HILGARDIA

A Journal of Agricultural Science Published by the California Agricultural Experiment Station

VOLUME 10 | DECEMBER, 1936 | NUMBER 10

CONTENTS

UNIVERSITY OF CALIFORNIA · BERKELEY, CALIFORNIA

SOME EFFECTS OF THALLIUM SULFATE UPON SOILS

A. S. CRAFTS

SOME EFFECTS OF THALLIUM SULFATE UPON SOILS[1, 2]

A. S. CRAFTS[3]

INTRODUCTION

WITH THE INCREASING USE of poisons for pest control in agriculture, new and little-known chemicals are frequently introduced. The ultimate effects of these reagents upon soils and crops may present serious problems, and the continued use of certain of them cannot be safely recommended until their long-time behavior is understood.

Brooks (*1*)[4] has warned of the possible sterilization effects of thallium sulfate used in rodent control, and McCool (*4*) has confirmed the highly toxic nature of this chemical in soils.

In pest control, toxicity is of eminent importance; and in weed work, soil effects are of special interest. Although thallium compounds are too expensive to be practical in weed control, their behavior in soils characterizes a certain type of toxic materials. A study of their reactions should contribute to our general information.

A preliminary report on work done on the problem of thallium toxicity in California soils has been published (*2*). The method used in toxicity studies, as already described by the author (*3*) in a previous paper, consists principally in pot-culture tests using 500-gram lots of soils in No. 2 cans as the culture media. The chemicals to be tested are applied to the soils in various ways, and their effects upon indicator plants (Kanota oats) are measured by recording height and fresh weight of the latter after a 30-day growth period. The details of the individual tests with thallium will become apparent in the following pages.

[1] Received for publication May 8, 1936.

[2] This investigation was undertaken at the request of a special committee appointed in the University of California in 1932 to study problems involved in rodent and wild-life control. The use of chemicals, including thallium sulfate, for rodent control was studied by this committee. Certain claims had been made as to the possible or probable sterilizing effect of thallium salts if distributed in connection with rodent control. The literature then available did not provide satisfactory answers to these claims. The Division of Botany of the College of Agriculture was asked by the committee to conduct a study of the effect of thallium sulfate on soils. Dr. T. I. Storer of the Zoölogy Division of the College of Agriculture, who was a member of the above committee, coöperated in the planning and execution of the experiments. The paper presented herewith incorporates the results of this study. Dr. Crafts found, however, that certain general principles with respect to the effect of salts of heavy metals on soils could be elucidated by use of thallium sulfate, and the studies were therefore carried farther than necessary to provide an answer to the original request.—C. B. Hutchison, Director of the Agricultural Experiment Station.

[3] Assistant Professor of Botany and Assistant Botanist in the Experiment Station.

[4] Italic numbers in parentheses refer to "Literature Cited" at the end of this paper.

EXPERIMENTS

Toxicity Studies.—Two toxicity series have been run with thallium sulfate. The first, a short concentration series in Yolo clay loam, having been cropped twelve times, gives a picture of the effects of time and repeated cropping upon the availability of this chemical. The results of the first, third, and fifth crops in comparison with crops with other sterilants have been reported (*3*). Table 1 gives the complete data on this experiment in terms of plant growth, which, of course, varies inversely

TABLE 1

TOXICITY OF THALLIUM SULFATE UPON SUCCEEDING CROPS IN YOLO CLAY LOAM, AS SHOWN BY GROWTH OF INDICATOR PLANTS*

Tl_2SO_4 Amount in air-dry soil	First run harvested Oct. 29, 1932		Second run harvested Jan. 22, 1933		Third run harvested May 6, 1933		Fourth run harvested Nov. 18, 1933		Fifth run harvested Jan. 14, 1934		Sixth run harvested Mar. 10, 1934	
	Ht.	Wt.	Ht.	Wt.	Ht.	Wt.	Ht.	Wt.	Ht.	Wt.	Ht.	Wt.
p.p.m.	*cm*	*gm*	*cm*	*gm*	*cm*	*gm*	*cm*	*gm*	*cm*	*gm*	*cm*	*gm*
15	28	9.6	31	7.5	35	8.8	25	6.6	29	5.2	35	8.1
30	28	8.6	28	6.1	35	8.7	26	6.6	30	5.8	34	9.6
60	25	5.1	20	3.3	31	5.6	25	6.9	30	4.6	35	9.2
120	20	1.8	13	1.8	23	2.9	23	2.8	22	3.2	24	3.8
180	15	1.0	8	1.0	18	1.7	18	1.8	16	2.2	17	2.0
240	10	0.5	6	0.4	10	0.6	15	1.1	12	1.5	11	1.3
300	7	0.4	5	0.3	8	0.5	11	0.8	12	1.2	7	0.5
375	4	0.2	4	0.3	7	0.4	8	0.6	11	0.9	6	0.3
450	3	0.1	3	0.2	5	0.2	7	0.5	10	0.6	6	0.1
600	3	0.1	3	0.2	3	0.2	8	0.4	8	0.5	6	0.1
Check	28	9.4	28	8.0	33	8.3	24	6.2	30	5.3	32	8.6

Tl_2SO_4 amount in air-dry soil	Seventh run† harvested July 23, 1934		Eighth run harvested Oct. 27, 1934		Ninth run harvested Mar. 1, 1935		Tenth run harvested Nov. 20, 1935		Eleventh run harvested Feb. 3, 1936		Twelfth run harvested April 17, 1936	
	Ht.	*Wt.*	*Ht.*	*Wt.*	*Ht.*	*Wt.*	*Ht.*	*Wt.*	*Ht.*	*Wt.*	*Ht.*	*Wt.*
p.p.m.	*cm*	*gm*	*cm*	*gm*	*cm*	*gm*	*cm*	*gm*	*cm*	*gm*	*cm*	*gm*
15	12	3.7	28	4.2	28	5.2	23	5.6	29	6.8	31	9.2
30	12	3.6	25	3.3	29	5.5	22	5.3	28	5.9	32	8.1
60	12	4.0	28	4.4	28	5.6	24	5.9	29	5.8	29	8.4
120	12	3.6	26	3.4	24	3.3	22	3.5	24	3.3	33	7.6
180	9	2.1	19	1.6	16	1.5	16	1.6	18	1.4	24	3.2
240	7	1.1	14	1.0	11	0.8	10	1.0	14	0.8	17	1.6
300	5	0.5	9	0.5	8	0.6	9	0.4	12	0.4	10	0.6
375	4	0.4	7	0.3	7	0.5	8	0.3	14	0.3	8	0.2
450	4	0.2	7	0.2	6	0.4	8	0.2	8	0.2	7	0.1
600	4	0.1	6	0.2	6	0.3	7	0.2	9	0.2	7	0.1
Check	12	3.4	27	4.2	26	4.8	23	5.9	29	6.6	32	9.8

* All cultures run in triplicate; checks replicated six times. All values are averages of the replicates.

† Run No. 7 was conducted out of doors at Berkeley; all others were conducted in the greenhouse at Davis.

with toxicity. In this table rapid changes in toxicity are indicated by sudden changes in fresh weight, as between 60 p.p.m. and 120 p.p.m. in the first run.

The differences in toxicity evident in these results indicate a drop to about one-half the initial toxicity shown by the first run; then values tend to fluctuate in response to changes in light, temperature, and humidity; they follow no definite trend. Low values are shown in run 7,

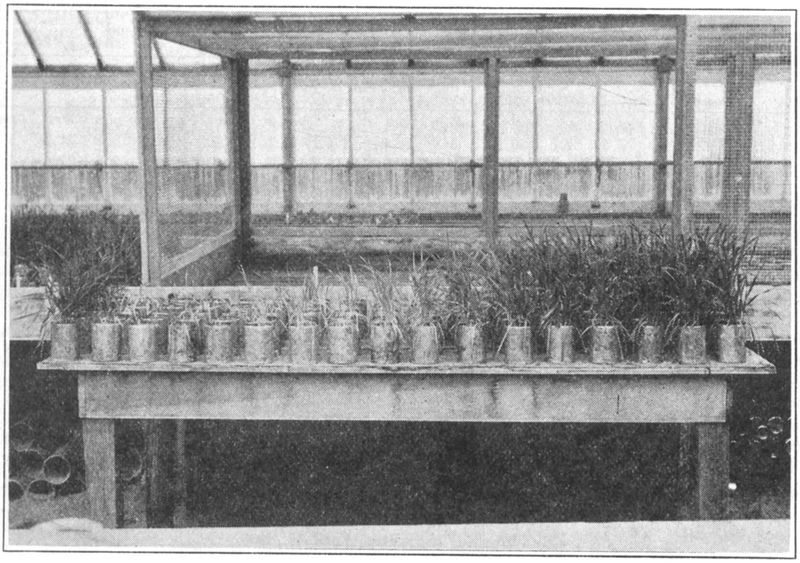

Fig. 1.—A concentration series with thallium sulfate in Yolo clay loam on test in the greenhouse. One row of checks is located at each end of the series. The concentration increases from right to left. Photograph taken on January 19, 1933, showing the first run reported in table 2.

probably because that run was conducted out of doors in Berkeley under conditions of high light intensity and high humidity. The other eleven runs were made in the greenhouse at Davis under conditions of low humidity during a large portion of the year.

The second toxicity experiment was conducted with four California soils, using thallium sulfate alone. The air-dry soils were moistened with solutions containing thallium sulfate in the concentrations given in the first column of table 2. Each culture was replicated five times, and the complete set run twice. Figure 1 shows the first run in the Yolo clay loam. Table 2 gives the yield data.

The differences in toxicity of thallium sulfate in the four soils is striking. They do not correlate well with water-holding capacities nor with the concentrations based on air-dry weights. No significant changes were

TABLE 2

TOXICITY OF THALLIUM SULFATE IN FOUR TYPES OF CALIFORNIA SOILS, AS SHOWN BY GROWTH OF INDICATOR PLANTS

Tl_2SO_4 in moistening solution, p.p.m.	Yolo clay loam			Fresno sandy loam			Stockton adobe clay			Columbia fine sandy loam		
	Tl_2SO_4 in air-dry soil	Ht.	Wt.	Tl_2SO_4 in air-dry soil	Ht.	Wt.	Tl_2SO_4 in air-dry soil	Ht.	Wt.	Tl_2SO_4 in air-dry soil	Ht.	Wt.
First run, harvested January 29, 1933												
	p.p.m.	*cm*	*gm*	*p.p.m.*	*cm*	*gm*	*p.p.m.*	*cm*	*gm*	*p.p.m.*	*cm*	*gm*
25	7.5	32.5	10.6	3.3	20.6	3.4	5.8	12.7	1.5	3.7	21.2	5.4
50	15.0	30.7	10.0	6.5	20.1	3.3	11.7	12.7	1.4	7.5	22.4	5.7
75	22.5	29.5	9.4	9.8	19.6	3.0	17.5	12.5	1.3	11.2	21.4	5.4
100	30.0	28.4	9.1	13.1	18.3	3.0	23.3	9.5	1.0	15.0	21.2	5.6
150	45.0	27.0	7.8	19.6	18.1	3.0	35.0	9.7	1.1	22.5	20.3	5.1
200	60.0	24.0	5.1	26.2	16.5	2.6	46.6	9.0	1.0	30.0	20.1	5.2
275	82.5	21.2	3.4	36.0	14.0	2.0	64.2	7.5	0.5	41.2	20.5	4.6
350	105.0	18.8	2.5	45.8	12.8	1.6	81.7	7.7	0.6	52.5	19.0	4.3
450	135.0	13.7	1.5	58.9	12.0	1.5	105.0	5.3	0.5	67.5	18.3	4.3
550	165.0	11.9	1.8	72.0	9.2	1.0	128.5	5.1	0.4	82.5	16.3	3.1
650	195.0	12.5	1.3	85.0	7.9	0.9	151.8	5.0	0.4	97.5	15.2	2.6
800	240.0	4.8	0.5	104.6	5.1	0.7	186.8	4.8	0.3	120.0	12.5	1.9
1,000	300.0	6.0	0.9	131.0	3.8	0.3	233.3	4.4	0.3	150.0	10.4	1.7
1,500	450.0	5.0	0.5	196.1	3.0	0.2	350.0	3.9	0.3	225.0	6.5	1.1
2,000	600.0	5.0	0.6	262.0	2.5	0.2	467.0	3.5	0.3	300.0	5.8	0.9
Check	.....	31.5	10.0	.....	19.1	3.4	.....	12.5	2.0	.....	21.4	5.7
Check	.....	28.2	10.4	.....	20.5	3.8	.....	12.5	2.1	.....	21.5	6.2
Second run, harvested April 17, 1933												
	p.p.m.	*cm*	*gm*	*p.p.m.*	*cm*	*gm*	*p.p.m.*	*cm*	*gm*	*p.p.m.*	*cm*	*gm*
25	7.5	30.5	8.8	3.3	18.3	3.2	5.8	15.1	2.6	3.7	25.4	3.4
50	15.0	31.3	8.6	6.5	17.8	2.9	11.7	17.0	2.7	7.5	25.4	3.5
75	22.5	31.0	9.0	9.8	17.3	2.5	17.5	17.2	2.6	11.2	25.0	3.8
100	30.0	31.5	8.7	13.1	14.0	1.9	23.3	16.6	2.4	15.0	24.4	3.5
150	45.0	28.3	7.7	19.6	12.2	1.3	35.0	15.4	2.0	22.5	23.6	3.2
200	60.0	16.2	6.7	26.2	10.2	0.7	46.6	13.7	1.8	30.0	23.6	3.2
275	82.5	13.2	4.6	36.0	9.9	0.5	64.2	10.1	1.3	41.2	22.1	3.0
350	105.0	20.0	3.2	45.8	5.1	0.1	81.7	9.4	0.5	52.5	20.1	2.5
450	135.0	15.7	1.8	58.9	4.0	0.1	105.0	8.7	0.3	67.5	18.0	2.0
550	165.0	12.0	0.7	72.0	3.7	0.1	128.5	7.6	0.2	82.5	14.7	1.6
650	195.0	10.3	0.6	85.0	3.0	0.1	151.8	7.1	0.1	97.5	11.5	1.1
800	240.0	9.0	0.2	104.6	2.5	0.1	186.8	6.4	0.1	120.0	9.1	0.9
1,000	300.0	6.2	0.2	131.0	2.5	0.1	233.3	5.5	0.1	150.0	6.4	0.3
1,500	450.0	4.4	0.2	196.1	2.0	0.1	350.0	5.0	0.1	225.0	5.1	0.2
2,000	600.0	3.9	0.1	262.0	2.0	0.1	467.0	5.0	0.1	300.0	5.1	0.2
Check	.....	28.0	8.0	.....	17.8	3.2	.....	14.8	2.5	.....	26.0	3.8
Check	.....	30.5	9.0	.....	17.6	3.0	.....	14.8	2.5	.....	22.9	3.8

shown in the second run. This chemical shows extreme and persistent toxicity in soils of low fertility.

The response of the cereals to thallium sulfate in toxic concentrations is characteristic. Whereas chlorates and arsenic in toxic doses retard growth of the complete embryo, thallium checks the development of the shoot but has little effect on the coleoptile. Table 3 gives the relative development of shoots and coleoptiles of the oat seedlings 5 days after planting the second crop in two of the soils reported in table 2.

TABLE 3

RELATIVE DEVELOPMENT OF SHOOTS AND COLEOPTILES OF OATS GROWN IN THE SECOND RUN ON THALLIUM-TREATED SOILS, 5 DAYS AFTER PLANTING

Soil type	Plant part	Tl_2SO_4 in moistening solution, p.p.m.												Check
		100	150	200	275	350	450	550	650	800	1,000	1,500	2,000	
		cm	*cm*	*cm*	*cm*	*cm*	*cm*	*cm*	*cm*	*cm*	*cm*	*cm*	*cm*	*cm*
Yolo clay loam	Shoots	15.0	15.0	15.0	15.0	15.0	12.5	12.5	10.0	7.5	4.0	3.2	2.5	15.0
	Coleoptiles	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	4.5	4.0	4.0	4.0	5.0
Fresno sandy loam	Shoots	15.0	12.5	11.5	10.0	7.5	5.0	4.0	3.2	2.5	0.7	0.0	0.0	15.0
	Coleoptiles	5.0	5.0	5.0	5.0	5.0	5.0	4.4	4.0	4.0	3.8	3.2	2.5	5.0

In the higher concentrations the shoots grow very slowly, sometimes not protruding beyond the tips of the coleoptiles. In these extreme cases the seedlings usually die after two or three weeks. Where the chemical is less concentrated, the shoots continue growth; but with the development of the leaf blades they become chlorotic and weak. As shown in table 2, only the plants in the very low concentrations attained anything like normal development. Plants that make a perfectly normal start, as, for instance, those reported on the left in table 3, may subsequently show chlorosis, weakening, and decline. This fact is illustrated in table 2 where, in the second run in Fresno sandy loam, the plants in the culture containing 100 p.p.m. of Tl_2SO_4 in the soil solution made but little more than half the normal growth. These differences would be even greater if the plants were grown for a longer period.

Soil-Tube Tests.—The distribution of a sterilant within the soil after its application to the surface depends primarily upon the fixing power of the soil for the chemical. This property was studied by the soil-tube method previously described (*3*). Briefly, this consisted in slowly moistening columns of air-dry soil with Tl_2SO_4 solutions, dividing the columns each into 9 fractions of equal weight and approximately 10 cm in height, and growing oats upon the fractions. Results are shown in table 4.

TABLE 4

FIXING POWER OF CALIFORNIA SOILS FOR THALLIUM SULFATE AS SHOWN BY GROWTH OF INDICATOR PLANTS IN FRACTIONS OF THE TREATED SOIL COLUMNS*

Soil type	Fraction of column	H_2O check		Concentration of thallium sulfate in the moistening solution									
				25 p.p.m.		50 p.p.m.		100 p.p.m.		200 p.p.m.		400 p.p.m.	
		Ht.	Wt.	Ht.	Wt.	Ht.	Wt.	Ht.	Wt.	Ht.	Wt.	Ht.	Wt.
	cm	*cm*	*gm*	*cm*	*gm*	*cm*	*gm*	*cm*	*gm*	*cm*	*gm*	*cm*	*gm*
Yolo clay loam harvested Jan. 24, 1933	0–10	19	3.2	17	2.0	13	1.1	13	0.7	10	0.6	4	0.4
	10–20	21	3.5	21	3.7	19	3.5	19	3.3	20	3.1	20	2.8
	20–30	20	3.7	19	3.0	20	3.5	19	3.2	20	3.4	19	3.6
	30–40	20	3.6	21	3.5	20	4.2	20	3.3	23	3.8	19	3.5
	40–50	21	3.6	20	3.3	20	3.8	19	3.5	20	3.2	19	4.2
	50–60	20	3.4	20	3.3	20	3.9	19	3.3	20	3.4	19	3.2
	60–70	22	3.9	21	3.3	30	9.2	21	4.2	27	7.0	28	8.0
	70–80	29	9.2	29	9.6	30	9.9	30	9.4	28	9.3	30	10.0
	80–90	27	7.5	27	6.5	31	10.0	31	7.9	29	7.6	23	6.3
Fresno sandy loam harvested Feb. 19, 1933	0–10	16	3.0	7	0.8	5	0.7	3	0.3	3	0.2	2	0.1
	10–20	17	2.9	15	2.5	15	2.8	15	2.9	15	2.9	12	2.6
	20–30	18	3.3	18	3.5	16	3.0	17	3.1	16	3.1	13	2.7
	30–40	18	3.0	18	3.2	18	3.2	17	3.4	17	3.0	15	3.1
	40–50	18	3.4	17	2.9	18	3.3	18	3.3	17	3.2	17	3.2
	50–60	17	3.2	18	3.2	18	3.6	16	3.0	17	3.1	19	4.0
	60–70	17	3.1	18	3.3	17	3.1	17	3.1	17	3.3	17	3.0
	70–80	17	3.2	17	3.2	17	3.2	17	3.2	17	3.2	17	3.1
	80–90	18	3.4	18	3.6	21	5.6	17	3.3	17	3.6	17	3.4
Stockton adobe clay harvested March 5, 1933	0–10	13	1.9	8	0.4	8	0.1	6	0.1	6	0.1	5	0.1
	10–20	14	2.0	13	2.1	13	2.0	15	2.2	14	1.9	14	1.7
	20–30	14	2.0	13	2.0	13	1.9	14	2.0	15	2.2	14	1.9
	30–40	14	2.1	13	2.0	13	2.0	14	2.1	14	2.1	14	1.9
	40–50	13	2.0	13	2.1	13	1.8	13	2.0	14	2.0	13	1.7
	50–60	14	2.2	13	1.9	14	2.2	14	2.2	14	2.0	14	1.6
	60–70	14	2.2	13	1.9	14	2.1	14	2.3	14	2.2	14	1.5
	70–80	14	2.3	14	2.3	14	2.3	14	2.2	13	2.0	13	2.1
	80–90	13	2.1	13	2.2	13	1.9	14	2.2	13	2.1	13	1.7
Columbia fine sandy loam harvested March 24, 1933	0–10	19	3.4	18	2.7	13	2.5	8	0.1	5	0.1	5	0.1
	10–20	20	3.3	20	3.3	19	3.6	20	3.0	20	3.1	18	3.2
	20–30	20	3.5	19	3.4	20	3.6	20	3.5	30	3.8	20	3.5
	30–40	21	3.7	20	3.6	20	4.0	20	3.6	20	3.8	20	3.6
	40–50	20	3.9	20	3.9	20	3.7	21	3.9	21	4.0	21	3.9
	50–60	20	3.7	20	3.8	21	3.9	20	4.0	20	3.8	20	3.8
	60–70	20	3.9	20	3.6	21	4.2	21	4.2	20	3.7	20	3.7
	70–80	23	5.8	21	5.8	23	4.7	25	6.6	23	4.6	25	7.2
	80–90	29	7.5	30	6.8	28	7.1	30	8.5	30	8.9	28	6.2

* Average fresh weight of plants in 12 untreated checks: Yolo clay loam, 9.9 grams; Fresno sandy loam, 3.3 grams; Stockton adobe clay, 2.0 grams; Columbia fine sandy loam, 5.3 grams.

Apparently all the chemical was held in the top 10 cm of soil in all these tests. In the more fertile soils, namely the Yolo clay loam and the Columbia fine sandy loam, there was appreciable leaching of soil nutrients. Since the moisture was so measured that it did not quite completely wet the soil, these nutrients were present in the lower portions of the soil columns and stimulated the plants in these fractions. In the Fresno sandy loam and Stockton adobe clay no appreciable leaching of nutrients

TABLE 5

FIXING POWER OF YOLO CLAY LOAM FOR THALLIUM SULFATE*
(Harvested April 10, 1933)

Fraction† of column	Concentration of Tl_2SO_4 in moistening solution, p.p.m.								Fraction‡ of column	Concentration of Tl_2SO_4 in moistening solution, p.p.m.	
	25		100		500		1,000			1,000	
	Ht.	Wt.	Ht.	Wt.	Ht.	Wt.	Ht.	Wt.		Ht.	Wt.
cm	*cm*	*gm*	*cm*	*gm*	*cm*	*gm*	*cm*	*gm*	*cm*	*cm*	*gm*
0.0- 2.5	18	1.7	5	0.1	3	0.1	1	0.0	0.0- 1.2	1	0.0
2.5- 5.0	23	6.2	22	6.5	23	6.9	18	2.3	1.2- 2.5	1	0.0
5.0- 7.5	24	6.6	24	6.1	25	6.4	23	6.7	2.5- 3.7	8	0.2
7.5-10.0	25	7.2	25	6.9	25	6.3	25	7.0	3.7- 5.0	23	7.6
10.0-12.5	25	6.8	25	7.3	25	7.1	28	7.1	5.0- 6.2	25	7.8
12.5-15.0	25	6.8	26	7.3	28	7.5	26	6.7	6.2- 7.5	28	9.2
15.0-17.5	25	6.5	25	7.2	29	7.8	28	7.6	7.5- 8.7	28	8.5
17.5-20.0	25	6.9	26	7.3	28	7.6	26	6.9	8.7-10.0	28	9.1
20.0-22.5	25	7.1	28	7.4	28	7.0	26	6.9	10.0-11.2	28	9.3
22.5-25.0	26	7.3	28	7.6	28	7.1	27	7.2	11.2-12.5	27	8.7
25.0-27.5	28	7.6	28	8.1	27	7.2	26	7.1	12.5-15.0	27	8.2
27.5-30.0	25	6.7	28	7.4	27	7.0	27	6.8	15.0-17.5	27	9.0

* Average fresh weight of 10 untreated checks = 9.8 grams.

† Each fraction mixed with 375 grams air-dry soil and moistened with 112.5 cc tap water so that the culture has a thallium concentration one-quarter that of the moistening solution.

‡ Each fraction mixed with air-dry soil and tap water to make 650 grams of moistened soil per culture.

occurred; growth was uniform in all the lower fractions. The checks in column 3, table 4 were simply cultures in newly moistened soils.

Thallium sulfate is apparently held very firmly in all these soils. In none was there any evidence that the capacity of the soil for the sterilant was exceeded. The top 10 cm (table 4) held all the chemical applied to each tube. Since the quantity of moistening solution applied was just short of enough to wet the soil to the full depth, and this top fraction is one-ninth of the total depth, approximately one-ninth of the water would be held in this top fraction. Where the moistening solution contained 400 p.p.m., the concentration in the top fraction would therefore be 3,600 p.p.m. This was about 1,080 p.p.m. on the air-dry soil basis in the Yolo clay loam, 471 in the Fresno sandy loam, 840 in the Stockton adobe clay, and 540 in the Columbia fine sandy loam.

To ascertain the depth to which the chemical was penetrating, a series of 5 tubes was run using Yolo clay loam and fractionating into layers approximately 2.5 cm thick (table 5). These 2.5 cm portions were mixed in each case with 375 grams of air-dry soil. The mixtures were then placed in cans and moistened with 112.5 cc of tap water. In other words, the soil in each fraction was diluted with three parts of untreated soil. Consequently, in table 5 the concentrations of thallium sulfate expressed in terms of the moistening solution must be divided by 4 to give the actual values for the cultures. In the fifth tube the column was fractionated at each 1.2 cm, and the portions were made up to 650 grams of moistened soil by adding 7 parts of dry soil and wetting with tap water.

These results of what constitutes a more detailed study of the fixing of thallium sulfate by Yolo clay loam conclusively show that this chemical in solutions up to 500 p.p.m. in concentration will be all taken up in the top 2.5 cm of this soil from a volume sufficient to wet a 90-cm column (table 5). When the concentration reaches 1,000 p.p.m., the top 3.7 cm will hold the chemical. If the concentration in this top 3.7 cm were uniform, it would be 24,000 p.p.m. on the basis of the soil moisture or 7,200 p.p.m. in the air-dry soil. Since the growth was somewhat greater in the third culture, the concentration was probably greater in the top 2.5 cm. The capacity of Yolo clay loam to hold thallium sulfate may be safely estimated at around 10,000 p.p.m. on the dry-soil basis. In this soil, therefore, thallium is held up to a concentration of 1 per cent of its weight against the leaching effects of moving water in a form available to plants. Such a chemical, if applied to the soil, would remain in a relatively shallow layer for a considerable period, which renders it sterile to plant growth.

Most agricultural soils in California are subject to considerable moisture movement. The resistance of a chemical sterilant to the leaching effects of rains or irrigation is of vital importance. Thallium sulfate resists leaching to a marked degree, as shown by the following experiments. Tubes of air-dry soils, moistened with solutions containing 100 p.p.m. and 200 p.p.m. of thallium sulfate, were leached with varying amounts of distilled water. When the leaching was finished they were allowed to come to equilibrium by standing with their lowermost layers in contact with air-dry soil until the moisture stopped moving. They were then fractionated, planted with oats, and at the end of a 30-day period the oats were harvested as in the previous tests. Tables 6, 7, 8, and 9 present the data on these experiments.

With the Yolo clay loam, as the volume of water used in leaching becomes great enough to carry the soil nutrients out of the tube, the

TABLE 6

RESULTS OF LEACHING THALLIUM SULFATE IN YOLO CLAY LOAM WITH DIFFERENT DEPTHS OF WATER, AS SHOWN BY GROWTH OF INDICATOR PLANTS*

Tl_2SO_4, 100 p.p.m. in moistening solution, cultures harvested January 27, 1933

Depth	Leached with 5 cm H_2O		Leached with 10 cm H_2O		Leached with 15 cm H_2O		Leached with 20 cm H_2O		Leached with 25 cm H_2O	
	Ht.	Wt.	Ht.	Wt.	Ht.	Wt.	Ht.	Wt.	Ht.	Wt.
cm	*cm*	*gm*	*cm*	*gm*	*cm*	*gm*	*cm*	*gm*	*cm*	*gm*
0–10	7	1.1	5	0.6	7	1.6	10	0.8	13	2.2
10–20	19	3.9	20	3.4	20	3.6	18	3.2	19	3.5
20–30	19	3.8	21	4.4	20	3.7	19	3.4	20	4.3
30–40	20	4.2	22	3.8	20	3.6	19	3.1	19	3.8
40–50	22	3.6	22	3.5	19	3.3	19	3.5	19	3.8
50–60	22	3.9	22	3.5	19	3.5	19	3.6	20	4.7
60–70	24	5.8	21	3.4	18	2.9	18	3.2	18	3.5
70–80	30	10.0	20	3.4	18	3.1	19	3.4	19	3.8
80–90	30	10.9	29	11.0	19	3.7	18	3.3	18	3.5

Tl_2SO_4, 200 p.p.m. in moistening solution, cultures harvested February 7, 1933

Depth	Leached with 37.5 cm H_2O		Leached with 50 cm H_2O		Leached with 75 cm H_2O		Leached with 125 cm H_2O		Leached with 200 cm H_2O	
	Ht.	Wt.	Ht.	Wt.	Ht.	Wt.	Ht.	Wt.	Ht.	Wt.
cm	*cm*	*gm*	*cm*	*gm*	*cm*	*gm*	*cm*	*gm*	*cm*	*gm*
0–10	5	0.5	5	0.5	5	0.4	5	0.5	5	0.4
10–20	22	4.0	20	4.2	22	4.5	18	4.2	17	3.0
20–30	22	4.3	19	3.6	23	5.2	20	4.7	18	4.0
30–40	22	4.5	20	4.0	24	5.0	20	4.8	19	4.1
40–50	22	4.7	20	3.9	23	5.2	20	4.2	19	3.8
50–60	23	5.2	21	4.4	22	3.6	20	4.2	18	3.2
60–70	20	3.9	22	4.3	22	3.7	18	3.3	17	3.0
70–80	20	3.9	20	4.4	22	4.0	17	3.0	17	3.2
80–90	20	4.1	20	4.0	22	4.6	15	2.8	15	2.6

Check tubes moistened with water, cultures harvested February 7, 1933

Depth	Leached with 37.5 cm H_2O		Leached with 50 cm H_2O		Leached with 75 cm H_2O		Leached with 125 cm H_2O		Leached with 200 cm H_2O	
	Ht.	Wt.	Ht.	Wt.	Ht.	Wt.	Ht.	Wt.	Ht.	Wt.
cm	*cm*	*gm*	*cm*	*gm*	*cm*	*gm*	*cm*	*gm*	*cm*	*gm*
0–10	19	4.0	18	3.4	19	3.8	18	3.5	17	3.0
10–20	19	3.8	19	3.7	20	4.3	18	3.7	17	3.1
20–30	20	4.1	20	4.0	20	4.2	18	3.5	17	3.2
30–40	19	3.7	23	4.9	20	4.6	19	4.1	18	4.0
40–50	19	4.0	21	4.2	19	4.0	17	3.1	19	3.4
50–60	20	4.3	22	4.5	20	4.4	17	3.2	20	4.7
60–70	19	4.3	19	3.6	19	3.3	17	3.1	19	3.7
70–80	19	3.7	19	3.4	20	4.0	18	3.3	21	4.5
80–90	19	4.3	19	3.5	19	3.9	19	3.5	19	3.6

* Average weight of plants in 30 untreated checks = 11.6 gm.

TABLE 7

RESULTS OF LEACHING THALLIUM SULFATE IN FRESNO SANDY LOAM WITH DIFFERENT DEPTHS OF WATER, AS SHOWN BY GROWTH OF INDICATOR PLANTS*

Tl_2SO_4, 100 p.p.m. in moistening solution, cultures harvested February 16, 1933

Depth	Leached with 5 cm H_2O		Leached with 10 cm H_2O		Leached with 15 cm H_2O		Leached with 20 cm H_2O		Leached with 25 cm H_2O	
	Ht.	Wt.	Ht.	Wt.	Ht.	Wt.	Ht.	Wt.	Ht.	Wt.
cm	*cm*	*gm*	*cm*	*gm*	*cm*	*gm*	*cm*	*gm*	*cm*	*gm*
0–10	1	0.1	1	0.1	1	0.2	1	0.2	1	0.1
10–20	14	2.6	14	2.3	13	2.4	14	2.3	13	2.1
20–30	14	2.6	14	2.4	13	2.2	13	2.5	15	2.8
30–40	13	2.5	14	2.6	13	2.4	14	2.8	14	2.3
40–50	14	2.7	14	2.6	13	2.5	14	2.5	14	2.7
50–60	14	2.9	14	2.8	14	2.7	15	2.6	14	2.4
60–70	14	2.7	14	2.8	14	2.6	14	2.5	14	2.8
70–80	14	2.8	14	2.9	14	2.4	14	2.4	14	2.7
80–90	14	3.1	15	2.8	14	2.4	15	2.5	14	2.3

Tl_2SO_4, 200 p.p.m. in moistening solution, cultures harvested March 20, 1933

Depth	Leached with 37.5 cm H_2O		Leached with 50 cm H_2O		Leached with 75 cm H_2O		Leached with 125 cm H_2O		Leached with 200 cm H_2O	
	Ht.	Wt.	Ht.	Wt.	Ht.	Wt.	Ht.	Wt.	Ht.	Wt.
cm	*cm*	*gm*	*cm*	*gm*	*cm*	*gm*	*cm*	*gm*	*cm*	*gm*
0–10	3	0.1	3	0.1	2	0.1	1	0.1	2	0.1
10–20	15	2.7	15	2.7	15	2.7	14	2.5	14	2.4
20–30	14	2.5	15	2.8	15	2.7	15	2.6	15	2.8
30–40	15	2.6	15	2.8	15	2.8	15	2.7	15	2.9
40–50	16	2.8	16	2.8	16	2.7	15	3.2	16	2.9
50–60	14	2.6	16	2.9	14	2.8	15	2.9	16	3.0
60–70	14	2.8	15	2.9	14	2.7	14	2.9	15	2.8
70–80	15	2.6	15	2.9	15	2.5	15	2.8	16	2.7
80–90	15	2.8	15	2.7	15	2.3	14	2.6	18	3.3

Check tubes moistened with water, cultures harvested March 20, 1933

Depth	Leached with 37.5 cm H_2O		Leached with 50 cm H_2O		Leached with 75 cm H_2O		Leached with 125 cm H_2O		Leached with 200 cm H_2O	
	Ht.	Wt.	Ht.	Wt.	Ht.	Wt.	Ht.	Wt.	Ht.	Wt.
cm	*cm*	*gm*	*cm*	*gm*	*cm*	*gm*	*cm*	*gm*	*cm*	*gm*
0–10	15	2.7	16	2.5	15	2.7	13	2.4	14	2.2
10–20	16	2.9	16	2.7	15	2.7	15	2.7	15	2.5
20–30	15	2.9	17	3.0	15	2.8	15	2.9	15	2.7
30–40	15	2.9	18	3.1	17	2.9	15	2.9	16	3.0
40–50	16	2.9	17	2.8	18	3.1	16	2.8	18	3.0
50–60	15	2.9	18	3.1	17	3.0	17	2.9	18	3.1
60–70	16	2.9	16	2.7	16	3.1	18	2.8	20	3.6
70–80	15	2.8	18	3.0	18	3.0	17	2.7	19	2.8
80–90	16	3.0	18	3.0	17	2.8	18	3.1	17	2.7

* Average weight of plants in 30 untreated checks = 3.5 gm.

TABLE 8

RESULTS OF LEACHING THALLIUM SULFATE IN STOCKTON ADOBE CLAY WITH DIFFERENT DEPTHS OF WATER, AS SHOWN BY GROWTH OF INDICATOR PLANTS*

Tl_2SO_4, 100 p.p.m. in moistening solution, cultures harvested March 5, 1933

Depth	Leached with 5 cm H_2O		Leached with 10 cm H_2O		Leached with 15 cm H_2O		Leached with 20 cm H_2O		Leached with 25 cm H_2O	
	Ht.	Wt.	Ht.	Wt.	Ht.	Wt.	Ht.	Wt.	Ht.	Wt.
cm	*cm*	*gm*	*cm*	*gm*	*cm*	*gm*	*cm*	*gm*	*cm*	*gm*
0–10	5	0.1	5	0.1	7	0.2	7	0.1	7	0.1
10–20	13	1.7	13	1.7	13	2.1	13	1.7	12	1.7
20–30	13	2.0	13	2.1	14	2.1	13	2.1	13	1.9
30–40	13	2.0	13	1.9	14	2.1	14	2.2	13	1.8
40–50	13	1.7	14	2.1	13	1.9	14	2.3	14	2.1
50–60	12	2.0	13	2.0	14	2.2	14	2.0	14	2.2
60–70	14	2.2	14	2.1	14	2.0	14	2.2	14	2.3
70–80	14	2.2	13	2.0	13	2.1	14	2.2	14	2.1
80–90	14	2.2	13	2.2	13	2.0	13	2.1	14	2.3

Tl_2SO_4, 200 p.p.m. in moistening solution, cultures harvested March 20, 1933

Depth	Leached with 37.5 cm H_2O		Leached with 50 cm H_2O		Leached with 75 cm H_2O		Leached with 125 cm H_2O		Leached with 200 cm H_2O	
	Ht.	Wt.	Ht.	Wt.	Ht.	Wt.	Ht.	Wt.	Ht.	Wt.
cm	*cm*	*gm*	*cm*	*gm*	*cm*	*gm*	*cm*	*gm*	*cm*	*gm*
0–10	2	0.1	2	0.1	2	0.1	2	0.1	2	0.1
10–20	18	2.0	15	1.7	15	2.1	15	1.9	18	1.7
20–30	18	2.1	16	1.8	17	1.7	15	1.9	15	1.9
30–40	15	1.6	17	2.1	18	1.9	17	2.0	16	1.9
40–50	17	2.0	17	1.7	16	1.9	18	1.8	16	1.9
50–60	17	1.9	18	1.9	17	1.8	17	2.2	16	1.8
60–70	18	2.0	17	1.7	17	1.9	17	1.8	16	2.1
70–80	17	2.0	17	2.1	17	2.1	16	1.9	17	2.1
80–90	18	2.1	16	1.8	16	1.9	15	1.7	16	1.7

Check tubes moistened with water, cultures harvested March 20, 1933

Depth	Leached with 37.5 cm H_2O		Leached with 50 cm H_2O		Leached with 75 cm H_2O		Leached with 125 cm H_2O		Leached with 200 cm H_2O	
	Ht.	Wt.	Ht.	Wt.	Ht.	Wt.	Ht.	Wt.	Ht.	Wt.
cm	*cm*	*gm*	*cm*	*gm*	*cm*	*gm*	*cm*	*gm*	*cm*	*gm*
0–10	15	1.7	15	1.7	15	1.6	15	1.9	15	2.0
10–20	15	1.6	15	1.7	15	1.7	15	2.0	15	1.9
20–30	15	1.8	15	1.8	15	1.9	15	1.8	15	1.9
30–40	15	1.8	15	1.8	15	1.9	15	2.1	15	1.9
40–50	15	1.8	15	1.8	16	1.9	15	1.7	16	2.1
50–60	15	2.0	15	1.9	16	1.9	15	1.8	15	2.2
60–70	15	1.9	15	1.8	15	1.8	15	1.9	15	1.9
70–80	15	1.9	15	1.8	15	1.8	15	1.9	16	2.1
80–90	16	1.9	15	1.9	15	1.8	15	1.8	15	1.9

* Average weight of plants in 30 untreated checks = 1.9 gm.

TABLE 9

RESULTS OF LEACHING THALLIUM SULFATE IN COLUMBIA FINE SANDY LOAM WITH DIFFERENT DEPTHS OF WATER, AS SHOWN BY GROWTH OF INDICATOR PLANTS*

Tl_2SO_4, 100 p.p.m. in moistening solution, cultures harvested March 23, 1933

Depth	Leached with 5 cm H_2O		Leached with 10 cm H_2O		Leached with 15 cm H_2O		Leached with 20 cm H_2O		Leached with 25 cm H_2O	
	Ht.	Wt.	Ht.	Wt.	Ht.	Wt.	Ht.	Wt.	Ht.	Wt.
cm	*cm*	*gm*	*cm*	*gm*	*cm*	*gm*	*cm*	*gm*	*cm*	*gm*
0–10	5	0.1	7	0.2	10	0.3	18	0.8	18	1.5
10–20	20	3.3	21	3.2	21	3.4	23	3.2	22	3.0
20–30	19	3.2	20	3.1	23	3.4	20	2.8	22	3.4
30–40	19	3.1	23	3.6	22	3.4	22	3.1	23	3.3
40–50	18	3.0	21	3.2	20	2.9	20	3.1	23	2.9
50–60	20	3.8	20	3.3	20	3.0	20	2.9	22	3.1
60–70	23	3.7	19	3.4	19	2.8	20	2.7	21	2.8
70–80	23	3.8	23	3.8	21	3.5	20	2.8	23	3.2
80–90	21	4.3	21	3.7	23	3.9	20	2.8	21	2.7

Tl_2SO_4, 200 p.p.m. in moistening solution, cultures harvested April 4, 1933

Depth	Leached with 37.5 cm H_2O		Leached with 50 cm H_2O		Leached with 75 cm H_2O		Leached with 125 cm H_2O		Leached with 200 cm H_2O	
	Ht.	Wt.	Ht.	Wt.	Ht.	Wt.	Ht.	Wt.	Ht.	Wt.
cm	*cm*	*gm*	*cm*	*gm*	*cm*	*gm*	*cm*	*gm*	*cm*	*gm*
0–10	10	0.3	10	0.7	7	0.6	6	0.5	6	0.3
10–20	15	2.3	18	2.3	18	2.4	18	2.2	18	2.3
20–30	16	2.5	18	2.4	18	2.7	18	2.2	18	2.7
30–40	18	2.2	18	2.5	19	2.3	18	2.8	18	2.3
40–50	18	2.5	20	2.7	18	2.6	18	2.2	17	2.3
50–60	19	2.4	18	2.5	18	2.7	18	2.4	15	2.7
60–70	19	2.4	18	2.5	19	2.8	18	2.6	18	2.9
70–80	18	2.5	18	2.7	18	2.5	19	2.6	18	2.7
80–90	18	2.4	20	2.6	20	2.7	18	2.7	17	2.4

Check tubes moistened with water, cultures harvested April 4, 1933

Depth	Leached with 37.5 cm H_2O		Leached with 50 cm H_2O		Leached with 75 cm H_2O		Leached with 125 cm H_2O		Leached with 200 cm H_2O	
	Ht.	Wt.	Ht.	Wt.	Ht.	Wt.	Ht.	Wt.	Ht.	Wt.
cm	*cm*	*gm*	*cm*	*gm*	*cm*	*gm*	*cm*	*gm*	*cm*	*gm*
0–10	18	2.3	17	2.1	18	2.3	18	2.4	15	2.2
10–20	19	2.4	18	2.2	18	2.2	17	2.2	15	2.0
20–30	18	2.3	18	2.3	18	2.4	18	2.3	16	2.6
30–40	18	2.5	18	2.3	19	2.3	18	2.3	18	2.5
40–50	18	2.7	18	2.3	18	2.3	18	2.6	16	2.1
50–60	18	2.4	19	2.5	18	2.4	19	2.5	18	2.5
60–70	18	2.2	19	2.4	19	2.3	18	2.2	18	2.5
70–80	18	2.3	18	2.3	19	2.2	20	2.6	18	2.4
80–90	18	2.3	19	2.5	20	2.5	19	2.4	18	2.6

* Average weight of plants in 10 untreated checks = 5.5 grams for March 23, 1933, cultures; average of those in 30 untreated checks = 3.1 grams for April 4, 1933, cultures.

stimulated growth found in the lower fractions, with little or no leaching, does not occur. Likewise with the greater amounts of water, there is some indication that when the moistening solution contains only 100 p.p.m. of Tl_2SO_4 the toxicity in the top 10 cm becomes somewhat lessened. When the moistening solution carries 200 p.p.m. of Tl_2SO_4, up to 200 cm of water has no effect upon the toxicity in this top fraction. There is no significant reduction in growth in any of the lower fractions. If leached, the chemical is carried downward in a subtoxic concentration.

With Fresno sandy loam the results are very much the same. Leaching with volumes equivalent to as much as 200 cm of water has no discernible effect upon the location or toxicity of the thallium sulfate within the limits of this experiment. Especially in the less fertile soils, this toxicant is evidently firmly fixed and resists leaching strongly. There is a slight indication that in the Yolo and Columbia soils, where the toxic concentration is higher, when moistening was done with solutions containing 100 p.p.m. of Tl_2SO_4 there was some movement of chemical, and growth was increased. This evidence, however, is hardly conclusive.

Toxicity of Bait.—The next experiments were designed to show the effect of thallium-treated grain upon the growth of adjacent plants. Two types of bait were used: potted barley, which had received the normal treatment[5] with thallium sulfate in preparation for field use, and whole barley similarly treated. Kanota oats were used as the indicator plants. Cans containing 500 grams each of dry Yolo clay loam were moistened and planted with the oats. Then the kernels of treated grain were placed in the soil in the same manner as the oats, the distances between the oats and the poisoned grain being varied. Table 10 summarizes the data on these tests, including checks grown at the same time. The whole treated barley germinated and some of the plants grew (table 10). Since the potted barley was heated in the hulling process, the embryos were killed and the kernels did not germinate when planted.

There were planted 470 treated barley seeds in all these tests, of which 246 grew, a survival of practically 50 per cent. These 246 plants weighed 129.9 grams, the average fresh weight per plant being 0.53 gram, 47 per cent of that of the untreated check barley.

In the experiments on the effects of the thallium-treated grain on oat plants, the variation in number of plants per can renders the average weight per plant of little value; but the average total fresh weight per can of oats grown is a fair basis for comparison. These data show that with the 0.25-cm spacing the growth is about 30 per cent less than that of the check plants of untreated oats; with the wider spacing no significant

[5] This treated grain carried 1 per cent Tl_2SO_4 by weight.

differences can be detected. Evidently the sterilizing effect of thallium-coated grain broadcast on the land as bait will be strictly localized and, if the bait is properly scattered, little or no reduction in the natural growth of plants should occur, even if the grain remained on the land through the winter following the application.

TABLE 10

EFFECTS OF THALLIUM-TREATED GRAIN UPON ADJACENT PLANTS IN YOLO CLAY LOAM

Spacing of plants	Description of plants	Total number of plants	Average number of plants per can	Total fresh weight	Average fresh weight per can	Average fresh weight per plant
	Whole barley tests					
cm				*gm*	*gm*	*gm*
	Treated whole barley	38	7.6	16.4	3.28	0.43
0.25	Oats, indicator plants	37	7.4	23.5	4.70	0.63
	Barley and oats—5 cans	75	15.0	39.9	7.98	0.53
	Treated whole barley	59	11.8	18.7	3.74	0.32
0.50	Oats, indicator plants	56	11.2	39.9	7.98	0.71
	Barley and oats—5 cans	115	23.0	58.6	11.72	0.51
	Treated whole barley	35	7.0	14.0	2.80	0.40
1.00	Oats, indicator plants	59	11.8	45.6	9.12	0.77
	Barley and oats—5 cans	94	18.8	59.6	11.92	0.63
	Treated whole barley	33	3.3	16.8	1.68	0.51
2.00	Oats, indicator plants	77	7.7	91.8	9.18	1.19
	Barley and oats—10 cans	110	11.0	108.6	10.86	0.99
	Potted barley tests*					
cm				*gm*	*gm*	*gm*
0.25	Oats, total 5 cans	50	10.0	41.9	8.38	0.84
0.50	Oats, total 5 cans	58	11.6	46.0	9.20	0.79
1.00	Oats, total 5 cans	79	15.8	56.2	11.24	0.71
2.00	Oats, total 10 cans	76	7.6	94.9	9.49	1.25
	Check plants					
				gm	*gm*	*gm*
	Treated whole barley	81	8.1	64.0	6.40	0.79
	Untreated whole barley	100	10.0	113.2	11.32	1.13
	Untreated oats	100	10.0	117.6	11.76	1.18

* Growth of indicator oats. Potted barley, being heated in the hulling process, does not germinate.

Another series of tests was made in the greenhouse to find the effect of thallium-coated grain upon growing oats, the bait being applied 10 days after the oats were planted. Twenty cans of Yolo clay loam were moistened and planted on February 7, 1933. The seeds germinated on February 11, and the seedlings were growing rapidly by February 12. On February 17 eight cans received thallium-coated grain (potted-barley bait) in varying dosages, eight cans received equivalent dosages of thallium sulfate, applied in solution, and four cans remained as checks. The data on these series are given in table 11. The cultures were watered every 2 or 3 days, and the chlorosis characteristic of thallium injury soon appeared. The plants that received the larger doses of thallium sulfate continued to show injury in the cultures, but those receiving less of the chemical showed some signs of recovery toward the end of the test. Judging from these figures, very large dosages of poisoned barley would be required to affect the existing growth of plants in the field. There was a significant difference between the effects of the thallium from the two different methods of application. Apparently the chemical is absorbed by the potted barley and held so that it will not wash off. In these tests the bait lay on top of the soil and was flooded with each irrigation. Probably the chemical that did wash off was quickly fixed in the soil, above the zone of active roots.

TABLE 11

EFFECT OF THALLIUM SULFATE FROM BAIT AND IN SOLUTION ON GROWING PLANTS

Tl_2SO_4*			Bait treatment				Solution treatment, growth of plants†	
			Potted barley*		Growth of plants†			
Per culture	Per acre	P.p.m. of air-dry soil	Per culture	Per acre	Height	Weight	Height	Weight
gm	*lbs.*	*p.p.m.*	*gm*	*lbs.*	*cm*	*gm*	*cm*	*gm*
0.0	0.0	0.0	0.0	0	25	10.7	24	10.0
0.0	0.0	0.0	0.0	0	25	10.9	25	10.4
0.005	8.3	10.0	0.5	830	25	11.0	25	11.3
0.010	16.6	20.0	1.0	1,660	25	10.7	25	11.2
0.025	41.5	50.0	2.5	4,150	25	10.9	24	11.0
0.050	83.0	100.0	5.0	8,300	25	10.0	25	9.2
0.100	166.0	200.0	10.0	16,600	23	8.7	23	4.9
0.150	249.0	300.0	15.0	24,900	23	9.1	20	4.5
0.200	332.0	400.0	20.0	33,200	23	7.9	20	4.6
0.300	498.0	600.0	30.0	49,800	21	5.9	15	1.4

* In the bait treatment, the thallium sulfate was applied by means of thallium-coated grain; the amount of grain applied to give the dosage is reported in the fourth column.

† Plants per can = 10.

Field-Plot Tests.—One further experiment was made with thallium-coated grain on square-foot plots in the field. In an enclosure in the corner of a pasture two areas covering approximately 49 square feet each were laid out. After the plots had been treated, the whole was covered with a cage of ¼-inch mesh galvanized hardware cloth. The treatments were made on February 10, 1933, and the areas were harvested on May 4. Table 12 gives the dosages and weights of harvested plants on these plots.

Two sets of plots were laid out, each on a checkerboard pattern, and all intervening areas were harvested as checks.

The only plots in this test showing significant reductions in yield are Nos. 23 and 48. These received 28.35 grams or 1 ounce each of poisoned grain, scattered evenly over the square-foot area. The cover of grass and range plants was noticeably thinner on these areas. The grain on plots

TABLE 12

The Effect of Thallium-Sulfate-Treated Grain upon Growing Pasture Plants

Plot No.	Dosage per sq. ft.	Fresh weight of crop	Plot No.	Dosage per sq. ft.	Fresh weight of crop
	gm	*gm*		*gm*	*gm*
1	0.22	153.35	26	0.22	76.30
2	check	102.35	27	check	78.00
3	0.44	129.30	28	0.44	105.20
4	check	121.80	29	check	135.15
5	0.89	137.70	30	0.89	105.00
6	check	163.10	31	check	101.35
7	check	121.80	32	check	103.25
8	check	151.60	33	check	115.45
9	check	111.80	34	check	114.85
10	check	115.10	35	check	167.75
11	1.77	130.35	36	1.77	124.85
12	check	85.15	37	check	96.00
13	3.54	125.00	38	3.54	159.80
14	check	123.55	39	check	127.35
15	7.09	111.65	40	7.09	150.75
16	check	120.45	41	check	137.60
17	check	129.65	42	check	130.90
18	check	154.30	43	check	158.65
19	check	163.10	44	check	115.65
20	check	147.15	45	check	136.70
21	14.17	104.85	46	14.17	114.90
22	check	106.10	47	check	95.75
23	28.35	85.30	48	28.35	87.60
24	check	155.10	49	check	164.55
25	56.70	112.45	50	56.70	145.10

25 and 50 was piled in the center of each plot; but the area actually covered was so small that, although bare of vegetation, it had little effect on the yield of the total plot. No. 25 is somewhat reduced in comparison with Nos. 20 and 24, the two adjacent check plots. No. 50 shows no significant reduction. After these plots were laid out, 2.91 inches of rain fell; and the thallium chlorosis could be observed on the plants of the more heavily treated plots while they were young. As the season advanced they seemed to recover; and at harvest time little permanent injury was found, except as noted above. The following year, when these plots were harvested again no significant differences in yield were found on any of them.

DISCUSSION

The physiological effect of thallium upon plants has not been studied extensively. The differential effect upon the growth rate of shoot and coleoptile of oats is shown in table 3. Since the shoot is formed by cell division in the embryo, whereas the coleoptile develops mainly by enlargement of previously formed cells, meristematic regions may respond characteristically to this element. Chlorosis of older tissues seems to be a constant symptom of thallium poisoning but may be entirely secondary.

Some excellent work has been done at Charles University in Prague by Prat and his colleagues (*5*) on the absorption of thallium salts from water and from nutrient solutions by plants. Using broad beans and corn, these workers found that practically all the chemical was absorbed within 72 hours from a $TlNO_3$ solution 1×10^{-4} molecular in concentration. The plants died in 2 to 4 days. The same amount of thallium nitrate in a nutrient solution (Shive R_5C_2) had little effect on the plants. Although they absorbed the nutrient salts, the thallium remained in the solution unchanged in amount for 5 to 10 days, and only 10 per cent to 40 per cent was absorbed in 13 days. Whereas plants readily absorb thallium from pure water solution, but little was taken up from nutrient solutions or from balanced solutions containing $CaCl_2$.

These workers (*5*) also found a definite effect of thallium upon meristematic cells. These cells take on a mature appearance, and division becomes abnormal and ceases after 48 hours. The illustrations given by them show a pronounced stunting of the roots of plants affected by thallium; large necrotic areas appear on the primary root, and many secondary roots are killed. These effects are much less evident on the plants from the nutrient solutions. Apparently little thallium should be absorbed from soils, especially from those favorable for plant growth.

The writer ashed the tops of several plants that were chlorotic from the presence of thallium in the soil. The ash, moistened with a few drops of concentrated HCl, was heated to dryness and extracted with $\frac{N}{10}$ HCl. A sample of the supernatant liquid was sent to Heyrovsky for analysis by means of the Polarograph. Heyrovsky[6] replied concerning the sample: "I could not ascertain any thallium in it." This statement checks with the results of the workers at Prague. Apparently the chlorosis may be a secondary response to the effect of thallium upon the roots. If this element is present in the tops of affected plants, it occurs in such minute amounts that the sensitive Polarograph method cannot detect it. The

[6] Personal correspondence from Professor J. Heyrovsky, June 5, 1933.

roots of these plants were small and unhealthy. Often the plants could be pulled out of the soil, most of the roots breaking off or the xylem pulling out, leaving the cortical tissue behind.

Evidently thallium is very toxic to plants that are growing in water or in poorly balanced solutions. As table 2 indicates, the toxicity of this element varies in different soils, being less toxic in those which are most fertile. Probably lack of fertility reflects a condition in the soil solution that favors absorption of the poison much as does distilled water. Whether this condition is caused by a deficiency in certain mineral nutrients is hard to say without further study; but the assumption seems reasonably well justified, at least in the soils under consideration.

The workers at Prague (*5*) found appreciable injury to roots of plants in a nutrient solution (Shive R_5C_2 conc. 0.88 Atm.) containing 1×10^{-4} molecular $TlNO_3$. In distilled water containing a like amount of thallium, the plants soon died. This concentration of $TlNO_3$ corresponds to about 27 p.p.m. in the solution.

In Yolo clay loam (table 2) about 50 per cent growth took place at 60 p.p.m. in the soil, and complete sterility occurred at 240 p.p.m. The corresponding concentrations in the less fertile soil are roughly 46 p.p.m. and 131 p.p.m. The concentrations in the soil solution at field capacity would be three times as great in Yolo clay loam and up to six times as great in lighter soils. Apparently the fixation of thallium compounds in soils renders them less available to plants than they are in solutions. This factor, in addition to the antagonistic action in the balanced solution, makes the critical concentrations in soils fairly high. For complete sterility, apparently, the thallium concentration in the soil must reach 100 p.p.m. or more on a basis of Tl_2SO_4. For fertile soils it would be even somewhat higher.

McCool (*4*) found much higher toxicities in his experiments. Though his method of mixing the chemical in the soil is questionable, probably the more important factors causing these differences were the soils and plant species used. Soils from the humid eastern United States probably compare more nearly with the Fresno and Stockton soils in fertility than with the recent alluvial Yolo and Columbia series. Toxicities would undoubtedly run high in the former soils. On the average, furthermore, the cultivated varieties of plants used by McCool were probably more susceptible than the oats used in the experiments here reported. Most range plants in California would probably be even more tolerant of thallium sulfate in the soil.

Two vital factors are involved in the problem of soil sterility as related to the control of rodents by thallium-treated grain. The first is the quantity of thallium being placed on the soil per unit area; the second is the final disposition of this poison. To render a soil sterile against annual weeds, one must provide a minimum toxic concentration of the chemical in at least the top inch. An acre-inch of soil weighs roughly 300,000 pounds, and 30 pounds of Tl_2SO_4 would be required to render it sterile. For a 50 per cent reduction in growth, 15 pounds would be needed. Perennial plants would be little affected by even larger doses than this. Considering the fixing power of soils for thallium compounds, even greater amounts of the chemical would be necessary for complete sterilization.

From the high saturation capacity indicated by the data in table 5, an acre-inch of soil could hold up to one hundred times the amount of thallium sulfate required to render it sterile. This fact is important in relation to the distribution of the chemical in rodent control. The usual practice in distributing the bait is to spread one spoonful[7] containing about 20 grams of poisoned grain over an area of 3 to 6 square feet. A bait contains approximately 400 kernels. If each of these was able to sterilize 1 square centimeter (table 10), then seven to fourteen applications would be required to cover the original 3 to 6 square feet, and over 100,000 baits to cover an acre. This would be equivalent to roughly 5,000 pounds of grain bearing 50 pounds of Tl_2SO_4, and a lethal concentration of the chemical would be provided in the top 1.2 cm of soil if evenly distributed. The actual depth of penetration would probably be much less than this, and many seeds should be able to germinate and grow from below this level. Table 10 also shows that there would be no effect during the first year.

These calculations have been based on the sterilizing capacity of baits lying on the surface of the soil. If the baits were eaten by rodents, the chemical would be distributed, by death of the squirrels, more or less at random, through the top several feet of soil; and immensely greater amounts of thallium would obviously be required to have any appreciable effect. Only animals dying on the surface would leave the thallium in a position to affect the top soil. Such an occasion is rare.

When the problem is viewed from the standpoint of field practice, the disparity between the figures given above and the actual amounts used in rodent control is striking. In an initial campaign with thallium-treated bait, average dosage may run up to a pound of grain per acre or more. Because of the effectiveness of this poison, however, the dosage may be rapidly reduced. In one California county the average dosage had decreased to 1/35 of a pound of bait per acre in five years. Since this

[7] A standardized spoon of definite size is used for this purpose.

bait carried only 1 per cent Tl_2SO_4 by weight, evidently the chemical reaching the soil is negligible as compared with that required for sterilization.

Though the results of these studies are of little value in the actual field of soil sterilization and are mostly negative in relation to the rodent-control problem, one point seems noteworthy. If sterilization of soil by thallium-treated grain should ever occur, it would result from the accumulation of untaken baits. This grain would also be a source of danger to other animals and would represent a waste of material. This poison, therefore, should be handled by competent and experienced men so that the majority of baits will be placed where they will be taken. If this precaution is observed, soil sterilization is not a factor in the control of ground squirrels with thallium-treated grain.

It is regrettable that such warnings as those of Brooks (*1*, p. 106) and McCool (*4*, p. 295) should be issued without some preliminary study of the actual field practice involved.

SUMMARY

Experiments indicate that thallium sulfate is very toxic in soils. Thirty pounds will sterilize an acre-inch of average soil. Toxicity decreases, however, with time and cropping.

Thallium toxicity varies with soil type, a range of three times or more having been shown in the soils studied.

The toxicity of thallium is greater in soils low in fertility. It cannot be correlated with the soil type nor with water-holding capacity.

Thallium toxicity is evidenced by retarded shoot growth, a nearly normal development of the coleoptile, chlorosis of leaves, stunting of older plants, and early death where the concentrations are high.

Thallium sulfate was strongly fixed in four soils. The saturation capacity of Yolo clay loam for this chemical was about 10,000 p.p.m. on a dry-weight basis.

Leaching with as much as 200 cm of distilled water had practically no effect upon the thallium toxicity in these soils.

Thallium-treated barley, as commonly used for squirrel bait, had little or no effect upon germination or growth of oats planted in the same can and spaced within 0.5 cm of the grains. Growth was reduced when the spacing was 0.25 cm. Thallium-treated whole barley gave a 50 per cent germination, and the fresh weight of the seedlings at 30 days was 47 per cent of that of the checks.

Oat seedlings were unaffected by the application of treated barley to the soil, followed by irrigation, except where the dose was excessive.

Thallium-treated barley also had little effect upon growing plants in a pasture area. The heaviest application, equivalent to over 2,500 pounds of grain to the acre, reduced the growth less than 50 per cent.

Workers at Charles University, Prague (*5*), have shown that plants do not readily absorb thallium salts from balanced nutrient solutions. Ashed plants from the test here reported failed to give a thallium test by the sensitive Polarograph method of Heyrovsky.

Thallium sulfate in concentrations of 100 p.p.m. or more on a dry-weight basis should be completely toxic in most soils. The concentration at saturation would be around a hundred times this value.

About 30 pounds of thallium sulfate uniformly distributed would be required to sterilize an acre-inch of soil. Under natural conditions of application it would probably be tied up in a much shallower layer of soil. At least 5,000 pounds of squirrel bait, carrying 1 per cent Tl_2SO_4 uniformly distributed, would be necessary to sterilize an acre completely.

If the baits are taken by squirrels, the thallium is distributed at random in localized regions in the top several feet of soil. Under these conditions the dosage mentioned above would give no sterilization except where an animal might die on the surface.

In actual field practice, dosage seldom exceeds 1 pound of thallium-treated grain per acre, bearing 0.01 pound of Tl_2SO_4. Dosage rapidly decreases as the rodents are brought under control.

The differences between these rates of dosage and those mentioned above show that little need be feared from the sterilization of soils by thallium-treated squirrel bait.

LITERATURE CITED

[1]Brooks, S. C.
1932. Thallium poisoning and soil fertility. Science 75:105–06.

[2] Crafts, A. S.
1934. The effects of thallium sulfate upon soils. Science 79(2038):62.

[3] Crafts, A. S.
1935. The toxicity of sodium arsenite and sodium chlorate in four California soils. Hilgardia 9(9):459–98.

[4] McCool, M. M.
1933. Effect of thallium sulfate on the growth of several plants and on nitrification in soils. Boyce Thompson Inst. Contrib. 5(3):289–96.

[5] Prat, S., J. Babicka, and I. Polivkova.
1932. The resorption of mineral salts by roots. Publication de la Faculte des Sciences de L'Universite Charles. C 121:1–23.