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THE EFFECT OF THALLIUM ON PLANT GROWTH

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INTRODUCTION

For more than 10 years thallium compounds have proved useful in the control of the rat, the Zuni prairie dog, the California ground squirrel, and certain rodents that have been found particularly difficult to combat by other means. Several reviews have appeared discussing general features of the action of thallium and of its use in rodent control (7, 12, 19). Böttger (3) reported it to be widely distributed in the vegetable kingdom, finding it qualitatively in certain mineral waters, wines, tobacco, beets, and chicory, but no published data have been found showing the occurrence of thallium in the soil. Buschke and Langer (6) stated that plants may take up thallium from the ground, since they found traces in the plant ash, and that if rat poison should be used on field or garden the thallium would pass into the plants and might cause poisoning.

The question has been raised in several recent papers whether thallium applications to pasture lands in the control of ground squirrels under field conditions will prove harmful to crop growth (4, 8, 14, 15). This subject has been studied in detail for more than 10 years, and the official agencies engaged in the distribution of thallium-treated material have always had this in mind (12).

REVIEW OF LITERATURE

A detailed search of the literature shows that it is not possible to make any arbitrary statement regarding the toxicity of thallium to plants or animals, unless a number of circumstances are considered. Detailed data found in this search are recorded in table 1, with corresponding references to the literature, and results obtained by the authors also are included.

1 Italic numbers in parentheses refer to Literature Cited, p. 7.
Table 1.—Action of thallium on plant growth

[Data from literature indicated by references; concentrations calculated as parts of Tl per million]

<table>
<thead>
<tr>
<th>Test plants and materials</th>
<th>Medium</th>
<th>Concentration affecting growth</th>
<th>Literatures references</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Stimulates Normal Retards Inhibits or stops</td>
<td></td>
</tr>
<tr>
<td><strong>Escherichia coli</strong></td>
<td>Water</td>
<td>0.1-1.6 12.5 1,500</td>
<td>5</td>
</tr>
<tr>
<td>Bacillus lactic acid</td>
<td>Milk</td>
<td>8.0-8.0  80</td>
<td>22</td>
</tr>
<tr>
<td>Fomes annosus</td>
<td>Culture</td>
<td>0.1-3.8  16-160</td>
<td>10, 13</td>
</tr>
<tr>
<td>Mold fungi</td>
<td>Agar jelly</td>
<td>0.08-0.8  80</td>
<td>21</td>
</tr>
<tr>
<td>Yeasts</td>
<td>Asparagus</td>
<td>800-2,000 2,000</td>
<td>22</td>
</tr>
<tr>
<td>Do</td>
<td>Soil</td>
<td>340</td>
<td>9</td>
</tr>
<tr>
<td>Lepidium salivarium</td>
<td>Water</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>Viola faba</td>
<td>Water (distilled)</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>Lupinus albus</td>
<td>do</td>
<td>1</td>
<td>20</td>
</tr>
<tr>
<td>Zea Mays</td>
<td>do</td>
<td>1</td>
<td>20</td>
</tr>
<tr>
<td>Nicotiana tabacum</td>
<td>Water</td>
<td>1</td>
<td>16</td>
</tr>
<tr>
<td>Do</td>
<td>Soil</td>
<td>25-60</td>
<td>16</td>
</tr>
<tr>
<td>Zea mays</td>
<td>do</td>
<td>10-80</td>
<td>10,000</td>
</tr>
<tr>
<td>Triticum aestivum</td>
<td>do</td>
<td>1.5-7.0 30-80</td>
<td>15</td>
</tr>
<tr>
<td>Fagopyrum esculentum</td>
<td>do</td>
<td>1.5-7.0 30-80</td>
<td>15</td>
</tr>
<tr>
<td>Medicago sativa</td>
<td>do</td>
<td>1.5-7.0 30-80</td>
<td>15</td>
</tr>
<tr>
<td>Lathium perenne</td>
<td>do</td>
<td>1.5-7.0 30-80</td>
<td>15</td>
</tr>
<tr>
<td>Soja mar</td>
<td>do</td>
<td>1.5-7.0 30-80</td>
<td>15</td>
</tr>
<tr>
<td>Arena sativa</td>
<td>do</td>
<td>22,000</td>
<td>1,000</td>
</tr>
<tr>
<td>Triticum sp</td>
<td>do</td>
<td>1</td>
<td>1,000-10,000</td>
</tr>
<tr>
<td>Phleum pratense</td>
<td>do</td>
<td>100</td>
<td>1,000</td>
</tr>
<tr>
<td>General range plants</td>
<td>do</td>
<td>8</td>
<td>80</td>
</tr>
</tbody>
</table>

1 See footnote 1, p. 1.
2 Also personal communications from Moir.
3 Authors' data.

The metal thallium has a bacteriostatic action on *Escherichia coli*, *Bacillus typhosus*, *B. dysentery*, *E. streptococci*, and *E. staphylococci*. This action is exerted only in the presence of oxygen and is attributed to oxidation to the hydroxide. To inhibit the growth of *E. coli* (5), concentrations of thallous acetate or carbonate of the order of 1,000 milligrams per liter (1,000 parts per million) are required. Morris (18) found that thallous carbonate has a phenol coefficient of 6.5. Thallous carbonate, nitrate, and sulphate in a starch or farina agar jelly prevented the growth of various mold fungi (10, 19). Organic thallium compounds were ineffective. In checking the growth of the fungus *Fomes annosus*, Bateman (2) found that thallous sulphate was half as toxic as mercuric chloride and three times as toxic as silver nitrate.

Schulz (23) showed in 1886 that thallous sulphate or tartrate in sterile gelatin meat broth or sugar solution had a marked effect upon the activity of yeasts. In 5 hours yeast growth on sugar solution (measured by CO₂ production) showed definite stimulation. In a similar study, Richet (22) made more than 2,500 tests of the influence of thallous nitrate on lactic acid fermentation. He showed that there is a sudden hereditary mutation of the organism. Concentrations of 2,750 mg per liter appeared to be the upper limit of habituation. Habituated organisms showed decreased growth in thallium-free media.

The growth of yeast is stimulated by low concentrations of thallium salts, but inhibited by strong solutions (17, p. 456; 21; 22). Richards (21) found that thallium may be one of the growth stimulants for yeast that has been referred to as "bios", but on account of its toxicity it should not be added to a medium when yeast is to be used.
as a food for man. Certain samples of commercial asparagine contained thallium.

The effect of thallium compounds on the germination of seeds and the growth of plants in pot cultures has been reported (9, 13, 15, 16, 20). Germination or growth of the seed of *Lepidium sativum* was completely prevented by 340 parts of Tl per million (9). Seedlings of *Vicia faba, Lupinus albus,* and *Zea mays* showed slight growth but died in 2 to 4 days. Practically all the thallium had been resorbed from solution in 24 to 72 hours. In the same concentration in Shive's solution, plants exposed to thallium compounds grew nearly as well as the checks, and the thallium concentration was unchanged during 10 days. There was no relation between the quantity of thallium present and the development of the root surface. Equimolar solutions of cadmium nitrate, chloride, or sulphate were more toxic than thallium solutions (20). In solution or pot cultures certain concentrations of thallium salts produced symptoms resembling "frenching" in tobacco plants. In many instances the stem was killed at the surface of the soil. This was attributed to the direct application of the solution, which was not leached to any considerable extent from the surface layers (16). The growth of wheat, buckwheat, alfalfa, rye, and soybean plants was slightly retarded by 1.5 to 7 parts of Tl per million (table 1). Wax beans were somewhat more resistant. The injury was greatest in sandy loam soil. Leaching did not prevent the harmful action that appeared to be associated with an alteration in the base equilibrium, with the liberation of aluminum and calcium (15).

Perhaps the most striking results in studies of the toxicity of various metallic salts to seedlings have been attained with copper sulphate. These results are of special interest because of the wide-spread use of copper compounds as fungicides. Kanda (11) reported that 0.000,000,0249 percent solutions of copper sulphate (a concentration of 1 in 4,000,000,000) definitely checked the growth of seedlings of peas, broadbeans, and buckwheat. No comparable studies on thallium compounds were reported by him, but this would suggest that copper is several hundred thousand times as poisonous to the growth of plant seedlings as is thallium.

Brooks (4, p. 106) stated that a bait containing 0.5 g of thallous sulphate was suspended on stakes a few inches above the grassy slope in an arboretum in the Hawaii Sugar Planters' Association in July 1929. In July 1931 there was a patch of bare earth 1 to 3 feet long and perhaps one-third as wide.

Not a single trace of plant life was or had been apparent on these areas during the intervening 2 years * * *. One bait, containing 0.5 gm of *Tl* *S* *O* *d* would under average conditions sterilize not less than half a cubic foot of soil.

He concluded: Continued scattering of thallium sulphate baits will presumably lead to: "(a) complete denudation of numerous small areas of pasture or range land * * * (b) General toxicity or complete sterility of cultivated land * * *". This was so greatly at variance with the writers' observations in California and elsewhere, where thalgrain (grain coated with 1 pound of thallous sulphate per 100 pounds) has been exposed, that contact was established with the Hawaiian authorities to learn more about this.
Barnum (1) showed that the concentration of thallous sulphate proving effective was 1 pound per 1,000 pounds of grain, or one-tenth of the concentration needed for effective control in California. He furnished the following statement: 2

The observed and much heralded destruction of vegetation which has been reported from Hawaii was induced unintentionally by myself as follows: At the request of Dr. H. L. Lyons of this Station, poison bait was prepared in July 1931, to control a small population of mongoose in the Manoa Arboretum. These animals threatened extinction of a number of imported birds released sometime prior in this region. The preparation was made by mixing 1 lb. of ground fresh meat with 32 gms. of \( \text{Tl}_2\text{SO}_4 \). From the mixture torpedoes, each containing 1 full spoon of the mixture, were made of small sheets of paper. The torpedoes were distributed in suitable places, near wooden markers, in the Arboretum. Some were eaten; others remained and decomposed in the grass, kept green by the daily rains. Small areas of grass surrounding these uneaten torpedoes were killed and the areas remained denuded for several months. I have never seen the same effect following thallium-wheat applications in cornfields. The dosage in the meat balls was much higher than that commonly used in treatment of grain. The protein mixture may have been toxic in itself.

A small test was laid out wherein 0-5-10-15 gms. of \( \text{Tl}_2\text{SO}_4 \) per L. of water were applied to grass spots of approximately 1 sq. yd. each, but no permanent toxic herbicidal values were obtained.

Of personal communications received from a number of individuals who have used thallous sulphate mixtures, a typical report is that of John T. Moir, manager of the Koloa Sugar Co., Koloa, Hawaii: 3

We have never noted any damage to field crops attributable to the thallium-sulfate-poison rat baits. The bulk of our rat bait is distributed along field edges. As a result the same areas have received repeated doses although not in the same exact spot, perhaps. No killing of vegetation has been noted. In fact, weeds continue as strong as ever.

While this investigation was in progress, Crafts (8) published an abstract of his studies on the effect of thallous sulphate on four California soils. He found that soils varied in their power of fixing thallium. Thalgrain had no effect on the germination or growth of oats one-half centimeter away; if one-fourth centimeter away, growth was reduced. "Except where the dosage was excessive, oat seedlings were unaffected by the application of treated barley to the soil, followed by irrigation." The heaviest application, equivalent to 27 pounds of thallous sulphate per acre, reduced growth less than 50 percent. The application of 5,000 pounds of poisoned grain per acre might sterilize the top 1.5 inches. However, the average initial dosage of poisoned grain is only one-third pound per acre, and this is decreased later to one thirty-fifth pound or less. He concluded:

The success of this material should permit similar reductions in other regions, so that the amount of chemical becomes totally insignificant so far as soil sterilization is concerned. The writer observed no loss in fertility in range lands successfully treated for 5 successive years. The only denuded areas found were the open burrows, fresh mounds, and beaten trails of squirrels in untreated fields. Regardless of other objections to thallium compounds in rodent control, the possibility of losing agriculturally valuable land through sterilization seems remote.

**EXPERIMENTS**

In order to determine the effect of thallium on plant growth under controlled conditions, a double investigation was undertaken, one part in the laboratory and the other in the field.

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1 Personal communication, Sept. 12, 1933.
2 Personal communication, Apr. 2, 1932.
EFFECT OF THALLIUM ON PLANT GROWTH

LABORATORY INVESTIGATIONS

Experiments on a laboratory scale were conducted on loam soil in trays and in pots at Denver, Colo., over a period of a year. In series 1, the seed of peas, sweet corn, field corn, clover, and timothy were planted in trays 6 by 6 by 3 inches.

In control trays these were allowed to germinate over a period of 2 months, which established the rate of normal growth. On the sixty-first day a solution containing 49 mg of thallium (in the form of Tl₂SO₄) was applied once to each tray. This represents the average quantity of thallium that might be applied in an ordinary bait spot of thallgrain placed in ground-squirrel control. No detrimental effects on plant growth were noted in these trays.

Seeds in other trays were handled similarly, except that 49 mg of thallium per tray were mixed with the soil before the seeds were planted. Germination was delayed and reduced in all these trays, and after slow growth all plants died.

Seeds in other trays were allowed to germinate and grow normally for 12 days and then were irrigated with a solution containing 100 mg of thallium per liter (in the form of Tl₂SO₄) on the twelfth, twentieth, twenty-seventh, and thirty-third days. Each irrigation contained 100 mg of thallium, so that a total of 400 mg of thallium was applied to each tray over a period of about a month. This completely inhibited vegetative growth.

These laboratory results suggest that thallium is toxic to the germinating plant but not to the growing plant, except in strong concentrations.

In series 2, in a large mixer, 0, 5, 10, 100, 1,000, and 10,000 mg of thallium per kilogram (as Tl₂SO₄) were thoroughly mixed with loam soil and three lots of each were placed in 1-gallon jars. The surface soil was then prepared for planting, and 12 corn seeds, 1 g of timothy, or 1.5 g of clover were planted in each jar. The 18 jars were then watered from time to time. With the soils containing 5 and 10 mg of thallium per kilogram the growth of corn was definitely stimulated; the clover was somewhat less stimulated; and the timothy showed some slight stimulation in later growth. In soils containing 100 mg per kilogram or more, toxic effects were noted with all seedlings. A concentration of 1,000 mg per kilogram stopped the germination of timothy, and 10,000 mg per kilogram stopped the germination of corn and clover. These results would suggest that thallium is beneficial to plant growth when present to the extent of 5 to 10 mg per kilogram of soil; that the toxic effect begins to develop with concentrations of 100 to 1,000 mg per kilogram; and that 10,000 mg per kilogram of soil are necessary to prevent germination.

FIELD INVESTIGATIONS

Field studies were made on typical areas of plant growth in California, the thallium being applied in the form of thallous sulphate directly to the soil, either as a dry salt, in irrigation water, or as thallgrain. The regular thallgrain for ground-squirrel control was used in these experiments, and only the thallgrain results are incorporated in this report. Every attempt was made to duplicate the conditions under which it is commonly employed in rodent-control operations, to learn what damage (if any) might follow routine rodent-control
procedure. In the original treatment of an infested area an average of 1 pound of thalgrain per acre is used for the first treatment, and one-fifth to one-tenth pound per acre on subsequent treatments. Normally 27 g of thalgrain are distributed over an area of 2 to 4 square feet around ground-squirrel burrows. Since 1 pound of thalgrain is sufficient for 16 bait spots, it will actually cover 32 square feet, on the basis of the strongest concentration. If the entire acre were covered, approximately 13 pounds of thallous sulphate, or 10 pounds of thallium, would be required.

In March 1932, on a typical range area in Santa Clara County, Calif., 8 quadrats with suitable checks were established, each quadrat 2 feet square. All vegetation in each was listed and mapped for density and for percentage of the entire vegetative growth, density being tabulated on the basis of 10 as complete coverage. On these quadrats the soil was Altamont clay loam, but comparative studies with other types of California soil gave identical results.

The quantity of thalgrain applied to each quadrat and the thallium content are given in table 2. There was no rain from March 1932, when the thalgrain was distributed, until the following December. No damage was detected to any plants growing in the quadrats; all developed, matured, and died on the treated as well as on the control quadrats. In March 1933, following the winter rains, or 1 year after the distribution of thalgrain on the quadrats, the composition and the density of vegetative growth was redetermined for each quadrat and compared with the original values.

<table>
<thead>
<tr>
<th>Quadrat no.</th>
<th>Thalgrain per acre</th>
<th>Thallous sulphate per acre</th>
<th>Vegetative density (10.0=total cover)</th>
<th>Quadrat no.</th>
<th>Thalgrain per acre</th>
<th>Thallous sulphate per acre</th>
<th>Vegetative density (10.0=total cover)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pounds</td>
<td>Pounds</td>
<td>Original</td>
<td>After 1 year</td>
<td>Pounds</td>
<td>Pounds</td>
<td>Original</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>0</td>
<td>10.0</td>
<td>10.0</td>
<td>5</td>
<td>3,000</td>
<td>50</td>
</tr>
<tr>
<td>2</td>
<td>1,000</td>
<td>10</td>
<td>7.0</td>
<td>8.0</td>
<td>6</td>
<td>7,000</td>
<td>75</td>
</tr>
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<td>3</td>
<td>2,000</td>
<td>20</td>
<td>6.0</td>
<td>2.0</td>
<td>7</td>
<td>10,000</td>
<td>100</td>
</tr>
<tr>
<td>4</td>
<td>3,000</td>
<td>30</td>
<td>7.0</td>
<td>0.5</td>
<td>8</td>
<td>20,000</td>
<td>200</td>
</tr>
</tbody>
</table>

These quadrat experiments show that very high concentrations of thalgrain, when left on the surface of the ground throughout a year cause inhibiting effects on growth of vegetation. A marked decrease in plant growth was observed following the application of 3,000 pounds or more of thalgrain per acre. Some decrease in vegetative growth was observable when 20 to 30 pounds of thallous sulphate per acre were applied, corresponding to 2,000 to 3,000 pounds of thalgrain per acre. In interpreting these figures it must be remembered that in control work the maximum application of thalgrain in the original treatment is only 1 pound per acre, but that this is applied to so limited a portion of the entire surface that it would correspond to approximately 1,000 pounds of thalgrain per acre if the entire area were covered. This quantity caused a slight stimulation in vegetative growth on the treated quadrat. It must also be remembered that thalgrain is distributed only when the animals to be controlled will take it rapidly. Usually nine-tenths of the baits are eaten
during the first day, and practically all within a week. Therefore, the distributed thallium is removed from the surface before it can produce any effect on the vegetation.

Repeated studies of range areas treated as often as nine times failed to show any damage to vegetation. With removal of the ground squirrels the soil returns to a proper condition, and normal plant growth rapidly occurs. In general, the use of thallium in rodent control has consistently increased the growth of vegetation from 10 to 25 percent, without any evidence of damage to soil fertility.

A few experiments were conducted to determine whether thallium compounds would prove suitable as weed killers. Ribes were placed in pots of soil and treated with varying concentrations of thallium, up to the rate of 1,280 pounds per acre. No injurious effects were observed over a period of 8 weeks. This suggests that such hardy plants as Ribes are more resistant than grains and grasses.

Assuming, for comparative purposes only, that the action of applied thallium would be localized in the upper 3 inches of soil: Then, 1 acre, or 43,560 square feet, one-fourth foot deep would correspond to approximately 10,000 cubic feet of soil and would weigh approximately 1,000,000 pounds. Under this assumption, 10 pounds of thallous sulphate per acre would correspond to 10 parts per million, and the results on a field scale are in harmony with those in the laboratory.

CONCLUSIONS

Under laboratory and field conditions on various types of soil, the addition of thallium compounds up to 10 parts per million (10 pounds of thallous sulphate per acre, equivalent to 1,000 pounds of thalgrain per acre) had no injurious effects on vegetation, and in many instances appeared to stimulate plant growth.

With the application of larger quantities, injury was observed. Under field conditions no damage occurred during 9 months of dry weather, but it developed following the rainy season.

Thallium compounds when applied to the soil in varying concentration up to 1,280 pounds per acre failed to kill or apparently even to injure Ribes in 8 weeks.

In control work, ground squirrels consumed thalgrain so rapidly that no damage to plant growth was found on areas treated as frequently as nine times.

Under the conditions used in the control of rodents by properly trained personnel, no evidence of injury to vegetative growth by thalgrain has been found.

LITERATURE CITED


(16) McMurtrey, J. E., Jr. 1932. **Effect of thallium on growth of tobacco plants.** Science (n. s.) 76: 86.


