
Leaves		168	89.2	18.1
Stems		94	93.0	6.6
Roots		65	93.9	4.7
Total		327	91.2	28.7
Experiment 2.				
Control	1.26			
Leaves		205	90.8	18.8
Stems		100	93.0	7.0
Roots		66	93.4	4.4
Total		371	91.9	30.2
Treated	1.16			
Leaves		177	90.0	17.7
Stems		94	93.1	6.5
Roots		63	93.4	4.1
Total		334	91.5	28.3

Table No. 1 (continued).

Yield Data.

	Tillers per Plant.	Green Weights (Grams per 100 Plants)	Moisture (as %)	Dry Weights (Grams per 100 Plants)
Experiment 3.				
Control	3.02			
Leaves		109	81.9	19.7
Stems		102	89.3	11.0
Roots		119	93.5	7.7
Total		330	88.4	38.4
Treated	2.93			
Leaves		102	82.3	18.1
Stems		99	89.0	10.9
Roots		109	93.7	6.8
Total		310	88.5	35.8
Experiment 4.				
Control	2.09			
Leaves		77.3	84.7	11.87
Stems		59.7	90.6	5.63
Roots		65.4	92.1	5.16
Total		202.4	88.8	22.66
Treated	2.14			
Leaves		77.0	84.8	11.73
Stems		61.1	90.7	5.77
Roots		65.6	92.1	5.23
Total		203.7	88.9	22.63

The transpiration by the plants has been measured as water added to keep the containers at level. The evaporation from blank containers has been determined. In this way a net transpiration value for the plants has been derived. Using these values a transpiration coefficient has been calculated as follows, after that of Briggs and Shantz (8) :

$$\text{Transpiration Coefficient:} \quad \frac{\text{Volume of water transpired.}}{\text{Weight of dry material formed.}}$$

The results of this calculation are in the next table.

Table No. 2

Experiment	Plants	Transpiration Coefficient
1	Control	235
	Treated	152
2	Control	194
	Treated	180
3	Control	692
	Treated	548
4	Control	653
	Treated	618

To determine the absorption of nutrients from the culture solution, analyses were made of the dry plant material. These analyses have been done according to the recognized quantitative methods advocated by the Association of Official Agricultural Chemists in the publication (9) "Official and Tentative Methods.....", 4th edition, 1936. The results of these analyses are recorded in the following table.

Table No. 3

Plants Analysed.	As percent of dry plant material.						
	Ash	Ca	MgO	K	S	P	N (total)
Experiment 1							
Control	18.14	1.19	0.79	7.78	1.98	0.85	6.13
Treated	17.36	1.17	0.71	7.54	1.71	0.76	5.72
Experiment 2.							
Control	17.66	1.46	0.82	7.46	1.92	0.75	6.48
Treated	17.47	1.46	0.83	7.39	1.84	0.74	6.51
Experiment 3.							
Control	18.11	1.42	0.64	7.38	2.06	1.02	6.61
Treated	18.16	1.27	0.53	6.73	2.84	0.95	5.87
Experiment 4.							
Control	18.56	1.24	0.60	7.61	1.94	1.31	6.34
Treated	17.73	1.18	0.58	7.23	1.98	1.27	6.30

V

The relation of the extent of visible injury to the factors involved has been the subject of exhaustive research by many investigators. This work has been done chiefly under field conditions. The results are obtained by observing the extent and character of the injury, by measurements of yield, and by correlating these with the experimental conditions. The results are compared with controls as standards. Information of this nature is extensive, and has an all-important bearing upon the subject of sulphur dioxide effects.

Growth of plants in culture solutions in a controlled environment and treated with low concentrations of sulphur dioxide has been studied by Swain and Johnson (6). This research shows careful study throughout and the authors reached the following conclusion:

"The results of this study, indicate that wheat plants grown in nutrient solutions under optimum conditions of artificial light and humidity which were favorable to rapid and uniform growth, and which at the same time could be accurately controlled and recorded, will tolerate an exposure to sulphur dioxide of several hours daily in concentrations below those at which typical foliar markings are produced without showing any signs of injurious actions in their general appearance, in their rate of growth, or in the dry weight of tissue which they develop."

Studies have been made of the effects of sulphur dioxide exposure upon stomatal movement in plants to determine possible correlations. These morphological investigations are based upon the reasonable assumption that any injury to the plant organism takes place through the leaf stomata.

The effect of exposure to sulphur dioxide upon the chemical composition of the growing plant has been studied ever since foliar accumulation of sulphur compounds was first observed. Correlations of sulphur content with the exposure have been made. Data relating to the effect upon carbohydrate metabolism and protein content has been compiled.

The writer has been privileged in observing an extremely interesting study of the effect of sulphur dioxide treatments on the carbon dioxide-oxygen metabolism of plants, carried out by Dr. M. Katz and associates. (10)

In this research the problem has been approached from the point of view of inorganic nutrient absorption through the roots. The assumption has been made that the chemical constitution, as shown by analysis, is a measure of the nutrient absorption. From the results of experiments with wheat plants (11), the writer reached the conclusion that the problem could only be considered when plants were not severely injured. The reasons for this are - that the chemical composition of plants may vary widely according to the stage of growth and, since the study is a relative one, it would be unwise to increase the probability or error.

The experimental conditions and results have been recorded in several tables above. The yield data, transpiration coefficients and analyses have been grouped in the following table. An accompanying table of relative values with the control as 100 has been made. The writer is unprepared to defend this latter on either logical or mathematical grounds. These tables may be conveniently referred to in this discussion.

Visible injury is not dependent upon the concentration of the gas alone, as has been shown by the classical experiments in this field. This finding is reaffirmed by these experiments. Humidity is a factor of primary importance. At 90 - 100% humidity, visible injury was produced by sulphur dioxide at concentrations of 0.40 p.p.m. and 0.30 p.p.m.; while at 37 - 66% relative humidity, no injury was produced by 0.27 p.p.m.; and at 55 - 70% humidity, no injury was produced by 0.36 p.p.m. The duration factor is also shown: 6 hours on 2 successive days at a concentration of 0.40 p.p.m. produced visible injury on 30% of the total leaf area of plants in the 3-4 leaf stage; but 12 hours on 3 days at 10-day intervals with a concentration of 0.30 p.p.m. produced visible injury on only 5% of the total leaf area. Where no visible injury was produced, the effects of duration are seen in comparing the dry weight yields.

Table No. 4

	Exper. 1		Exper. 2		Exper. 3		Exper. 4	
	C.#	T.#	C.	T.	C.	T.	C.	T.
Absolute Values.								
Tillers	1.61	1.51	1.26	1.16	3.02	2.93	2.09	2.14
Green weight	420	327	371	334	330	310	202.4	203.7
% Moisture	91.8	91.2	91.7	91.5	88.4	88.5	88.8	88.9
Dry weight	34.7	28.7	30.2	28.3	38.4	35.8	22.7	22.6
Transpiration	235	152	194	180	692	548	653	618
% Ash	18.14	17.36	17.66	17.47	18.11	18.16	18.56	17.73
% Calcium	1.19	1.17	1.46	1.46	1.42	1.27	1.24	1.18
% Magnesium	0.79	0.71	0.82	0.83	0.64	0.53	0.60	0.58
% Potassium	7.78	7.54	7.46	7.39	7.38	6.73	7.61	7.23
% Sulphur	1.98	1.71	1.92	1.84	2.06	2.84	1.94	1.98
% Phosphorus	0.85	0.76	0.75	0.74	1.02	0.95	1.31	1.27
% Nitrogen	6.13	5.72	6.48	6.51	6.61	5.87	6.34	6.30
Relative Values. (Control as 100)								
Tillers	100	93.7	100	92.1	100	97.0	100	102.4
Green weight	100	77.9	100	90.0	100	93.9	100	100.6
% Moisture	100	99.3	100	99.8	100	100.1	100	100.1
Dry weight	100	82.7	100	93.7	100	93.2	100	99.9
Transpiration	100	65.0	100	93.0	100	80.0	100	95.0
% Ash	100	95.7	100	98.9	100	100.3	100	95.5
% Calcium	100	98.3	100	100.0	100	89.3	100	95.1
% Magnesium	100	89.9	100	101.2	100	82.8	100	96.6
% Potassium	100	96.8	100	97.8	100	91.2	100	95.0
% Sulphur	100	86.4	100	95.8	100	137.4	100	102.1
% Phosphorus	100	89.4	100	98.7	100	93.1	100	96.9
% Nitrogen	100	93.3	100	100.5	100	88.8	100	99.4

C# - the control plants.

T# - the treated plants.

Tillering by treated plants did not differ greatly from the tillering by the controls. The ratio of treated to control varied from 92.1 : 100 to 102.4 : 100.

Dry weights of the treated plants were decreased in rough proportion to the degree of treatment within the experimental classes (a) producing visible injury, and (b) producing no visible injury. Plants with visible injury to 30% of the leaf area produced a dry weight 82.7% as heavy as that of the controls; while plants with injury to 5% of the leaf area produced dry weight 93.7% as heavy as the controls. Plants with no visible injury but exposed to 480 hours of treatment with sulphur dioxide at a concentration of 0.27 p.p.m. produced a dry weight 93.2% as heavy as that of the controls; while plants exposed to 51 hours of gas at a concentration of 0.36 p.p.m. produced 99.9% as much as the control dry weight.

Transpiration differences were very noticeable between the control and treated plants in each experiment. In order of experiment number, the ratios of control transpiration coefficient to those of the treated are: 100:65, 100:93, 100:80, 100:95. The difference in transpiration coefficients of injured plants is greater than the true transpiration difference, due to the reduction of transpiration surface through injury. Nevertheless, a diminishment of the per unit surface transpiration did take place. This might be explained partly upon the basis of partial closure of the stomata through some effect of the sulphur dioxide. Such an effect might be due to a change in acidity, held by Scarth (12) to be of great importance in stomatal movement. Or the diminishment of transpiration might be explained by postulating a diminished respiration rate. According to evidence advanced by workers in this field, transpiration is a process requiring a large expenditure of energy by the plant, and consequently the rate of respiration may become a limiting factor. These explanations would fully account for the measured decreases in transpiration recorded.

Calcium, magnesium, and potassium content per unit dry weight were diminished in all the treated plants excepting those in experiment 2, where the treatment was of 12 hours duration only. This is regarded as indicating a diminished absorption rate of these elements. The magnesium content in the plants grown in the greenhouse was about 0.8%, while in the plants grown in cabinets it was about 0.6%. This difference might be correlated with the light conditions and the leaf fractions of the total green weights.

Nitrogen (total) content was diminished appreciably in the treatment where visible injury to 30% of the leaf area was produced (N ratio was 100:93.3) and in the treatment of 480 hours duration in which no visible injury was produced (N ratio was 100:88.8). In the other two experiments there were no appreciable differences between control and treated plants. The nitrogen content was quite high in all plants. Phosphorus was also fairly high. The ratios of P:N in experiments number 1 and 3 are different. This might be regarded as an effect upon the phosphoproteins in the growing parts of the plant; that is, the amount of phosphorus was less in the plants which showed a diminished growth during the later stages.

Sulphur content showed great variation in the treated plants. Arranged in order of experiment numbers, the ratios of control to treated are: 100:86.4, 100:95.8, 100:137.4, 100:102.1. Consideration of the treatments and the results of analyses suggests that the sulphate absorption by treated plants from the nutrient solution is lowered, but that treatment of sufficient duration will increase the total sulphur. In experiment 3, the plants were treated for 480 hours; the sulphur content was increased 37.4% for the whole plant.

Ash analyses include silicon traces which cannot be excluded in culture work of this kind. The ash for all experiments, excepting number 3, was lower in the treated plants than in the control plants. Ratios of control to treated plants are 100:95.7, 100:98.9, 100:100.3, 100:95.5. This agrees, in general, with the results found in separate analytical procedures. The slightly higher ash found in the treated plants of experiment number 3 is evidently the result of the high sulfur content of the treated plants.

Absorption is regarded as a physiological function independent of transpiration. At the present time both functions can only be explained by postulating expenditure of energy by the plant to maintain them. Other researches seem to establish this fact. In these experiments a lowered transpiration was recorded and a lowered absorption of inorganic nutrients per gram dry weight was measured (assuming analyses to indicate the absorption) in treated plants as compared to control plants. This can be explained on the hypothesis that sulphur dioxide lowers the respiration rate of the plant without affecting the rate of photosynthesis in the same degree. No direct experimental evidence is advanced to substantiate this explanation.

SUMMARY:

Four experiments upon barley plants have been conducted under described environmental conditions. These experiments consisted of treatments with sulphur dioxide in a range of low concentrations with

averages from 0.27 p.p.m. to 0.40 p.p.m. The duration of exposure in the treatments varied from 6 to 480 hours; and the range of humidity between experiments was from 40% relative humidity to 100%.

Visible injury was only produced when the relative humidity was extremely high and the extent was influenced by the duration of exposure as well as the concentration of the gas. No visible injury was produced in medium and fairly low humidities by lengthy treatments of sulphur dioxide at the same concentrations.

Tillering by the plants was not appreciably altered by treatments. The yield, as measured by dry weights, was reduced in three experiments. The reduction in yield could be considered as roughly proportional to the severity of the treatment (a) producing visible injury to the plants and (b) producing no visible injury to the plants.

Transpiration by the plants was measured. In each experiment transpiration by the treated plants was decreased. Transpiration coefficients have been calculated.

The dry material was analyzed by recognized quantitative methods for the following elements: calcium, magnesium, potassium (including sodium trace), sulfur, phosphorus, and nitrogen (total); and an ash determination was made. The results showed a decrease in the concentration of these elements per unit dry weight in the more severe treatments. Sulfur was higher in the experiments of long duration. Consideration of the results lead to the conclusion that absorption of inorganic nutrients from solution is decreased by treatment with sulphur dioxide.

Transpiration and absorption are now regarded as plant functions requiring an energy expenditure by the plant. The decrease in transpiration and absorption of inorganic nutrients may be explained if the sulphur dioxide is assumed to decrease the respiration rate of the plant without the same relative decrease in the rate of photosynthesis.

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