

# HILGARDIA

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

---

VOLUME 16

MAY, 1945

NUMBER 10

---

## CONTENTS

### TOXICITY OF CERTAIN HERBICIDES IN SOILS

A. S. CRAFTS

### STUDIES ON THE ACTIVATION OF HERBICIDES

A. S. CRAFTS and H. G. REIBER

### MOVEMENT OF CARBON DISULFIDE VAPOR IN SOILS AS AFFECTED BY SOIL TYPE, MOISTURE CONTENT, AND COMPACTION

H. A. HANNESSON

---

UNIVERSITY OF CALIFORNIA · BERKELEY, CALIFORNIA

TOXICITY OF CERTAIN HERBICIDES IN SOILS<sup>1</sup>A. S. CRAFTS<sup>2</sup>

PREVIOUS PUBLICATIONS from this station have described a method for testing the toxicity of chemical sterilants in soils (Crafts, 1935)<sup>3</sup> and have presented results from such tests with arsenic, borax, and chlorate (Crafts, 1935; Crafts and Raynor, 1936). Further studies by this method have provided data on the characteristics of ammonium thiocyanate, sodium thiocyanate, ammonium sulfamate, dinitro-*o*-cresol, and certain other soil sterilants. At times when arsenic and chlorate cannot readily be obtained, the results of these studies may be especially useful; some of the chemicals tested may offer possibilities as substitutes. Furthermore, the present extensive use of substituted phenols in weed control presents problems concerning the possible deleterious effects of their accumulation in soils. With the introduction of new and more toxic organic herbicides, the possibility of using these as soil sterilants seems worth considering.

## TESTING METHOD

Briefly, the testing method involves growing indicator plants (Kanota oats) in soils moistened with solutions of the chemical being studied. Surface soils are pulverized, screened, and weighed into no. 2 cans. Each culture is then moistened enough to bring it to field capacity, the solutions being made up by diluting a stock solution. After standing overnight the cultures are seeded. The plants are grown for 30 days, being periodically watered by bringing the cultures up to their original moist weight.

In harvesting, a visual estimate is made of the average height of the plants; then they are cut off at the soil surface and weighed. All yield data in this paper are average values for fresh weight of three or more cultures at harvest time.

After weighing, the tops are returned to the can, and all cultures are dried for 30 days. Then the tops are set aside, the soil is removed and pulverized, the tops are placed in the bottom of the can, and the pulverized soil is poured back in and remoistened with tap water. The cultures are seeded, watered, and harvested as before.

The percolation tests are made in special soil tubes. Each tube consists of a celluloid liner supported by hardware cloth bent into the form of a cylinder. The bottom is closed with a circle of filter paper supported by a square of  $\frac{1}{8}$ -inch-mesh hardware cloth. In the percolation studies, series of these tubes

<sup>1</sup> Received for publication September 6, 1944.

<sup>2</sup> Associate Professor of Botany and Associate Botanist in the Experiment Station.

<sup>3</sup> See "Literature Cited" for complete data on citations, referred to in the text by name of author and date of publication.

are filled with air-dry soil and moistened from above by allowing the test solutions to drop on them slowly from small glass pipettes. After standing overnight each tube is laid on a table and opened, and the soil column cut into ten equal fractions. The moist fractions are carefully transferred to no. 2 cans and seeded. Watering and harvesting are the same as in the toxicity tests.

### CHEMICALS TESTED

*Ammonium Thiocyanate*.—A previous publication (Robbins, Crafts, and Raynor, 1942) has summarized earlier work with ammonium thiocyanate as a herbicide and has briefly reported the following tests. Data on the soil tests include results of three crops on ten California soils—Arbuckle clay loam, Stockton adobe clay, Aiken clay loam, Yolo sandy loam, Egbert loam, Fresno sandy loam, Yolo adobe clay, Columbia fine sandy loam, Yolo clay loam, and Sacramento clay. Figures 1 to 4 illustrate these results. The graphs show yields only to the 1,220 p.p.m. concentration level. Included in the test series were cultures having concentrations to 2,040 p.p.m.

In these tests the cultures were seeded on the same day that they were moistened with the ammonium thiocyanate solutions. Evidently the solutions were very toxic. The results differed from those with arsenic (Crafts, 1939*b*) in that little change occurred during the first few hours. Considering the first-run curves of figures 1 to 4, one finds a general relation between crop yield and toxicity. If the curves are examined in the order of increasing yields (approximately in the order in which the soils are listed above) it will be found that toxicity decreases in that order. Though some exceptions occur, the same relation holds generally in the second and third runs. This is also the relation that holds for chlorate toxicity in soils (Crafts, 1939*a*).

As shown by the curves for the second runs, toxicity has changed tremendously during the 30-day cropping period and subsequent 45-day drying period of these cultures. Whereas practically no plants survived at a concentration above 80 p.p.m. in the first run, most cultures had better crops at this concentration in the second run than they did in the untreated checks. Plants made fair growth in Yolo clay loam initially having 490 p.p.m. (fig. 4), and in Yolo adobe clay they weighed 1 gram per culture in cultures initially containing 1,220 p.p.m. (fig. 3).

The inverse relation between fertility and toxicity of ammonium thiocyanate is again apparent. There are three possible exceptions—Yolo adobe clay, Egbert loam, and Sacramento clay. The first is a heavy soil whose colloid was isolated by water separation. This colloid has a marked fixing capacity. While the first run was being made, the toxicity of thiocyanate was altered more in this soil than in any other. Since Egbert loam and Sacramento clay samples were high in organic matter, toxicity may result from a summation of the effects of thiocyanate and excess nitrate. Both these soils are extremely high in organic matter, and their curves drop steeply after a very short initial rise.

Curves for the third runs show that toxicity of the chemical continued to decrease. Five of the soils show greater yields at levels initially containing 920 p.p.m. than in the untreated checks, and four of these had similar yields at levels initially containing 2,040 p.p.m. Soils that still have toxic amounts

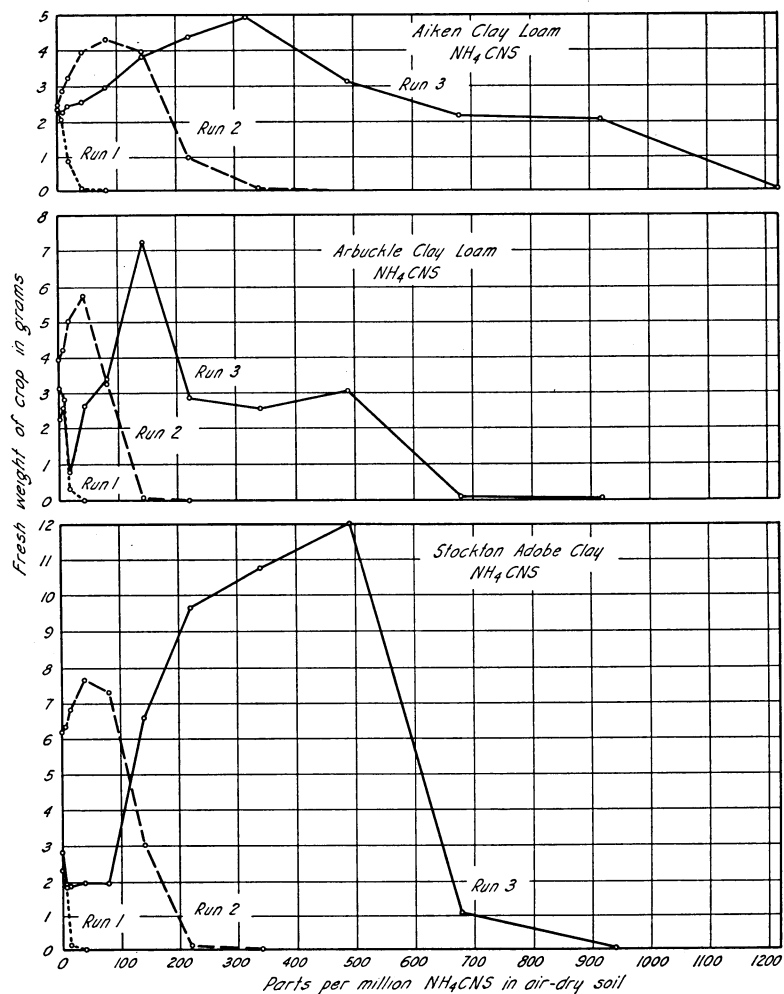


Fig. 1.—Toxicity of ammonium thiocyanate to indicator plants in Aiken clay loam, Arbuckle clay loam, and Stockton adobe clay.



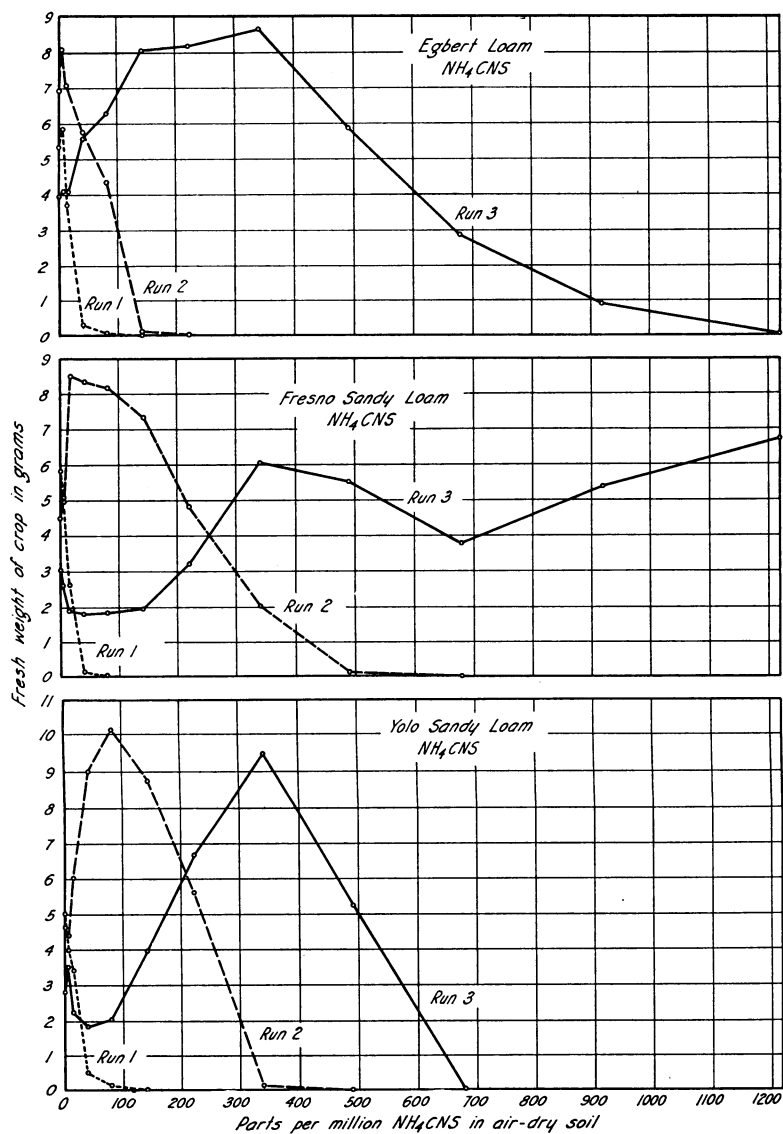


Fig. 2.—Toxicity of ammonium thiocyanate to indicator plants in Egbert loam, Fresno sandy loam, and Yolo sandy loam.

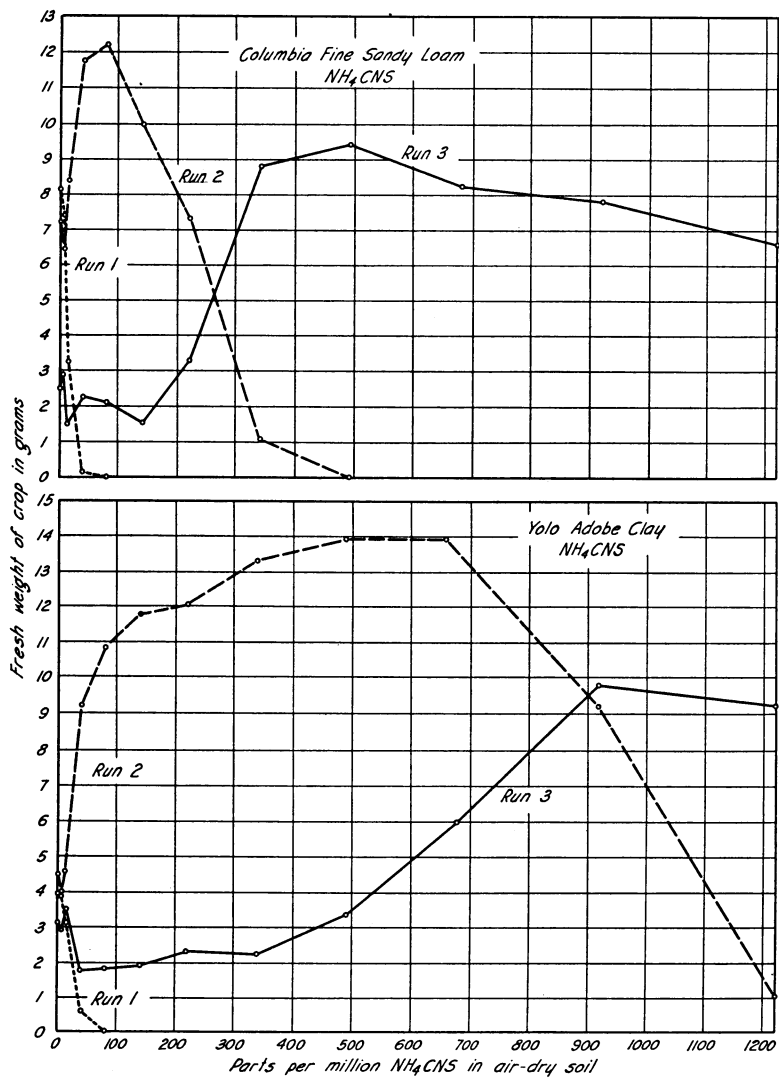


Fig. 3.—Toxicity of ammonium thiocyanate to indicator plants in Columbia fine sandy loam and Yolo adobe clay.

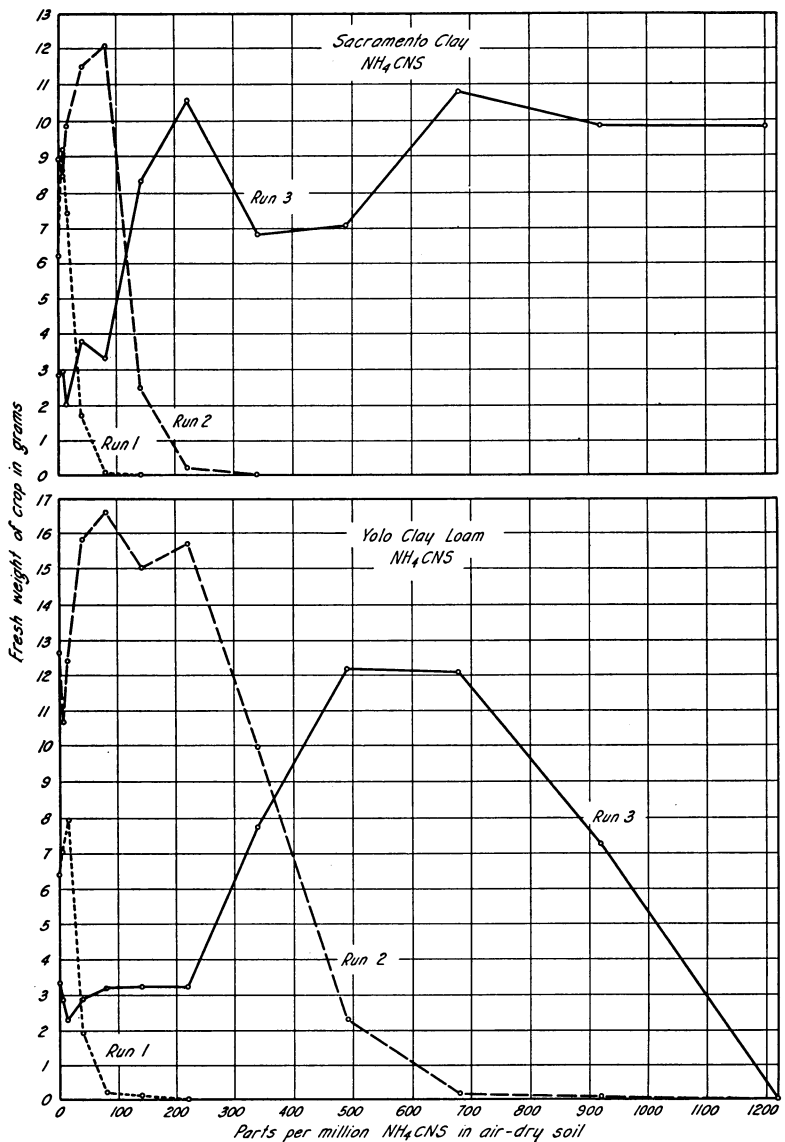


Fig. 4.—Toxicity of ammonium thiocyanate to indicator plants in Sacramento clay and Yolo clay loam.

of ammonium thiocyanate are Stockton adobe clay, inherently low in nitrogen; Yolo sandy loam, fairly light and low in colloid; Aiken clay loam, low in both nitrogen and available phosphate; and Egbert loam, in which excessively high nitrate might have contributed to the toxicity.

These curves have one interesting feature: the yields in the third run were low in the cultures that produced the greatest crops during the second run.

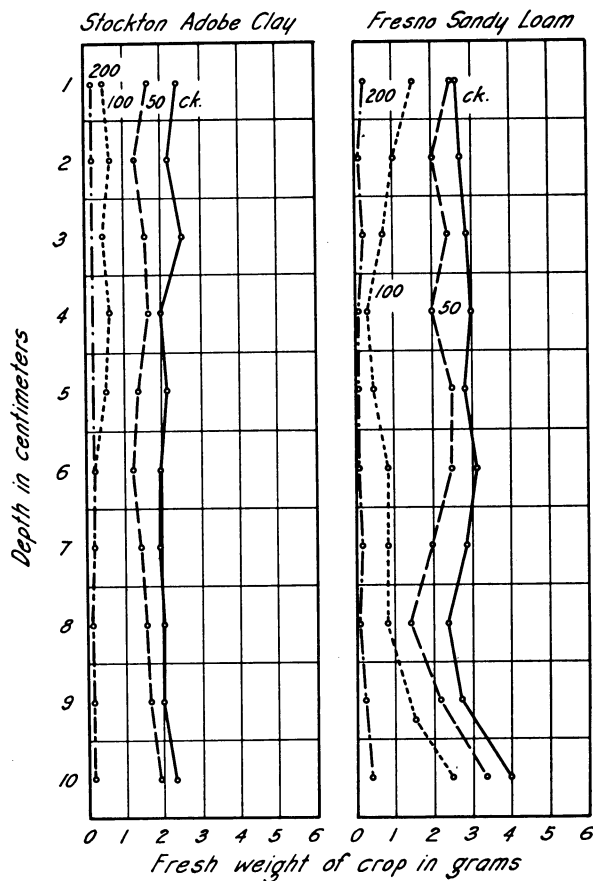


Fig. 5.—The relation of crop yield to the penetration of ammonium thiocyanate into columns of Stockton adobe clay and Fresno sandy loam. The chemical is not retained by these soils.

Evidently the nutrients tied up in the straw of the second crop were not released rapidly enough by decomposition of the straw to become available to the third crop. This effect is often noted in the field after large amounts of raw organic matter are plowed under.

The fourth runs showed no toxicity throughout the range tested—that is, from 0 application to cultures initially containing as much as 2,040 p.p.m. The fourth runs were planted December 13, 1937, almost a year after the initial planting.

Figure 5 gives the results of two percolation series with ammonium thiocyanate. As the graphs show, this chemical is not retained in an available form in the soil, but percolates down with the moisture as do chlorate (Rosenfels and Crafts, 1941) and nitrate.

According to the results just described, ammonium thiocyanate is extremely toxic when first applied to the soil; but thereafter it rapidly decomposes, losing its toxicity and contributing to the nitrate and probably the sulfate content of the soil. Since nitrate and sulfate are both plant nutrients, the decomposing ammonium thiocyanate acts as a fertilizer to stimulate plant growth.

The results also show that ammonium thiocyanate moves readily through the soil and hence would be subject to leaching by rains or irrigation. Apparently, therefore, its most logical use in weed control would be against annuals and shallow-rooted perennials in pastures or turf lands where the crop plants may rapidly occupy the areas made bare by the death of weeds. Utilizing the nutrients that result from decomposition of the herbicide, the crop should thrive and present greater competition to any seedlings that might grow from seed germinating in the soil.

Application should be timed to avoid heavy rains or irrigation immediately following, so that a sufficient interval is allowed for action of the toxicant.

The high toxicity of ammonium thiocyanate might suggest its use as a general contact herbicide. Other chemicals being tested, however, including the substituted phenols, offer so much promise that thiocyanates seem unlikely to compete with them.

*Sodium Thiocyanate.*—Figures 6 and 7 illustrate the effects of sodium thiocyanate upon soils. Tested in six soils, this chemical proved somewhat less toxic than the ammonium salt in the initial runs. It became much reduced in toxicity with cropping. By the third cropping it was nontoxic in four of the six soils at concentrations initially 1,220 p.p.m. and in the other two at concentrations initially 680 p.p.m. The toxicity of sodium thiocyanate, like that of the ammonium salt, seems unrelated to the textural grade of the soil. Relation to fertility is less apparent than with ammonium salt, but this may be only because fewer soils were tested.

Since sodium tends to replace calcium in the replaceable base complex of soils, with a corresponding deflocculation of the colloids and decrease of permeability to water, sodium thiocyanate could not be recommended for repeated use on western soils. Judging from tests in the field, it is not a particularly effective herbicide, either as a general contact spray or as a temporary soil sterilant. If it is used, the same recommendations apply as those outlined for the ammonium salt. Because of the lower toxicity, the dosage rate should be somewhat higher.

*Ammonium Sulfamate.*—Eleven soils were used in studying the toxicity relations of ammonium sulfamate—Aiken clay loam, Stockton adobe clay, Sierra fine sandy loam, Arbuckle clay loam, Yolo fine sandy loam, Willows adobe clay, Sacramento clay, Yolo adobe clay, Yolo clay loam, Hanford fine sandy loam, and Egbert loam. The first run was prepared and seeded on October 16 and 17, 1942. The tests were carried through four runs, terminating in mid-July of 1943.

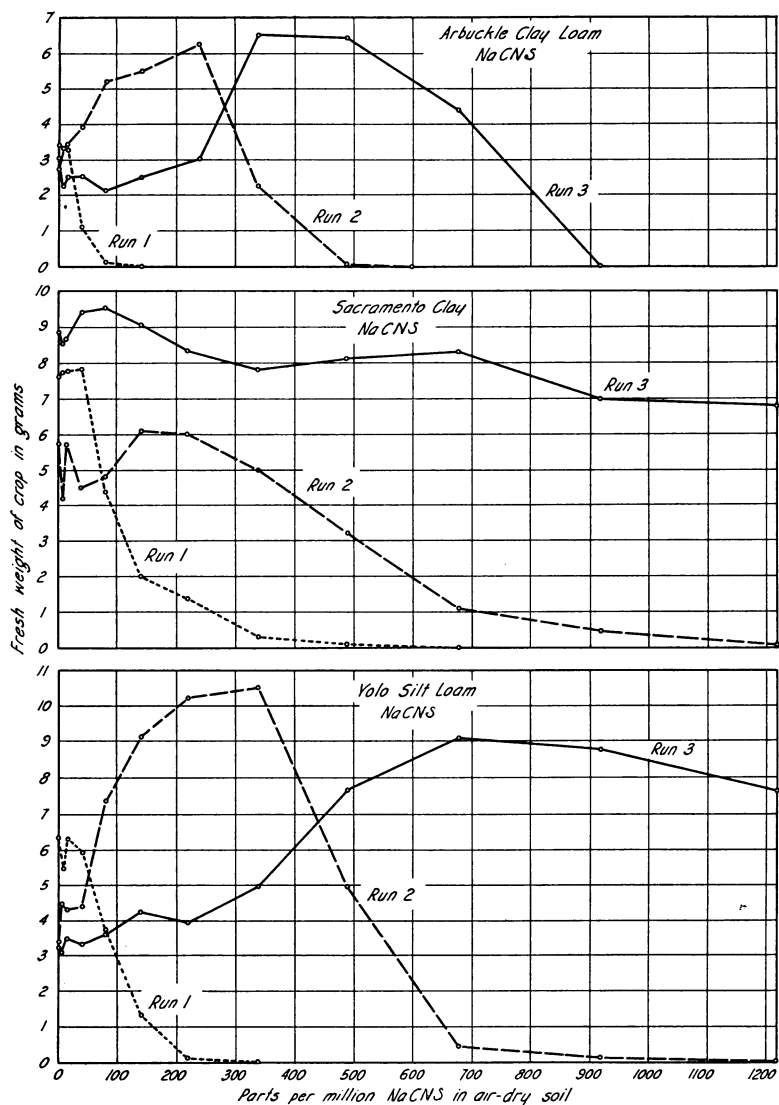


Fig. 6.—Toxicity of sodium thiocyanate to indicator plants in Arbuckle clay loam, Sacramento clay, and Yolo silt loam.

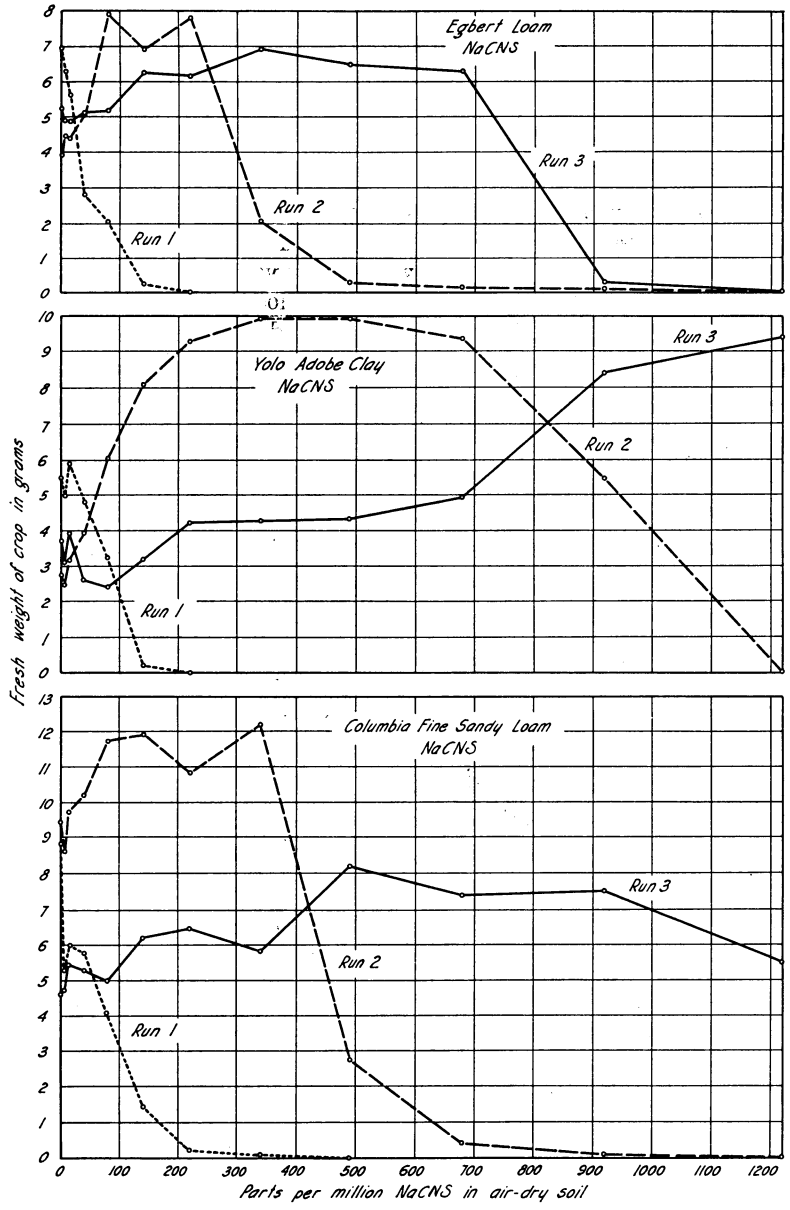


Fig. 7.—Toxicity of sodium thiocyanate to indicator plants in Egbert loam, Yolo adobe clay, and Columbia fine sandy loam.

Results of the toxicity tests (figs. 8, 9, and 10) show that sulfamate is much lower in initial toxicity than thiocyanate. When the curves are studied in relation to soil characteristics, toxicity again appears to be determined more by fertility than by textural grade. Egbert loam (fig. 9) is an exception. As with thiocyanate, its response to sulfamate may be complicated by its high initial content of nitrate. On the other hand, reports from eastern states indicate that sulfamate may be more toxic in acid soils; and Egbert loam, being very high in organic matter, has an acid reaction (Cosby, 1941).

By the time of the second runs, toxicity has markedly decreased. In most soils, concentrations that reduced growth to low values in the first run now have stimulated the yields to higher levels than those of the untreated checks. Only two soils, Aiken clay loam and Stockton adobe clay, are sterilized by concentrations initially below 500 p.p.m. Yolo adobe clay at a concentration initially 920 p.p.m. has a yield considerably higher than in the untreated check. Again toxicities are inversely related to fertility.

Curves for the fourth run show continued decrease in toxicity, but the change was much less marked than with thiocyanates.

An interesting feature of these toxicity curves is the indication of stimulation in the region of 15 to 40 p.p.m. during the first run. Since scarcely enough ammonia is present to improve the nutritional conditions of the plants, some stimulatory action may be involved. Fromm (1943) has reported such action on cultures of duckweed (*Lemna minor* L.). Possibly—to judge from the increased growth in the later runs—this chemical decomposes in the soil, and the products of decomposition (presumably nitrate and sulfate) act as nutrients to plants growing there. Sulfamate seems to lie between thiocyanate and chlorate with respect to breakdown in the soil. From its lack of response to soil type and its behavior in field plots, it appears not to be retained in the soil, but to move with soil moisture. It should therefore, like ammonium thiocyanate, find its most logical use in controlling annual and shallow-rooted perennial weeds in turf and pasture lands where the crops can avail themselves of the fertilizer elements provided. Likewise, sulfamate should be so applied that it comes immediately into contact with the plant tissues to be killed, a minimum of time being allowed for loss in toxicity by decomposition.

Reports have indicated that ammonium sulfamate spray is particularly effective against poison ivy, poison sumac, chokecherry, and other shrubs (Yeager and Calahan, 1942; Palmiter and Hildebrand, 1943; Steinbauer and Steinmetz, 1944). Descriptions of the results imply that the toxic effects may be translocated from the region of actual contact to structures below the soil surface. Since most of these reports emanate from regions of frequent summer rains, leaching into the root zone may perhaps play an important part in the effects noted. In California, tests with sulfamate and diesel oil on large, climbing poison oak (*Rhus diversiloba* T. and G.) showed no significant difference between the two herbicides when examined one year after the application, and neither gave a complete kill of roots. On small plants (under 2½ feet in height) the sulfamate killed the crowns and roots; the diesel oil killed only the stems, and the plants resprouted.

*Dinitro-o-cresol*.—Salts of dinitro-*o*-cresol and other substituted phenols are coming into use as selective and general contact herbicides. For this reason



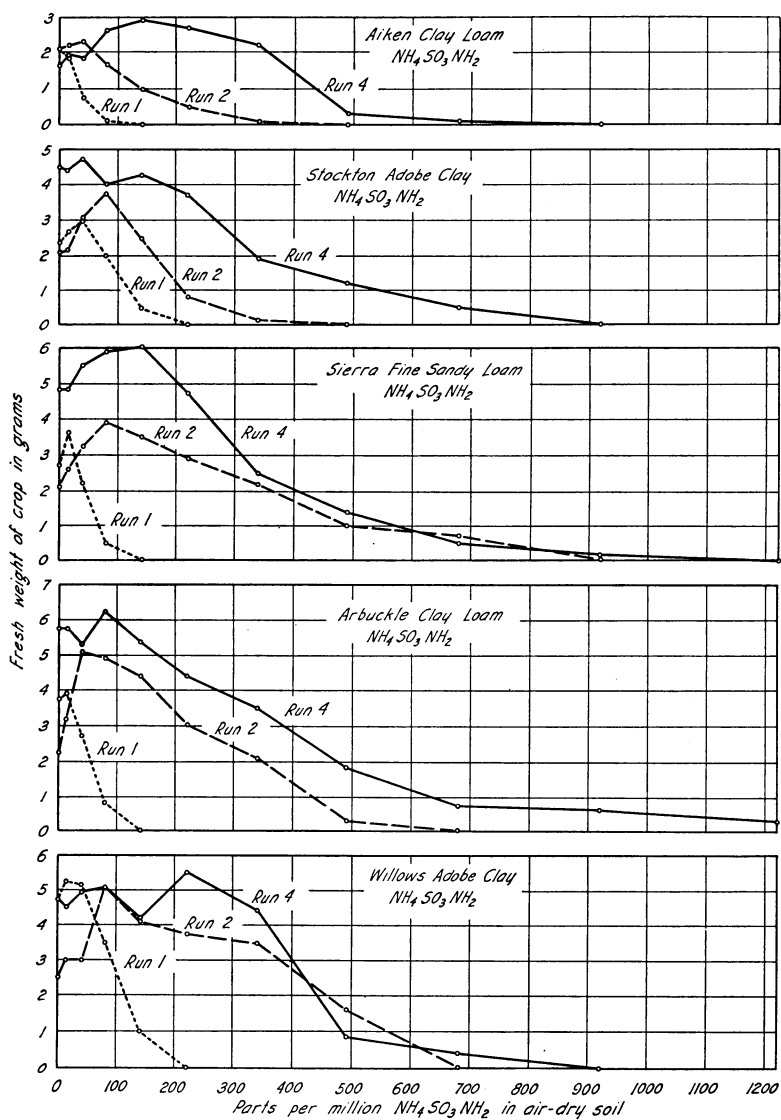


Fig. 8.—Toxicity of ammonium sulfamate to indicator plants in Aiken clay loam, Stockton adobe clay, Sierra fine sandy loam, Arbuckle clay loam, and Willows adobe clay.

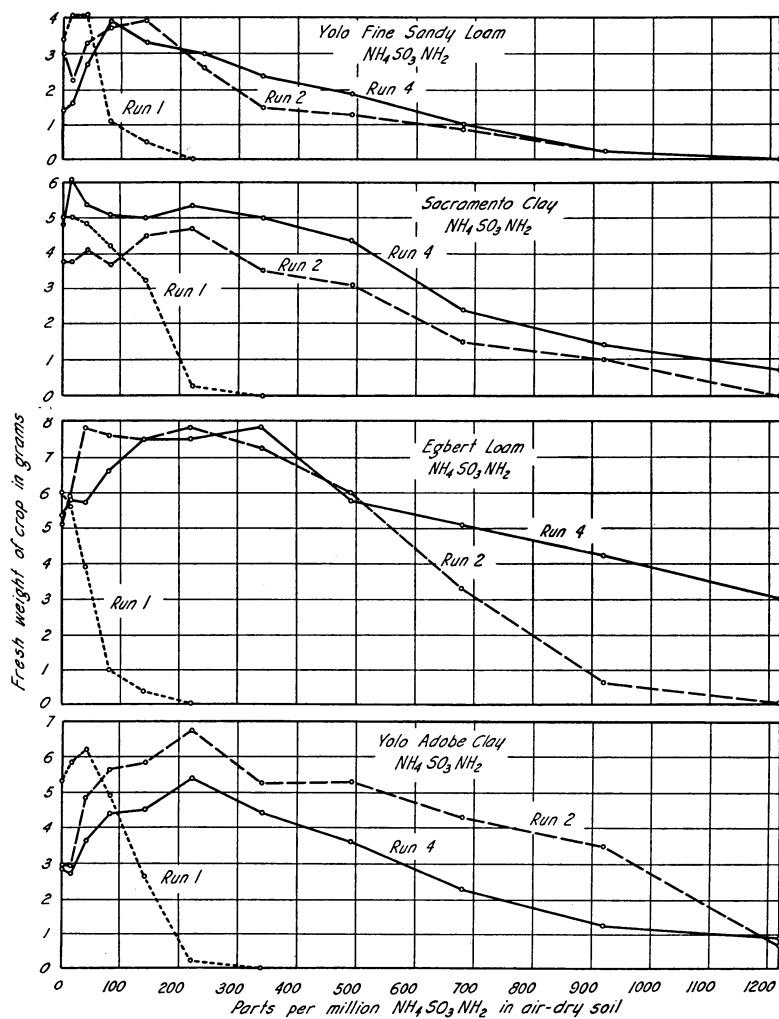


Fig. 9.—Toxicity of ammonium sulfamate to indicator plants in Yolo fine sandy loam, Sacramento clay, Egbert loam, and Yolo adobe clay.

it is necessary to know their fate in the soil, their toxicity levels, and the general relations between toxicity and soil characteristics. Studies have been made with Sinox, a proprietary herbicide containing sodium dinitro-*o*-cresylate as its active ingredient; Elgetol, a dormant spray material containing sodium dinitro-*o*-cresylate and a wetting agent; ammonium dinitro-*o*-cresylate; and dinitro-*o*-cresol in two forms.

The most extensive experiment compared the toxicities of sodium and ammonium dinitro-*o*-cresylates and dinitro-*o*-cresol used pure and used in a

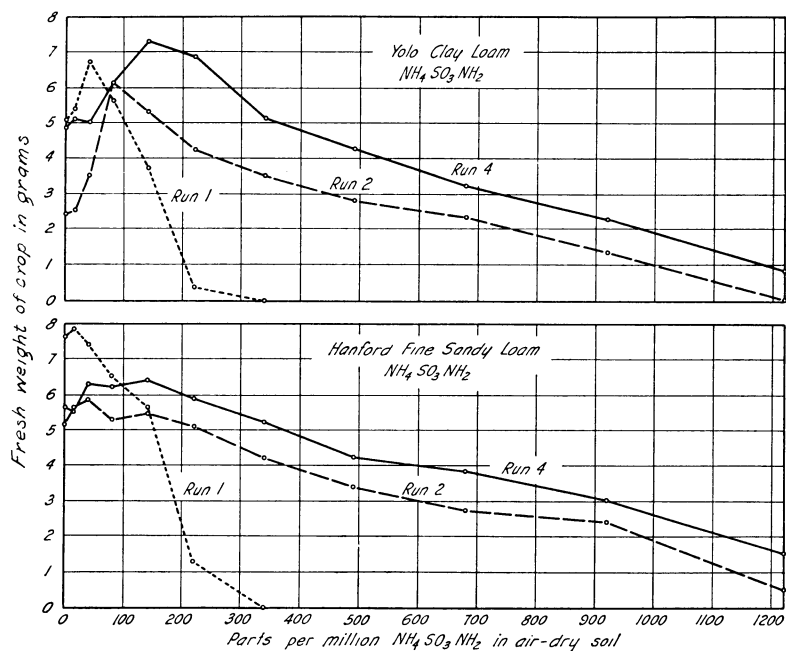


Fig. 10.—Toxicity of ammonium sulfamate to indicator plants in Yolo clay loam and Hanford fine sandy loam.

50:50 mixture with bentonite. The chemicals were added, in equimolecular amounts, to Yolo clay loam, Yolo fine sandy loam, Sierra fine sandy loam, and Stockton adobe clay. The soils were cropped three times, with drying periods between.

According to the data from this experiment, there were no differences in the toxicities of the four different chemicals added. Evidently the dinitro-*o*-cresol molecule or its ion are correspondingly toxic in soils, and the base involved is not important.

Because there were no differences, the data from the four test series were averaged, and curves were drawn showing the average toxicity of each in four soils and for three runs. Since the original test series were in duplicate, each point on each curve represents an average of eight crop weights. Figure 11 shows the curves.

Inspection of these curves reveals the following facts: dinitro-*o*-cresol has a high initial toxicity in all four of these soils, giving practical sterility at 140

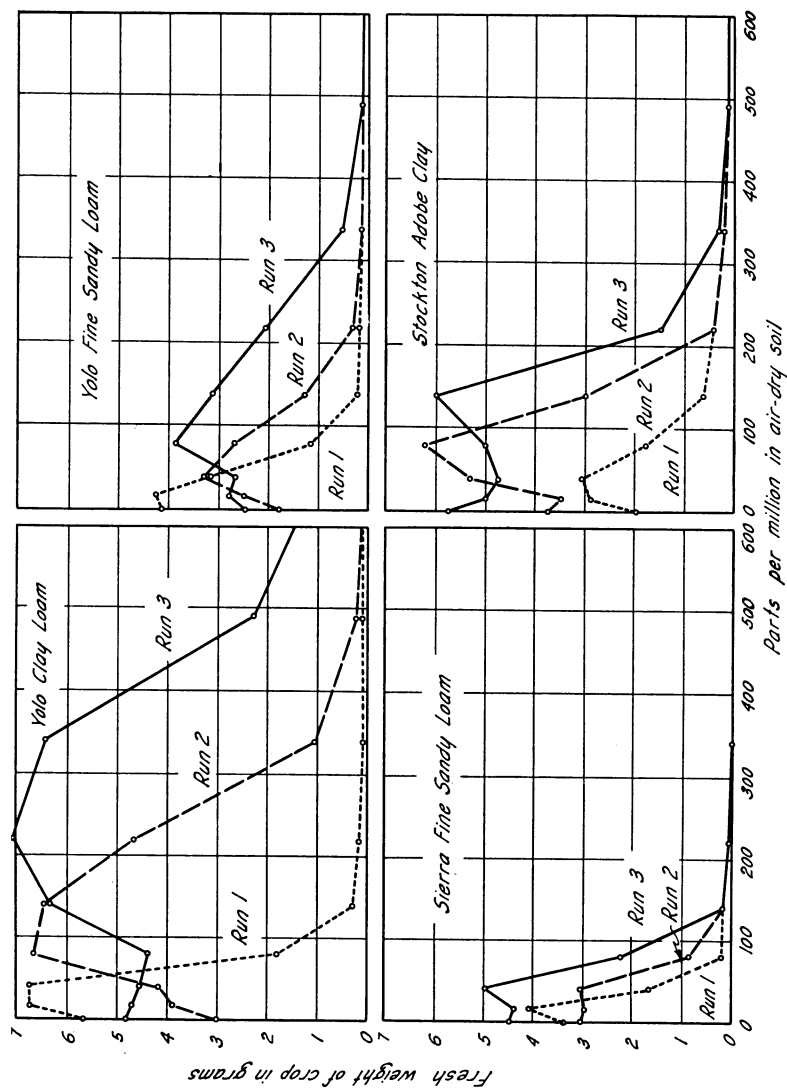


Fig. 11.—Toxicity of dinitro-o-cresol to indicator plants in Yolo clay loam, Yolo fine sandy loam, Sierra fine sandy loam, and Stockton adobe clay.

p.p.m. With certain exceptions, toxicity is highest in the light-textured soils. This fact is more readily noted in other soils than in the particular four shown in figure 11.

Toxicity decreases markedly with time and cropping, and this change is most prominent in the heavier soils. These results might suggest that dinitro-*o*-cresol is retained against leaching in soils in a form available to plants, much as arsenic is (Crafts, 1935). Percolation tests prove this to be true. Figure 12 shows the results of percolation studies on four soils.

The chemical is most firmly retained by the Yolo and Aiken soils, somewhat less by Stockton adobe clay, and least by Fresno sandy loam. Retention is less marked than with arsenic (Crafts, 1935), but more than with borax (Crafts and Raynor, 1936).

As these results demonstrate, dinitro-*o*-cresol behaves differently from chlorate, thiocyanate, and sulfamate. It is retained in the soil, depending upon the soil type, and might be expected to accumulate if sufficient leaching did not occur.

One other aspect of figure 11 is important. In the first run in all four soils, the crop at 15 p.p.m. is greater than that of the untreated check. This indicates stimulation by small amounts of the chemical. In the second runs this effect is even more prominent in three of the soils; and in the third run, after a slight initial drop, the increase becomes marked in cultures that in the first run were virtually sterile.

Of eleven soils tested with dinitro-*o*-cresol, nine show stimulation in the range of 5 to 15 p.p.m. in the first run. Of the two that fail to show it, Sacramento clay is high in organic matter; and Hanford fine sandy loam, though lighter in texture, is extremely fertile. These two soils were in a group of nine tested with Elgetol in February, 1938. They had the highest yields of any of the soils, the crops in the checks weighing 14.3 grams for the Hanford soil and 12.0 grams for the Sacramento. All soils that were run twice, except Sierra fine sandy loam, showed stimulation; and the increase in crop over the untreated checks was sometimes as much as 100 per cent.

In the curve for the third run (fig. 11) the crop yield, before rising, drops off in the region showing stimulation in the first and second runs. This may result from a tying up of nutrients in the crop in those cultures where the yield of the previous crop had been far above normal for the soil. Ultimately the yields of the third runs attained high values, indicating marked stimulation at concentrations initially toxic.

In the first analysis of the data illustrated in figure 11, curves were plotted for each chemical. Since the yields where the ammonium salt of dinitro-*o*-cresol was used did not exceed those for the sodium salt or for the parent compound, apparently the stimulation is not a straight nitrogen fertilization, at least during the first cropping. This stimulation has been noted in the field after Sinox treatment and has been attributed to partial soil sterilization. The more marked increases in yield during the second and third croppings probably involve nitrification of certain products of decomposition of the toxicant. Even here, the small amount of ammonia involved in the use of the ammonium salt had no effect upon yields.

Returning to the problem of the relation between toxicity and soil type:

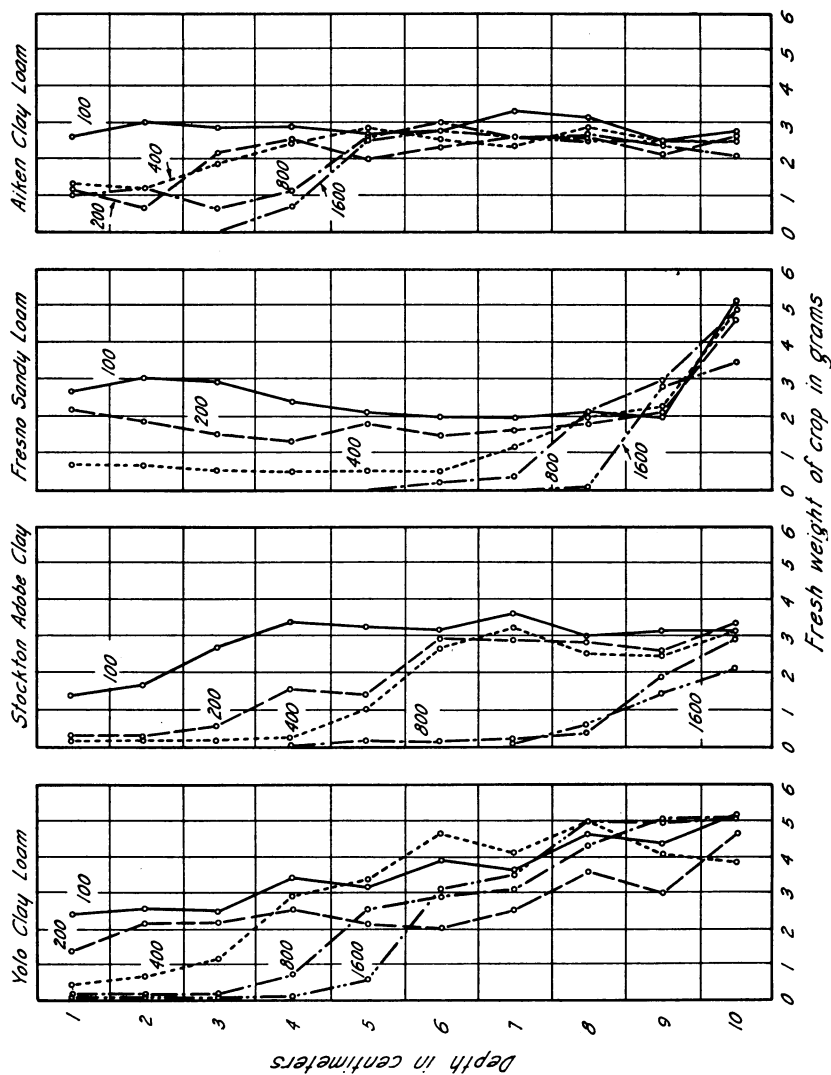


Fig. 12.—Penetration of sodium dinitro-o-cresylate into four California soils as shown by growth of indicator plants. The chemical is retained and does not move readily with soil moisture.

detailed studies of the curves for the eleven soils used show that the toxicities are affected by factors other than textural grade. If the yields in the eleven soils are expressed as percentages of check yields, so that differences inherent in the fertilities of the soil samples are compensated, the soils may be roughly grouped as follows: high-toxicity group—Sierra fine sandy loam, Fresno sandy loam, Yolo fine sandy loam; intermediate-toxicity group—Arbuckle clay loam, Stockton adobe clay, Hanford fine sandy loam, Yolo adobe clay; low-toxicity group—Yolo clay loam, Sacramento clay, Egbert loam, and Aiken clay.

Thus, generally speaking, the toxicity is highest in light soils, lowest in heavy ones. The most apparent exceptions are as follows: Hanford fine sandy loam should be in the high rather than the intermediate group; as previously mentioned (p. 474), this soil is extremely fertile, producing the highest yields of any in this study. Stockton and Yolo adobe clays should be in the low instead of the intermediate toxicity group; both are very low in fertility. The Egbert loam should have been in the intermediate instead of the high group; it is high in organic matter and very fertile.

In all the exceptions, apparently, the performance can be explained on the basis of irregular crop-yielding power. Whether this indicates (as with chlorates) a relation between absorption of dinitro-*o*-cresylate ion and nitrate ion, or whether it relates to the complex phenomenon of stimulation at low concentration, remains to be found out.

Two important aspects of dinitro-*o*-cresylate toxicity deserve consideration here. First, how hazardous is the accumulation of this chemical from successive applications as a herbicide? Second, is there any probability of its being used as a soil sterilant?

To answer the first question requires consideration of the quantitative aspects. An acre-foot of soil weighs roughly 3,600,000 pounds. To sterilize this would require for the light-textured group around 140 p.p.m. (about 500 pounds of chemical per acre foot); for the medium group 340 p.p.m. (1,200 pounds); and for the heavy soils around 680 p.p.m. (2,400 pounds). On the basis of an acre-inch the values would be roughly 40 pounds, 100 pounds, and 200 pounds, respectively.

Since 1 gallon of Sinox contains only 3 pounds of sodium dinitro-*o*-cresylate and since seldom more than 1½ gallons is applied per acre on croplands, the possibility of accumulating toxic quantities seems rather remote. Furthermore, losses of toxicity with time and cropping indicate that amounts much greater than those applied may be decomposed in the soil during each cropping. While the situation may be different in the fine sandy loam group, percolation results indicate that leaching would occur in these soils. For all practical purposes it seems very unlikely that residues of dinitro-*o*-cresol will ever become hazardous in agricultural soils. This consideration is important not only in grain crops but also in vegetable and orchard soils, where selective spraying and the use of dinitro compounds as dormant sprays are becoming more common.

A single exception to the consideration just mentioned has been noted. Where Sinox has been used as a preëmergence spray (a spray applied between planting of the seed and emergence of the seedlings), light rains following the application have held the chemical in solution in a thin layer at

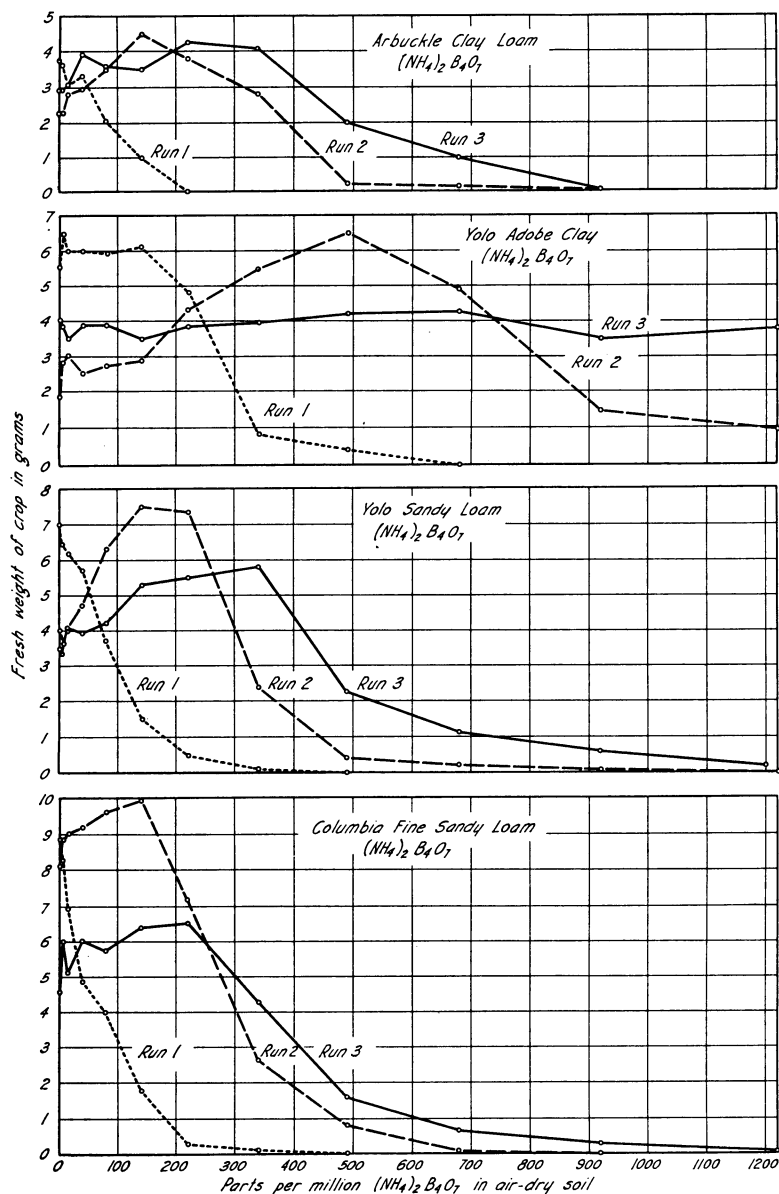


Fig. 13.—Toxicity of ammonium borate to indicator plants in Arbuckle clay loam, Yolo adobe clay, Yolo sandy loam, and Columbia fine sandy loam.



the soil surface. Onion seedlings pushing up through this moist surface soil have been seriously injured. For this reason Sinox cannot be recommended as a preemergence spray at a time when light showers are likely to occur.

As soil sterilants, substituted phenols seem unlikely to compete on a cost basis with arsenic, borax, and chlorate, three chemicals of outstanding value in this field.

*Ammonium Borate.*—Since the successful introduction of borax as a herbicide in the control of St. Johnswort, or Klamath weed (*Hypericum perforatum* L.) (Raynor, 1937), and as a general soil sterilant (Crafts and Raynor, 1936), the ammonium salt has been suggested as a possible substitute for use

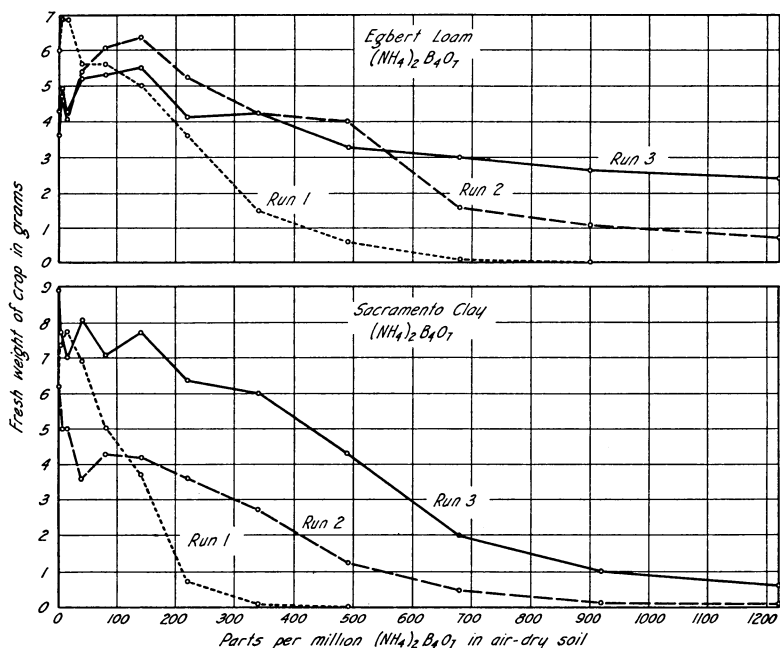


Fig. 14.—Toxicity of ammonium borate to indicator plants in Egbert loam and Sacramento clay.

on arable lands where sodium residues might injure the soil. Figures 13 and 14 show results of toxicity tests in six soils—Arbuckle clay loam, Columbia fine sandy loam, Yolo sandy loam, Sacramento clay, Egbert loam, and Yolo adobe clay. Toxicities are very similar to those for the sodium salt (Crafts and Raynor, 1936). Crop yields in general were no higher than with the sodium salt; apparently the amount of nitrogen introduced in the toxicant was not very important. The types of curves obtained indicate that the added boron affected plant growth more profoundly than did the sodium or ammonium ions.

Judging from the results of these tests, the sodium or ammonium salts of boric acid are of comparable toxicity in soils. The fertilizing effects of the ammonia involved in the ammonium salts were not significant in the soils tested. The only place where the ammonium salt might possibly prove bene-

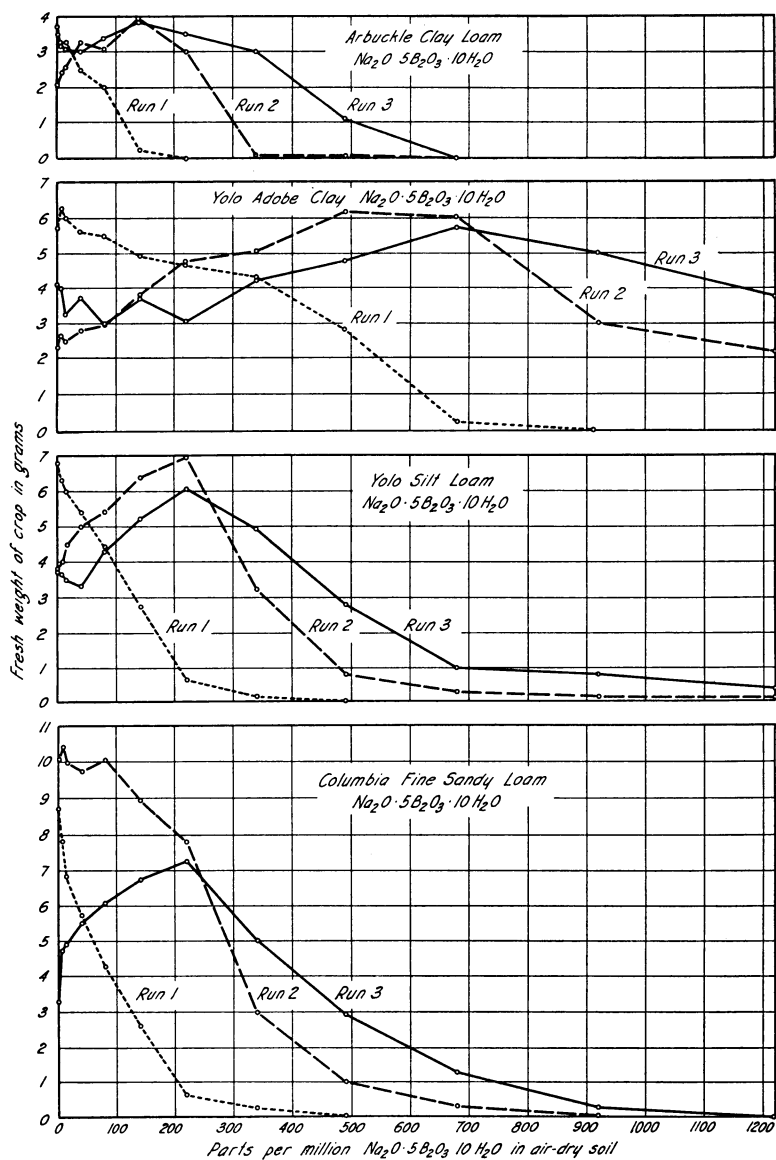


Fig. 15.—Toxicity of sodium pentaborate to indicator plants in Arbuckle clay loam, Yolo adobe clay, Yolo silt loam, and Columbia fine sandy loam.

ficial would be on arid soils already high in sodium salts. Since boron compounds are of little use as herbicides on such soils, there seems to be slight justification for the use of the ammonium salts under most conditions.

**Sodium Pentaborate.**—Another boron compound, sodium pentaborate, was also tested in the same six soils. The results (figs. 15 and 16) closely resemble those with borax (Crafts and Raynor, 1936). Toxicity was highest in Arbuckle clay loam; intermediate in Columbia fine sandy loam, Yolo silt loam, and

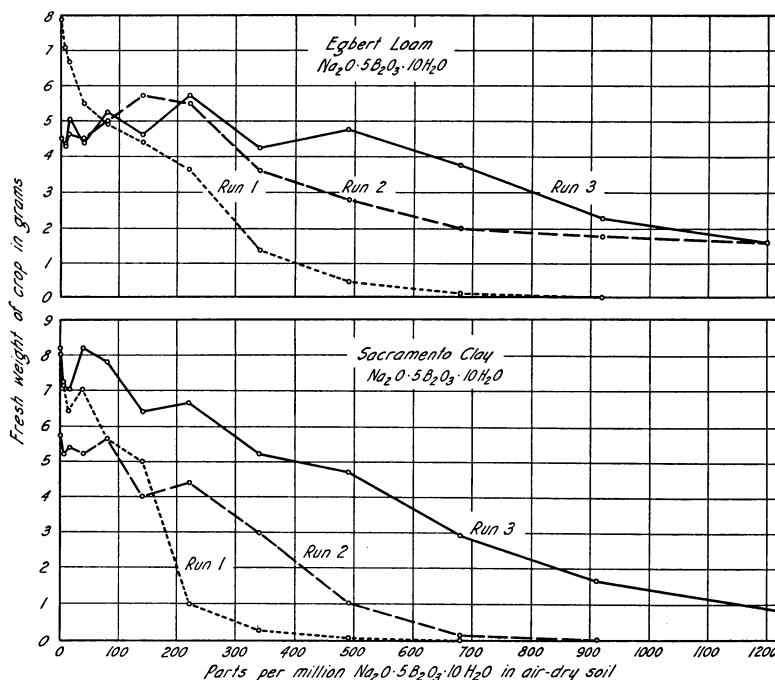


Fig. 16.—Toxicity of sodium pentaborate to indicator plants in Egbert loam and Sacramento clay.

Sacramento clay; low in Egbert loam and Yolo adobe clay. The toxicity of all boron compounds tested so far has been markedly low in adobe soils, and subtoxic concentrations have always brought about increased yield. This fact indicates a possible use of boron compounds in small amounts as fertilizers on such soils.

Toxicity of sodium pentaborate decreased with time and cropping. By the third crop, yields in soils initially sterile had become greater than those of untreated checks. Since no common nutrient element besides boron was added, and since some of the soils used were definitely not deficient in boron, these results indicate either that nutrients have been replaced and made available, or that partial sterilization has altered the relations of nutrients in the soil to increase fertility.

One other compound, ammonium persulfate, was tested. Since it proved low in toxicity, the results will not be given. It has no possible use as a soil sterilant.

## DISCUSSION

As crop-production methods become more mechanized and agriculture is intensified, chemical weed control will probably assume a role of increasing importance. Methods will be aimed not only at eliminating weed species but at controlling insect and fungus pests that overwinter and increase on weeds. Preventive measures, already exemplified in the Pierce's disease control area in Tulare County and in certain citrus orchards around Redlands where sprays are being substituted for cultivation, will become widespread. When this time comes, accurate knowledge on the toxicity of all promising chemicals will be needed.

Three methods are available for general weed control: (1) permanent soil sterilization; (2) temporary soil sterilization; and (3) control by periodic spraying with translocated sprays and general contact herbicides.

To sterilize the soil permanently, arsenic is by far the most economical chemical. Methods for treating soils with it have already been described (Robbins, Crafts, and Raynor, 1942).

Of nonvolatile chemicals for temporary soil sterilization, sodium chlorate, ammonium sulfamate, and ammonium thiocyanate have been tested. Among these, chlorate persists longest in the soil, sulfamate is less persistent, and thiocyanate decomposes very rapidly. Methods for using these chemicals will relate to their toxicity and to their relative persistence, since these properties determine their effectiveness against weed species. As already mentioned, ammonium sulfamate and ammonium thiocyanate will be of most logical use against annual or shallow-rooted perennial weeds in pasture or crop areas. Their ultimate role will depend upon the success attending their application and upon the prices at which they are offered.

For use as a general contact herbicide, arsenic is hazardous because of its poisonous properties, and chlorate because it forms an inflammable mixture on weeds. Thiocyanates are corrosive to machinery. Ammonium sulfamate has been relatively expensive. Most promising have been fuel oils, solutions of substituted phenols, and emulsions of fuel oils fortified with substituted phenols.

This paper, though not concerned with the relative merits of general contact sprays, does consider the cumulative effects of the chemicals used in arable soils.

Judging from years of experience, little or no harm results from the continued use of light and medium fuel oils (distillates) as contact sprays. Weed control on highways and in citrus groves has been practiced for years with no deleterious effects upon the soils. Apparently the residues dissipate by volatilization or are consumed by soil micro-organisms.

As mentioned earlier, dinitro-*o*-cresol or its salts, used at recommended dosages, seem not to endanger the soil. During cropping they decompose in the soil at such rates that no harmful accumulation could occur in the field.

As new herbicidal materials are developed, they might well be tested by methods similar to those employed in these studies, before being given unreserved approval for general use in the field.

## SUMMARY

Ammonium thiocyanate, when first applied to soils, is extremely toxic. It is not retained in an available form by the soil. Toxicity is inversely related to soil fertility and is rapidly reduced with cropping. Yields on soils sterile during the first cropping may surpass yields of untreated checks by the second or third cropping. These facts indicate that ammonium thiocyanate should be used on annual and shallow-rooted perennial weeds in cropped or pasture areas. The chemical should be so applied that it comes into immediate contact with the foliage or roots to be killed.

Sodium thiocyanate is somewhat less toxic than the ammonium salt. The toxicity of both is rapidly reduced during cropping; and yields increase, presumably because of oxidation to nitrate and sulfate. Sodium thiocyanate has not proved particularly effective in the field.

Ammonium sulfamate is lower in initial toxicity than the thiocyanate, but the change in toxicity is less marked during cropping. Toxicity is inversely related to fertility. Yields in the second and later crops showed marked stimulation above those of untreated checks. Again oxidation to nutrient ions has probably taken place.

Sodium dinitro-*o*-cresylate is toxic in soils at about the same concentration as ammonium sulfamate, and the change in toxicity with cropping is of similar magnitude. Toxicity is more definitely related to textural grade than to fertility; and this chemical is retained in an available form, particularly in soils of high colloid content. Retention is less than with arsenic but more than with borax. Initial applications in the concentration range of 5 to 40 p.p.m. greatly stimulated crop yields. This increase in yield shifted into the higher application range in the second and third croppings. Application rates, decomposition, and leaching results all indicate that no hazard exists from accumulation of dinitro-*o*-cresol or its salts in the soil after their use as selective or general contact herbicides.

Ammonium borate and sodium pentaborate resemble borax in their toxicity relations in soils. Ammonium persulfate was not toxic enough to be used in weed control.

## LITERATURE CITED

COSBY, S. W.

1941. Soil survey of the Sacramento-San Joaquin delta area, California. U. S. Bur. Plant Indus. Ser. 1935(21):1-48.

CRAFTS, A. S.

1935. The toxicity of sodium arsenite and sodium chlorate in four California soils. *Hilgardia* 9(9):459-98.  
1939a. Toxicity studies with sodium chlorate in eighty California soils. *Hilgardia* 12(3):231-47.  
1939b. The relation of nutrients to toxicity of arsenic, borax, and chlorate in soils. *Jour. Agr. Res.* 58:637-71.

CRAFTS, A. S., and R. N. RAYNOR.

1936. The herbicidal properties of boron compounds. *Hilgardia* 10(10):343-74.

FROMM, F.

1943. Growth stimulation by ammonium sulfamate in low concentration. *Science* 98:391-92.

PALMITER, D. H., and E. M. HILDEBRAND.

1943. The yellow-red virosis of peach; its identification and control. New York State (Geneva) Agr. Exp. Sta. Bul. 704:1-17.

RAYNOR, R. N.

1937. The chemical control of St. Johnswort. California Agr. Exp. Sta. Bul. 615:1-38.

ROBBINS, W. W., A. S. CRAFTS, and R. N. RAYNOR.

1942. Weed control. 543 p. McGraw-Hill Book Co., New York, N. Y.

ROSENFELS, R. S., and A. S. CRAFTS.

1941. Chlorate distribution and the effect of nitrate concentration on chlorate toxicity in soil columns. *Hilgardia* 14(2):71-79.

STEINBAUER, G. P., and F. H. STEINMETZ.

1944. Poison ivy and poison sumac. Maine Ext. Bul. 321:1-8.

YEAGER, A. F., and C. L. CALAHAN.

1942. Control of poison ivy (*Rhus Toxicodendron*) by spraying. Amer. Soc. Hort. Sci. Proc. 41:234-36.