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CONTENTS

TOXICITY STUDIES WITH ARSENIC IN EIGHTY CALIFORNIA SOILS

A. S. CRAFTS and R. S. ROSENFELS

ARSENIC FIXATION IN RELATION TO THE STERILIZATION OF SOILS WITH SODIUM ARSENITE

R. S. ROSENFELS and A. S. CRAFTS

TOXICITY STUDIES WITH SODIUM CHLORATE IN EIGHTY CALIFORNIA SOILS

A. S. CRAFTS

UNIVERSITY OF CALIFORNIA · BERKELEY, CALIFORNIA

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A. S. CRAFTS[2]

INTRODUCTION

THE SUCCESSFUL USE of sodium chlorate as a herbicide in a region having such diverse soil and climatic conditions as California requires accurate knowledge of the relation of soil and climatic factors to its toxic action. Several publications have discussed the more important of these factors (*1–5, 8–9*)[3] and preliminary work on their relative importance has been reported (*3–5, 8–11, 13*).

For practical weed control with sodium chlorate, one needs a schedule of dosages to meet various field conditions. The principal difficulty in developing such a schedule is the many factors involved in the end result of chlorate application (*2*). Besides the initial toxicity[4] as determined primarily by nitrate concentration of the soil (*5*), leaching by rains and difference in susceptibility of weed species to chlorate are involved.

To solve the problems of chlorate toxicity, one must separate these several factors and determine the range through which each may be manipulated independently of the others. Only thus may all possible situations be anticipated and each factor properly adjusted. St. Johnswort (Klamath weed), for instance, on a sandy soil with an annual precipitation of 40 inches will require an entirely different treatment than hoary cress on clay soil in an arid region. In this field, obviously, the commercial concerns distributing sodium chlorate for herbicidal purposes have done little or nothing. Realizing the need for more accurate dosage recommendations, the writer collected 80 type soils of California, including most of the series important in agriculture. The effects of soil type and soil fertility upon chlorate toxicity in these soils were investigated. The relation between fertility and chlorate toxicity (*5*) revealed in these tests has been used as a basis for a proposed schedule of dosage that should prove useful wherever the chemical may be evenly distributed.

[1] Received for publication January 17, 1938.

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

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

[4] The term "toxicity" has acquired a wide variety of meanings. For purposes of the present group of papers (*5, 7, 12*) the criterion adopted is the application of chemical causing an almost complete suppression of growth. This use of the word has developed because in the control of weeds the practical object is to inhibit development completely.

TABLE 1

TOXICITY OF SODIUM CHLORATE IN 4 CALIFORNIA SOILS, AS SHOWN BY GROWTH OF INDICATOR PLANTS*

Sodium chlorate expressed as p.p.m. $NaClO_3$ in air-dry soil	Yolo clay loam		Stockton adobe clay		Fresno sandy loam		Columbia fine sandy loam	
	Height	Fresh weight	Height	Fresh weight	Height	Fresh weight	Height	Fresh weight
				Fifth run, harvested October 25, 1934				
p.p.m.	*cm*	*gm*	*cm*	*gm*	*cm*	*gm*	*cm*	*gm*
10	31	5.9	25	2.9	26	3.0	28	3.6
30	32	6.5	25	2.8	26	3.0	28	3.4
60	30	5.3	27	3.4	26	2.9	27	2.9
100	32	6.0	27	3.4	26	2.4	27	2.9
150	33	6.2	27	3.8	28	3.1	28	3.2
210	38	7.0	26	2.9	28	3.8	29	3.6
280	38	6.1	26	2.9	27	2.2	30	4.1
360	32	4.2	28	4.0	25	2.3	28	2.7
450	30	3.6	28	4.5	19	1.1	24	2.2
550	28	3.2	28	4.7	18	0.8	22	1.7
660	24	2.0	29	3.8	12	0.5	20	0.9
780	19	1.2	26	2.5	10	0.4	19	0.9
940	17	0.8	21	1.5	7	0.2	13	0.7
1,050	14	0.6	16	0.7	6	0.2	10	0.4
1,200	13	0.5	9	0.4	5	0.2	9	0.4
1,360	11	0.4	8	0.2	5	0.1	8	0.3
1,530	9	0.3	7	0.3	0	0.0	6	0.2
1,710	9	0.4	5	0.2	0	0.0	6	0.2
1,900	8	0.2	5	0.1	0	0.0	5	0.1
2,100	7	0.2	0	0.0	0	0.0	0	0.0
2,310	6	0.2	0	0.0	0	0.0	0	0.0
2,530	6	0.2	0	0.0	0	0.0	0	0.0
2,760	5	0.1	0	0.0	0	0.0	0	0.0
Check	30	5.7	25	3.1	24	2.5	24	2.6
				Seventh run, harvested November 16, 1935				
p.p.m.	*cm*	*gm*	*cm*	*gm*	*cm*	*gm*	*cm*	*gm*
360	29	6.1	..	...	22	3.0	..	...
450	28	5.6	..	...	18	1.7	23	3.9
550	28	5.8	..	...	16	1.1	21	2.6
660	24	3.5	..	...	11	0.6	19	2.4
780	22	2.6	24	4.0	9	0.5	15	1.4
940	16	1.2	24	3.5	5	0.3	13	1.0
1,050	15	1.1	23	2.9	6	0.3	11	0.7
1,200	10	0.8	17	1.3	5	0.2	10	0.6
1,360	10	0.7	17	1.4	4	0.2	6	0.4
1,530	7	0.6	14	1.0	0	0.0	5	0.3
1,710	7	0.6	11	0.7	0	0.0	4	0.2
1,900	6	0.4	7	0.5	0	0.0	4	0.2
2,100	5	0.4	6	0.3	0	0.0	4	0.2
2,310	5	0.3	5	0.3	0	0.0	4	0.1
2,530	4	0.3	4	0.2	0	0.0	3	0.1
2,760	4	0.2	4	0.2	0	0.0	4	0.1
3,000	3	0.2	3	0.2	0	0.0	0	0.0
Check	23	3.9	18	2.6	21	2.9	21	3.3

* The check cultures represent the average of 20 replicates; all other values are the average of 5 replicates.

ADDITIONAL CROPS ON SOILS PREVIOUSLY TESTED

A previous publication (*4*) has discussed toxicity tests on 4 California soils, giving the data on the first 3 crops. This series was cropped four more times; and to complete the picture of the changes in toxicity that were revealed, table 1 has been prepared to show the results of the fifth and seventh crops. Values for the check cultures in this table represent the average of 20 replicates. All other values are the average of 5 replicates.

Considering all 7 runs, one sees that chlorate toxicity in the Stockton adobe clay, though highest at the beginning of the test, had dropped by the seventh run to a lower level than in the Yolo clay loam. The crop produced by the Stockton soil was, furthermore, consistently low. Although the initial toxicity seems related to the nitrate content of the soil (*5*), the loss in toxicity with time and cropping is caused by some soil factor apparently unrelated to fertility.

Toxicity in all 4 soils was lowered during these tests, and by the seventh run even that of the Fresno sandy loam had dropped to a value approximately that of the first run in the Yolo soil. By comparing points on the toxicity curve[5] for the first and seventh runs on these soils at the crop level of 1 gram, one finds the changes to be for Fresno sandy loam 150 to 560 p.p.m., or a difference of 410; for Columbia fine sandy loam 450 to 940 p.p.m., or a difference of 490; for Yolo clay loam 510 to 1,070 p.p.m., or a difference of 560; and for Stockton adobe clay 40 to 1,530 p.p.m., or a difference of 1,490. These are in the order of increasing clay content in these soils, but whether the changes are related to particle size or to some other property cannot be stated from these few tests.

EXPERIMENTAL METHODS ON EIGHTY SOILS

The soils and methods used in these tests have been described in detail in other papers (*4, 5*). The biological testing method developed through a series of stages from a simple technique involving single series of barley cultures in earthenware pots to a more carefully controlled practice with replication. One early concentration series is illustrated in figure 1. Concentrations of chlorate in these cultures, based on the air-dry weight of the soil, are 30, 120, 240, 375, 450, 600, and 900 p.p.m.

As these early tests soon showed the earthenware pots to be an uncontrolled factor, ordinary lacquered tin-plate cans were substituted. The No. 2 size of these cans holds 500 grams of most soils and is inexpensive

[5] Toxicity curves not published were constructed from table 1 and from table 9 of the earlier paper (*4*).

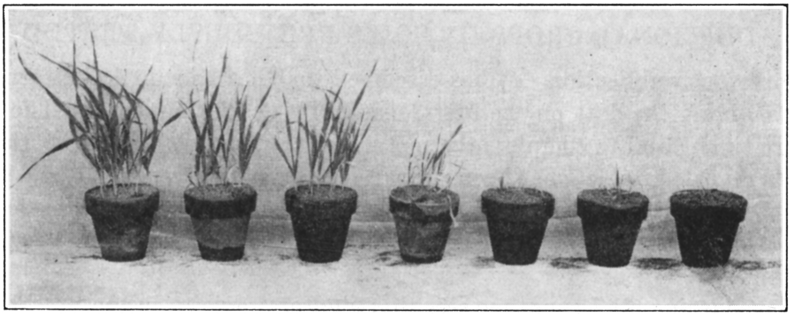

Fig. 1.—An early toxicity test with sodium chlorate in Yolo clay loam. Concentrations based on the air-dry soil are 30, 120, 240, 375, 450, 600, and 900 p.p.m. Barley was used as the indicator plant.

and convenient. Figure 2 shows a typical toxicity series in Ramada silt loam, an alluvial soil of intermediate texture and high fertility. In this series, concentrations from right to left are 0, 5, 15, 40, 80, 140, 220, 340, 490, and 680 p.p.m., based on the air-dry soil. This expanding series, developed after considerable experiment, has been used in the survey work reported in this and in an accompanying publication (*7*). As shown in the illustration, all tests were replicated three times.

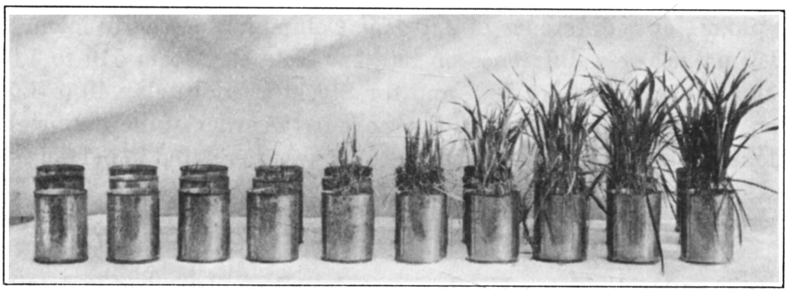

Fig. 2.—A test series with sodium chlorate in Ramada silt loam. Concentrations, based on the air-dry soil, are 680, 490, 340, 220, 140, 80, 40, 15, 5, and 0 p.p.m. Three replicates.

TOXICITY RESULTS ON EIGHTY SOILS

During the development of the testing method the significance of results was considered. One of the first series set up in cans was a chlorate-toxicity test involving 15 concentrations and 2 checks, or 17 cultures per series. This test was replicated ten times and carried through 3 croppings. Data on the first crop (table 2) show how much variation may be expected between individual replicates at the various chlorate levels. The average weight values in the last columns, if plotted, give a very smooth curve showing the relation between crop weight and chlorate concentration in the culture.

TABLE 2

TOXICITY OF SODIUM CHLORATE IN YOLO CLAY LOAM, AS SHOWN BY GROWTH OF INDICATOR PLANTS; 10 REPLICATIONS

(Harvested January 15, 1933)

Sodium chlorate expressed as p.p.m. $NaClO_3$ in air-dry soil	First replicate		Second replicate		Third replicate		Fourth replicate	
	Height	Fresh weight	Height	Fresh weight	Height	Fresh weight	Height	Fresh weight
p.p.m.	*cm*	*gm*	*cm*	*gm*	*cm*	*gm*	*cm*	*gm*
15	13.0	11.8	13.0	10.7	12.5	10.4	13.0	9.8
30	13.0	11.2	12.5	9.8	13.0	10.7	13.0	10.6
45	12.5	10.8	11.5	8.6	12.0	8.9	12.0	9.0
60	11.5	7.6	12.0	7.6	12.0	8.1	11.5	6.6
90	10.5	5.9	11.0	5.7	11.5	6.6	11.5	7.4
120	8.0	2.9	10.0	3.9	10.0	4.8	10.0	4.0
150	9.0	3.9	8.5	3.5	8.5	3.4	8.5	3.3
195	6.0	2.5	5.0	1.6	4.5	1.7	4.0	1.5
240	4.0	1.0	3.0	1.0	4.0	1.4	3.5	1.0
300	3.0	1.0	2.5	0.6	3.0	0.8	3.0	0.8
375	2.5	0.6	2.5	0.7	2.5	0.5	2.5	0.6
450	2.0	0.6	2.0	0.5	2.5	0.7	2.0	0.5
600	1.5	0.4	1.5	0.5	1.5	0.3	1.5	0.3
750	1.0	0.3	1.0	0.2	1.0	0.3	1.0	0.2
900	1.0	0.2	1.0	0.2	1.0	0.1	1.0	0.2
Check	13.0	10.5	13.0	10.1	12.0	10.3	13.5	11.5
Check	12.0	10.9	12.5	10.6	12.5	11.2	12.5	11.3

Sodium chlorate expressed as p.p.m. $NaClO_3$ in air-dry soil	Fifth replicate		Sixth replicate		Seventh replicate		Eighth replicate	
	Height	Fresh weight	Height	Fresh weight	Height	Fresh weight	Height	Fresh weight
p.p.m.	*cm*	*gm*	*cm*	*gm*	*cm*	*gm*	*cm*	*gm*
15	12.5	10.9	13.0	10.9	12.0	11.3	12.5	11.4
30	12.0	10.1	13.0	11.7	13.0	11.6	13.0	11.6
45	12.5	9.5	12.5	10.3	12.0	10.6	11.5	9.5
60	11.5	7.4	12.5	11.1	12.5	10.0	12.0	9.7
90	11.0	5.9	11.0	7.8	10.5	5.7	10.5	6.5
120	9.0	4.6	10.0	4.3	10.0	5.2	9.5	4.2
150	8.5	3.2	7.0	3.4	7.0	2.5	8.0	3.4
195	4.0	1.1	4.0	1.3	4.5	1.9	5.0	1.8
240	4.5	1.4	3.0	0.8	3.5	1.1	4.0	1.7
300	3.0	0.6	2.5	0.7	3.0	0.9	3.0	1.0
375	2.5	0.6	2.0	0.5	2.0	0.6	2.5	0.7
450	2.0	0.6	2.0	0.6	1.5	0.5	2.5	0.7
600	1.5	0.3	1.5	0.3	1.5	0.4	1.5	0.4
750	1.0	0.3	1.0	0.3	1.0	0.3	1.0	0.3
900	1.0	0.2	1.0	0.2	1.0	0.2	1.0	0.2
Check	13.0	11.0	13.0	11.4	13.5	11.7	13.0	11.2
Check	13.0	11.8	13.0	11.6	13.0	11.5	12.5	10.5

TABLE 2—(*Concluded*)

Sodium chlorate expressed as p.p.m. $NaClO_3$ in air-dry soil	Ninth replicate		Tenth replicate		Average		Average expressed as per cent of checks	
	Height	Fresh weight	Height	Fresh weight	Height	Fresh weight	Height	Fresh weight
p.p.m.	*cm*	*gm*	*cm*	*gm*	*cm*	*gm*	*per cent*	*per cent*
15	12.5	11.8	11.5	10.8	12.6	11.0	99.2	99.1
30	13.0	11.7	12.0	10.5	12.8	11.0	100.7	98.8
45	11.5	10.2	11.0	8.5	11.9	9.6	94.0	86.5
60	12.0	10.4	11.0	8.7	11.9	8.7	93.7	78.7
90	10.0	5.6	10.0	5.1	10.8	6.2	85.0	56.2
120	10.0	5.1	10.0	5.9	9.7	4.5	76.2	40.6
150	8.0	3.1	6.5	2.3	8.0	3.2	62.8	28.9
195	5.0	1.8	5.0	1.9	4.7	1.7	37.2	15.4
240	3.0	1.0	3.0	1.1	3.6	1.2	28.1	10.4
300	2.5	0.7	2.5	0.7	2.8	0.8	22.1	7.0
375	2.0	0.8	2.0	0.6	2.3	0.6	18.2	5.6
450	2.0	0.6	2.0	0.8	2.1	0.6	16.2	5.5
600	1.5	0.4	1.5	0.4	1.5	0.4	11.9	3.3
750	1.0	0.3	1.0	0.3	1.0	0.3	7.9	2.5
900	1.0	0.2	1.0	0.2	1.0	0.2	7.9	1.8
Check	12.5	11.3	12.0	12.1	12.8	11.1	101.5	100.3
Check	12.0	10.3	11.5	10.8	12.5	11.1	98.5	99.7

As too much work was involved in setting up and conducting tests involving this amount of replication, an attempt was made to reduce it by using only 5 replications. This arrangement was especially necessary because higher concentrations were needed if more than 1 cropping was to be used.

To ascertain the long-time behavior of arsenic, borax, and chlorate, series of tests using these chemicals in 4 California soils were established and have been reported—the borax results for 5 crops in a previous publication (*6*), the arsenic results for 7 crops in an accompanying paper (*7*), and the chlorate results in a previous paper (*4*) and in the present paper (table 1).

The early chlorate test indicated that crop production and toxicity were related, but with so few soils no generalization could be made. Consequently, chlorate tests were conducted on 80 type soils; and, with this number to judge from, the relation between high toxicity and low fertility became apparent. The soils used have been described in a companion paper (*7*). The technique was the same except that all chlorate tests included the 5 p.p.m. concentration and lacked that at 920 p.p.m.

Data on these tests, arranged in the order of increasing fertility as judged by crops on the untreated checks, are given in table 3. Where 2 or more series have the same crop weight in the checks, the ranking was determined by comparing total weights of the crops in the 3 check cultures. In making up the averages reported, the figures in the second decimal place have been discarded, so that the averages lack the detail of the original totals. Where the totals were the same for 2 or more series, the soil with the highest toxicity, as indicated by the fewest surviving cultures, was placed first.

The relation of high toxicity to low fertility is apparent from table 3 and figure 3. That texture has no effect upon toxicity is evident. Without doubt, when other factors are constant, chlorate toxicity is largely determined by the fertility of the treated soil.

Among the apparent exceptions, No. 23, Rositas fine sand, No. 36, Superstition gravelly sand, No. 50, Meloland fine sandy loam, and No. 66, Imperial clay, attract attention. These soils are all from the Imperial Valley. Formed under arid conditions, they are high in salts, with sulfates, chlorides, and bicarbonates in abundance. Whereas nitrates are reported most effective in reducing chlorate absorption by plants, other anions are also involved; and these 4 soils apparently exemplify this fact. These anions hinder the absorption of chlorate and reduce toxicity without increasing crop production as does nitrate. No. 3, Dunnigan clay, and No. 10, Tulare clay, are 2 other soils moderately high in salts and very low in fertility. These 6 constitute the only serious exceptions to be noted in table 3.

The factors limiting the crop produced on a given sample of soil are numerous and varied. Besides fertility they include temperature, light, humidity, length of day, and combinations of these as related to the microbiological processes occurring in the culture. Since most of these factors were under little or no control in the greenhouse where the toxicity studies have been made, tests at different times and on different samples of the same soil vary appreciably. Table 4 presents data on tests at various dates on a number of soils. As in the accompanying paper (*7*) on arsenic, these results indicate the variations caused by lack of constant culture conditions and stress the desirability of running comparative tests on many soils at one time.

Since the relation between application and crop produced varies when tests are run under varying environmental conditions and when different samples of a given soil type are used, nitrate content or possibly total anion content might be a better criterion for judging chlorate dosage than is crop production. For practical purposes, however, the simple biological test is convenient where greenhouse facilities are available; and when comparisons are made simultaneously on all soils to be tested, the results seem reliable enough to determine relative dosages for application in the field.

TABLE 3

Toxicity of Sodium Chlorate in 80 California Soils as Shown by Growth of Indicator Plants

No.	Soil type	Date of harvest	Chlorate concentration—$NaClO_3$ in p.p.m. in air-dry soil									
			0	5	15	40	80	140	220	340	490	680
			Fresh weight of plants									
			gm	*gm*	*gm*	*gm*	*gm*	*gm*	*gm*	*gm*	*gm*	*gm*
1	Aiken clay loam	Dec. 26, 1935	0.5	0.3	0.1	0.1				*		
2	Pinole loam	Dec. 26, 1935	1.2	1.3	0.5	0.1	0.1					*
3	Dunnigan clay	July 26, 1934	1.2	1.1	0.8	0.5	0.2	0.1				
4	Merced adobe clay	Dec. 26, 1935	1.4	1.5	1.3	0.3	0.1					
5	Conejo adobe clay	Dec. 26, 1935	1.4	1.3	0.5	0.1						*
6	Niland gravelly sand	May 15, 1935	1.4	1.2	0.6	0.5	0.3				*	
7	Aiken gravelly loam	Feb. 2, 1935	1.5	0.6	0.2	0.1			*			
8	Alamo adobe clay	Dec. 26, 1935	1.5	1.4	0.8	0.3	0.2					
9	Anita adobe clay	Dec. 26, 1935	1.6	1.5	0.6	0.1	0.1					
10	Tulare clay	Dec. 26, 1935	1.6	1.7	0.7	0.3	0.2	0.1				
11	Oakley sand	Dec. 26, 1935	1.7	0.9	0.4	0.1				*		
12	Corning gravelly loam	Feb. 1, 1935	1.7	1.3	0.4	0.1			*			
13	Fresno light clay	Dec. 26, 1935	1.7	1.0	0.5	0.1				*		
14	Yolo adobe clay	Dec. 26, 1935	1.8	1.2	0.4	0.2						
15	Tulare fine sandy loam	Dec. 26, 1935	1.8	1.2	0.6	0.2	0.1				*	
16	Tujunga sand	May 15, 1935	1.8	1.3	0.4	0.2	0.1				*	
17	Montezuma adobe clay	Dec. 26, 1935	1.8	1.5	0.5	0.2	0.1					
18	Clear Lake adobe clay	May 15, 1935	1.8	1.5	0.4	0.1	0.1					*
19	Farwell adobe clay	Dec. 26, 1935	1.8	1.4	0.6	0.3	0.1					*
20	Madera clay	Dec. 26, 1935	1.9	1.6	0.7	0.2	0.1					
21	Gridley loam	Dec. 26, 1935	1.9	1.6	0.8	0.4	0.1	0.1			*	
22	Landlow adobe clay	Dec. 26, 1935	1.9	2.0	1.5	0.5	0.2	0.1				
23	Rositas fine sand	May 15, 1935	2.0	1.8	1.0	0.8	0.4	0.2	0.2	0.1		
24	Sierra gravelly loam	Feb. 2, 1935	2.1	2.1	1.2	0.2	0.1	0.1			*	
25	Arbuckle clay loam	Aug. 19, 1934	2.1	1.9	1.0	0.3	0.2	0.1			*	
26	Panoche light loam	Dec. 26, 1935	2.1	1.7	0.7	0.3	0.1				*	
27	Diablo adobe clay	Dec. 26, 1935	2.2	2.0	1.2	0.4	0.2					
28	Stockton adobe clay	May 15, 1935	2.3	2.3	1.7	0.8	0.3	0.2	0.1			
29	Mariposa silt loam	Feb. 1, 1935	2.3	2.2	1.9	0.2	0.1	0.1				
30	Vina loam	Dec. 26, 1935	2.4	2.1	1.7	0.6	0.2	0.1				*
31	Willows adobe clay	Feb. 2, 1935	2.5	1.8	1.0	0.2	0.1				*	
32	Oakdale coarse sandy loam	Dec. 26, 1935	2.5	2.3	2.0	0.7	0.2	0.1				*
33	Tehama loam	Dec. 26, 1935	2.6	2.2	1.6	0.3	0.1				*	
34	Chino silty clay loam	May 17, 1935	2.6	2.3	1.3	0.7	0.4	0.2	0.1			
35	Holland loamy gravelly sand	Feb. 1, 1935	2.6	2.0	1.5	0.4	0.2	0.1		*		
36	Superstition gravelly sand	May 17, 1935	2.6	2.3	1.5	1.0	0.8	0.6	0.3	0.1		*
37	Marvin silty clay loam	Dec. 26, 1935	2.7	2.7	2.4	0.8	0.3	0.1				
38	Sites adobe clay	Feb. 1, 1935	2.8	3.0	2.3	0.5	0.3	0.1			*	
39	Salinas clay	Dec. 26, 1935	2.8	2.3	1.1	0.7	0.4	0.1				
40	Placentia light loam	May 15, 1935	2.8	2.4	1.4	0.8	0.4	0.1			*	
41	Foster fine sandy loam	Dec. 26, 1935	3.0	2.3	1.4	0.7	0.2	0.1				
42	Greenfield coarse sandy loam	Dec. 26, 1935	3.0	2.7	1.1	0.4	0.1	0.1				*

* Germination of seeds prevented at this and all higher concentrations. Fresh weight of plants in cultures between reported weight and point of no germination was less than 0.1 gram.

TABLE 3—(*Concluded*)

No.	Soil type	Date of harvest	Chlorate concentration—$NaClO_3$ in p.p.m. in air-dry soil									
			0	5	15	40	80	140	220	340	490	680
			Fresh weight of plants									
			gm	*gm*	*gm*	*gm*	*gm*	*gm*	*gm*	*gm*	*gm*	*gm*
43	Porterville adobe clay...	Dec. 26, 1935	3.0	2.8	1.9	0.7	0.4	0.1	0.1			
44	Rocklin sandy loam.....	Feb. 2, 1935	3.0	2.8	2.0	0.4	0.2	0.1	0.1			*
45	Salinas fine sandy loam..	Dec. 26, 1935	3.0	2.9	2.4	0.5	0.3	0.1				
46	Hanford fine sandy loam	Dec. 26, 1935	3.1	2.4	1.3	0.7	0.4	0.2	0.1			
47	Montezuma adobe clay..	May 15, 1935	3.1	3.1	2.6	0.9	0.4	0.2				*
48	Honcut loam............	Dec. 26, 1935	3.1	3.2	3.0	1.4	0.4	0.2	0.1			
49	Redding gravelly loam..	Jan. 11, 1936	3.2	2.7	2.7	1.3	0.4	0.1				*
50	Meloland fine sandy loam..................	May 17, 1935	3.2	3.3	3.2	2.4	2.1	1.6	1.1	0.9	0.5	0.4
51	Ramona sandy loam....	May 17, 1935	3.3	3.2	1.6	1.0	0.6	0.3	0.1		*	
52	Antioch clay loam.......	Dec. 26, 1935	3.3	3.5	3.2	1.5	0.6	0.3	0.1			
53	Merced fine sandy loam..	Dec. 26, 1935	3.6	3.6	2.4	0.8	0.3	0.2				
54	Yolo loam...............	Feb. 1, 1935	3.7	3.5	3.2	0.9	0.4	0.1			*	
55	Delano fine sandy loam..	Dec. 26, 1935	3.7	3.4	3.3	1.6	0.5	0.3	0.1			
56	Pleasanton loam........	Dec. 26, 1935	3.8	4.0	3.5	1.9	0.7	0.4	0.2			
57	Hanford sandy loam....	Dec. 26, 1935	3.9	3.4	2.3	1.2	0.5	0.2	0.1	0.1		
58	Madera loam............	May 17, 1935	3.9	3.8	3.3	1.4	0.4	0.1			*	
59	Yolo fine sandy loam....	Feb. 1, 1935	3.9	4.1	3.9	1.0	0.5	0.1			*	
60	Fresno sandy loam......	May 15, 1935	4.0	3.9	3.1	2.5	1.3	0.7	0.3	0.1		*
61	Yolo clay................	Feb. 1, 1935	4.1	4.0	3.9	1.3	0.5	0.1				
62	Arbuckle gravelly sandy loam..................	Feb. 2, 1935	4.1	4.3	4.0	1.9	0.7	0.2	0.1	0.1		
63	San Joaquin loam.......	May 17, 1935	4.1	3.9	3.4	1.3	1.0	0.5	0.2	0.1		
64	Chualar fine sandy loam.	Dec. 26, 1935	4.1	3.8	3.3	1.4	0.5	0.2				
65	Dublin adobe clay......	Dec. 26, 1935	4.1	3.5	2.4	1.1	0.7	0.4	0.2	0.1	0.1	*
66	Imperial clay............	May 17, 1935	4.3	4.4	3.6	1.9	1.2	0.9	0.6	0.4	0.2	0.1
67	Sierra sandy loam.......	Feb. 2, 1935	4.4	4.6	3.9	1.6	0.4	0.1			*	
68	Capay adobe clay.......	Feb. 1, 1935	4.5	4.7	4.5	0.9	0.2	0.1			*	
69	Esparto clay............	Feb. 1, 1935	5.4	5.8	6.3	3.0	1.0	0.2	0.1			
70	Sites fine sandy loam....	Feb. 2, 1935	5.6	6.1	5.6	3.8	1.5	0.4	0.1	0.1		*
71	Farwell loam............	Dec. 26, 1935	5.6	5.5	5.3	3.2	1.2	0.3	0.1			
72	Ramada silt loam.......	Dec. 26, 1935	5.7	5.8	4.8	3.2	1.5	0.7	0.2	0.1		
73	Egbert loam.............	May 15, 1935	6.2	6.0	5.9	5.0	4.6	3.2	1.4	0.7	0.4	0.1
74	Columbia silty clay loam	May 17, 1935	6.5	6.8	7.3	5.7	4.0	2.1	1.2	0.7	0.5	0.2
75	Panoche adobe clay.....	Dec. 26, 1935	6.9	6.2	5.5	4.0	2.5	1.2	0.8	0.4	0.3	0.1
76	Columbia fine sandy loam..................	May 15, 1935	7.8	7.5	7.8	6.0	3.8	2.6	1.8	1.1	0.7	0.3
77	Sacramento clay loam...	May 15, 1935	7.9	7.3	7.7	6.1	3.2	2.1	0.9	0.5	0.2	0.1
78	Yolo silt loam...........	Feb. 1, 1935	8.8	8.3	8.3	8.4	7.1	4.9	3.3	0.9	0.6	0.2
79	Yolo clay loam..........	Feb. 1, 1935	9.2	8.8	9.6	8.6	6.4	1.5	1.1	0.5	0.3	0.1
80	Yolo clay loam..........	May 15, 1935	11.2	12.0	11.8	9.4	7.1	4.7	2.9	1.4	0.8	0.4

* Germination of seeds prevented at this and all higher concentrations. Fresh weight of plants in cultures between reported weight and point of no germination was less than 0.1 gram.

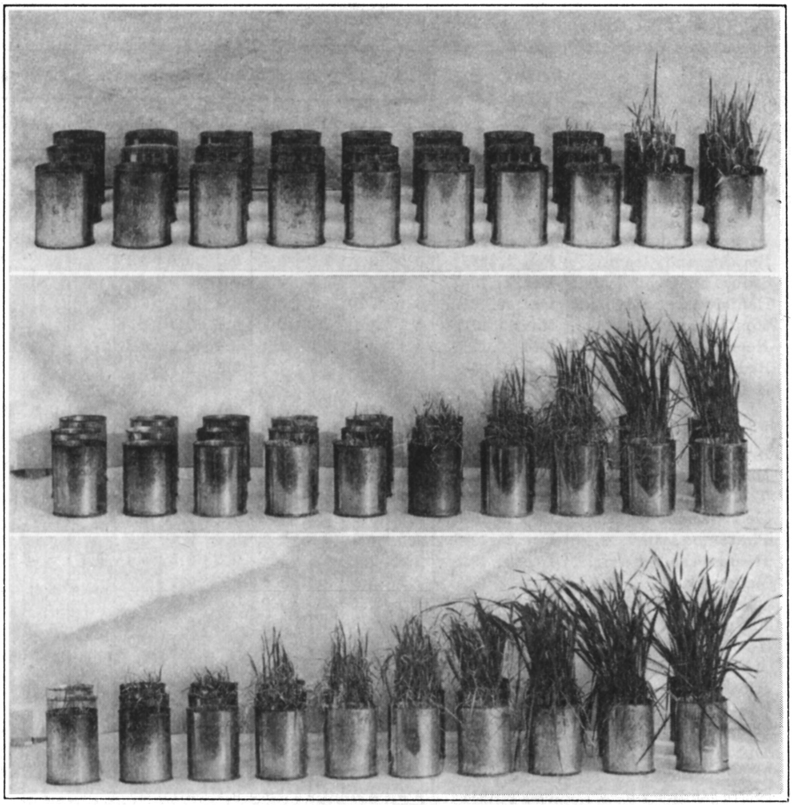

Fig. 3.—Test series with sodium chlorate in Aiken gravelly loam, Hanford sandy loam, and Panoche adobe clay. Concentrations run from 680 to 5 p.p.m. $NaClO_3$ with check cultures on the extreme right. Three replicates. Toxicity is closely correlated with fertility and is unaffected by texture.

DISCUSSION

To use sodium chlorate in weed control in semiarid regions one must know, among other things, the relative influence of its vertical distribution in the soil, and the comparative susceptibility of the plant species involved. Distribution, as previously explained (*2, 3, 4, 11*), depends largely upon leaching and is related both to precipitation and to soil type. Susceptibility in the practical sense includes: first, tolerance of the toxic action of the herbicide and, second, root distribution as related to penetration of the chemical into the soil.

How rainfall and soil type affect distribution of chlorate in the soil has been indicated (*2, 3, 4, 11*). With the extreme variations that occur in soil

TABLE 4

COMPARATIVE RESULTS OF TOXICITY TESTS ON REPEATED RUNS WITH SODIUM CHLORATE IN 6 CALIFORNIA SOILS

Soil type	Run No.	Date of harvest	Chlorate concentration—$NaClO_3$ in p.p.m. in air-dry soil									
			0	5	15	40	80	140	220	340	490	680
			Fresh weight of plants									
			gm	*gm*	*gm*	*gm*	*gm*	*gm*	*gm*	*gm*	*gm*	*gm*
Arbuckle clay loam....	1*	Feb. 1, 1935	2.1	1.7	0.7	0.1	0.1					
	2†	Aug. 19, 1934	2.1	1.9	1.0	0.3	0.2	0.1				
	3‡	Dec. 4, 1936	3.6	3.4	2.3	0.4	0.1	0.1				
	4§	Feb. 17, 1936	4.4	4.8	6.6	0.9	0.5	0.1	0.1			
Columbia fine sandy loam................	1†	May 15, 1935	7.8	7.5	7.8	6.0	3.8	2.6	1.8	1.1	0.7	0.3
	2‡	Nov. 26, 1936	8.8	9.2	9.1	8.1	5.2	2.2	0.7	0.1		
	3¶	Dec. 7, 1933	9.2	9.1	8.8	7.3	5.5	3.5	2.4	1.9	0.9	0.4
	4§	Feb. 17, 1936	11.4	11.0	10.4	8.8	6.5	4.4	4.1	1.0	0.6	0.1
Fresno sandy loam.....	1‡	Nov. 26, 1936	3.4	3.3	2.9	1.4	0.4	0.1	0.1			
	2†	May 15, 1935	4.0	3.9	3.1	2.5	1.3	0.7	0.3	0.1		
	3¶	Dec. 7, 1933	6.0	5.1	3.9	2.8	2.3	1.2	0.4	0.2	0.1	
	4§	Feb. 17, 1936	7.9	8.4	8.3	6.0	3.3	1.8	0.5			
Stockton adobe clay....	1‡	Nov. 26, 1936	2.2	1.6	1.1	0.3	0.1					
	2¶	Dec. 7, 1933	2.3	2.2	1.9	1.0	0.5	0.1	0.1			
	3†	May 15, 1935	2.3	2.3	1.7	0.8	0.3	0.2	0.1			
	4§	Feb. 17, 1936	5.5	5.0	4.0	1.4	0.4	0.1	0.1			
Yolo fine sandy loam...	1*	Aug. 19, 1934	3.6	3.0	1.7	0.7	0.4	0.2	0.1			
	2†	Feb. 1, 1935	3.9	4.1	3.9	1.0	0.5	0.1				
	3§	Feb. 17, 1936	5.6	5.6	4.8	4.9	3.2	1.1	0.1	0.1		
	4‡	Dec. 4, 1936	7.7	6.7	5.7	3.2	1.4	0.7	0.3	0.1		
Yolo clay loam.........	1†	Feb. 1, 1935	9.2	8.8	9.6	8.6	6.4	1.5	1.1	0.5	0.3	0.1
	2‡	Nov. 26, 1936	9.3	6.6	6.1	4.0	2.9	1.7	0.9	0.3	0.2	0.1
	3‖	Oct. 29, 1932	9.7	11.0	11.3	11.0	9.8	7.9	5.5	3.3	2.3	1.0
	4*	Aug. 19, 1934	11.0	10.1	8.9	6.7	4.4	2.6	1.2	0.7	0.3	0.2
	5¶	Dec. 7, 1933	11.1	10.7	9.5	7.8	6.0	4.6	3.8	1.8	1.2	0.2
	6**	Jan. 15, 1933	11.1	11.0	11.0	10.0	7.0	3.6	1.4	0.7	0.5	0.3
	7†	May 15, 1935	11.2	12.0	11.8	9.4	7.1	4.7	2.9	1.4	0.8	0.4
	8§	Feb. 17, 1936	17.0	17.4	16.5	11.3	9.1	4.9	2.6	0.9	0.3	0.1

* Repeat run standard check series.
† From table 3.
‡ Chemical nutrient series, from Crafts (*5*).
§ Nutrient series, from Crafts (*5*).
¶ By interpolation from Crafts (*4*, table 9).
‖ By interpolation from Crafts (*4*, table 1).
** By interpolation from table 2.

profiles and in the distribution of precipitation, exact recommendations are difficult to formulate, and local experience based upon empirical tests and field observation is essential to successful practice.

Plant susceptibility cannot easily be put on a comparative basis because it is hard to grow a wide variety of weed species simultaneously under constant culture conditions. Some work of this type has been done

(*3, 8, 13*), however, and more is contemplated. Collection of information is largely a matter of methods; and, as these are developed, all common weed species will be tested. The most valuable generalization coming from work thus far is that plants native to arid regions seem to tolerate more chlorate than plants of humid climates.

For any given plant, toxicity of chlorate seems to depend largely upon the numbers and kinds of anions in the culture medium. In leached soils, nitrate effects far overshadow those of other anions (*5*). In arid regions chlorides, sulfates, and bicarbonates enter the problem; and in these soils, probably, conductivity and nitrate content of soil extracts might be combined to provide a toxicity index. Perhaps, eventually, simple tests for nitrates and total salts will provide adequate information for formulating chlorate dosages.

Meanwhile an attempt will be made to draw up a schedule for the 80 soils that have been tested. At the outset, using field experience and the results of many plot tests, a basic scale of dosages adequate for controlling weeds that yield readily to chlorate is suggested. Such weeds are St. Johnswort, morning-glory, Russian knapweed, Canada thistle, and Johnson grass. Adequate penetration into the soil as determined by rainfall and soil type is assumed, and application should be made at such a time that decomposition of the chlorate is minimized. Under these conditions the soils of table 3, in which chlorate application up to 80 p.p.m. prohibited growth, should receive 1 pound per square rod. Those limiting growth at 140 p.p.m. should receive 2 pounds; at 220 p.p.m., 3 pounds; at 340 p.p.m., 4 pounds; at 490 p.p.m., 6 pounds; at 680 p.p.m., 8 pounds.

Under ideal conditions, of course, these dosages might be reduced even to one-half the values given. Under average conditions, this schedule is necessary. Against hoary cress, Bermuda grass, camel thorn, and white horse nettle this basic dosage should be doubled. Other common perennials range somewhere between these limits.

To workers versed in soil characteristics, one fact is apparent: though tests of the type in table 3 give a broad view of chlorate toxicity because this response is related to fertility, any generalized application of the dosage schedule may fail in many specific cases because fertility may vary so widely within a soil type. Numerous factors such as previous treatment, organic matter content, microflora, and the inevitable variations in deposition inherent in alluvial soils particularly, all tend to cause differences in fertility. Given such difficulties, one criterion may often prove useful in determining dosage in the field: the relative development of weeds or of crops in different localities at any given time is often the best available measure of fertility, and a casual survey of plant growth always helps in determining application rate of chlorate.

The chlorate dosages necessary on certain soils and against some weeds are not only too expensive but harmful to the soils. When dosage exceeds 8 pounds per square rod, the cost approaches that of carbon bisulfide. On agricultural areas, considering the time lost through the residual sterility from chlorate and the undesirability of introducing sodium into the replaceable base complex, it seems advisable to use carbon bisulfide and return the land rapidly to crop production. But on waste areas, where permanence is to be desired, especially if deep-rooted perennials occur, chlorate is the logical herbicide in all cases.

As these studies emphasize, there are situations where chlorate is the best herbicide, other situations where carbon bisulfide is preferable and, as an accompanying paper (*7*) points out, some conditions favor the use of arsenic. One should not forget that in weed control numerous reagents have proved effective. In a comprehensive plan, all these should be used. The field operator should familiarize himself with the various methods and their limitations and should use each reagent to maximum advantage in the situation to which it is adapted.

SUMMARY

Repeated cropping of chlorate-treated soils resulted in continued loss of toxicity. Toxicity to the first crop (*4*) was highest in Stockton adobe clay, second in Fresno sandy loam, third in Columbia fine sandy loam, and lowest in Yolo clay loam. By the seventh crop toxicities had shifted so that Fresno sandy loam stood highest, Columbia fine sandy loam second, Yolo clay loam third, and Stockton adobe clay lowest. Although fertility largely governs the initial toxicity of chlorate in soils (*5*), some other factor controls the change in toxicity with time and cropping.

The toxicity-testing method used in studies reported here and in previous papers has been developed from a simple concentration series with barley in earthenware pots to the present technique using oats in replicated series in No. 2 cans. A test with 10 replicates gave excellent results but proved labor-consuming and slow.

Using a simplified technique with 10 concentrations replicated three times, 80 agricultural soils of California were tested for initial toxicity when treated with sodium chlorate.

The general relation of toxicity to fertility (*5*) was confirmed. In nearly every case, soils deviating markedly from the expected results proved to have come from arid regions and consequently to be high in total salts.

Repeated tests on a given soil type conducted at different times vary in the toxicities shown and reveal less correlation between toxicity and fertility than do the series run in large numbers for comparative purposes (table 3). For this reason, soils to be compared should be tested simultaneously.

Leaching and species susceptibility are known to affect chlorate toxicity. Under average field conditions a schedule of dosages of from 1 to 8 pounds per square rod should control susceptible species effectively, the dosages between these limits being fixed by the fertility of the soil. Under ideal conditions this schedule might be reduced. Under average conditions and against resistant species it should be doubled.

When chlorate dosage runs above 8 pounds per square rod, the cost approaches that of carbon bisulfide. Considering the loss of crops and the undesirability of introducing sodium into the replaceable base complex, carbon bisulfide seems preferable under these conditions.

Several chemicals, including arsenic, chlorate, and carbon bisulfide, have proved useful in weed control. In a comprehensive program all should be used, each under the conditions where it is most effective and economical.

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