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CONTENTS

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TOXICITY STUDIES WITH ARSENIC IN EIGHTY CALIFORNIA SOILS[1, 2]

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INTRODUCTION

THE INCREASING USE of arsenic in herbicides, insecticides, and soil sterilants presents problems of great economic importance. The farmer, needing practical methods for controlling pests, seeks the cheapest and most effective reagents, whereas the soils investigator must try to conserve our agricultural areas for present and future generations.

Arsenic, being cheap, readily available, and extremely toxic, is in constant demand for weed and insect-pest control and is recommended by many companies, often without specific knowledge of dosages required, effective methods of application, or ultimate effects upon the soil.

In the field use of arsenic, workers naturally ask what form is most effective for the particular type of treatment being used, how much will be needed for the desired results, and how long the results will last. The soils investigator wants to know what the effects of long-time accumulation of arsenicals in soils will be, whether the soil is permanently harmed when crop yields have been reduced, and how one may remove or remedy the toxic condition resulting from arsenic in the soil.

A previous publication (*6*)[5] presented data on arsenic toxicity[6] in four

[1] Received for publication January 17, 1938.

[2] This paper was made possible by the coöperative project on control of noxious weeds conducted by the California Agricultural Experiment Station and the Division of Cereal Crops and Diseases, Bureau of Plant Industry, United States Department of Agriculture.

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

[6] The term "toxicity" has acquired a wide variety of meanings. For purposes of the present group of papers (*7, 8, 13*) 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

CHARACTERISTICS OF CALIFORNIA SOILS USED IN TOXICITY SERIES*

(All samples from surface 4 inches)

No.	Soil type	Origin	Mode of formation	Stage of development	Color	Remarks†	Moisture content of cultures	Soil used in each culture
				Sands				
							per cent	*gm*
1	Holland loamy gravelly sand	Acid igneous	Primary	Immature	Brown	Slightly acid	12.8	500
2	Niland gravelly sand	Mixed	Secondary alluvial	Youthful	Light brown-gray	Calcareous; saline	10.0	500
3	Oakley sand	Mixed	Secondary aeolian	Youthful	Light brown	Slightly acid	6.5	600
4	Rositas fine sand	Mixed	Secondary alluvial	Recent	Light brown-gray	Alkali; calcareous	14.5	500
5	Superstition gravelly sand	Mixed	Secondary alluvial	Youthful	Light gray	Calcareous	12.4	500
6	Tujunga sand	Acid igneous	Secondary alluvial	Recent	Light brown-gray	Neutral	12.3	500
				Gravelly and sandy loams				
							per cent	*gm*
7	Aiken gravelly loam	Basic igneous	Primary	Semimature	Red	Slightly acid	13.3	500
8	Arbuckle gravelly sandy loam	Sedimentary	Secondary alluvial	Youthful	Brown	Neutral	10.0	500
9	Chualar fine sandy loam	Acid igneous	Secondary alluvial	Immature	Dark brown	Neutral	13.0	600
10	Columbia fine sandy loam	Mixed	Secondary alluvial	Recent	Light gray-brown	Neutral	18.0	500
11	Corning gravelly loam	Mixed	Secondary alluvial	Semimature	Brown-red	Moderately acid	12.2	500
12	Delano fine sandy loam	Acid igneous	Secondary alluvial	Immature	Light red-brown	Basic	15.0	600
13	Foster fine sandy loam	Acid igneous	Secondary alluvial	Recent	Dark brown-gray	Neutral	16.2	500
14	Fresno sandy loam‡	Acid igneous	Secondary alluvial	Mature	Brown-gray	Alkaline	15.0	600
15	Greenfield coarse sandy loam	Acid igneous	Secondary alluvial	Youthful	Brown	Neutral	15.0	600
16	Hanford sandy loam	Acid igneous	Secondary alluvial	Recent	Light brown	Neutral	14.0	500
17	Hanford fine sandy loam	Acid igneous	Secondary alluvial	Recent	Light brown	Neutral	13.8	500
18	Meloland fine sandy loam	Mixed	Secondary alluvial	Recent	Light gray-brown	Alkali; calcareous	18.3	500
19	Merced fine sandy loam	Acid igneous	Secondary alluvial	Semimature	Dark gray	Neutral	15.6	500
20	Oakdale coarse sandy loam	Acid igneous	Secondary alluvial	Recent	Gray-brown	Neutral	10.8	600
21	Ramona sandy loam	Acid igneous	Secondary alluvial	Immature	Brown	Neutral	10.7	500
22	Redding gravelly loam	Mixed	Secondary alluvial	Mature	Brown-red	Moderately acid	13.3	500
23	Rocklin sandy loam	Acid igneous	Secondary alluvial	Mature	Brown-red	Slightly acid	17.9	500
24	Salinas fine sandy loam	Mixed	Secondary alluvial	Immature	Dark brown-gray	Neutral	14.4	500
25	Sierra gravelly loam	Acid igneous	Primary	Semimature	Brown-red	Moderately acid	12.5	500
26	Sierra sandy loam	Acid igneous	Primary	Semimature	Brown-red	Moderately acid	13.5	500
27	Sites fine sandy loam	Sedimentary	Primary	Semimature	Brown-red	Moderately acid	12.0	500
28	Tulare fine sandy loam	Mixed	Secondary alluvial	Immature	Light gray	Calcareous	20.0	500
29	Yolo fine sandy loam	Sedimentary	Secondary alluvial	Recent	Brown	Neutral	15.0	500

	Loams							
							per cent	*gm*
30	Egbert loam	Mixed organic	Secondary alluvial	Immature	Dark gray	Slightly acid	32.0	500
31	Farwell loam	Basic igneous	Secondary alluvial	Youthful	Chocolate-brown	Neutral	17.6	500
32	Gridley loam	Basic igneous	Secondary alluvial	Semimature	Brown	Slightly acid	22.1	500
33	Honcut loam	Basic igneous	Secondary alluvial	Recent	Red-brown	Slightly acid	21.4	500
34	Madera loam	Acid igneous	Secondary alluvial	Mature	Brown	Neutral	12.0	500
35	Panoche light loam	Sedimentary	Secondary alluvial	Recent	Brown-gray	Calcareous	14.0	500
36	Pinole loam	Sedimentary	Secondary alluvial	Immature	Yellow-brown	Slightly acid	15.0	500
37	Placentia light loam	Acid igneous	Secondary alluvial	Semimature	Brown-red	Neutral	10.4	500
38	Pleasanton loam	Sedimentary	Secondary alluvial	Immature	Brown	Neutral	16.7	500
39	Pond heavy loam	Acid igneous	Secondary alluvial	Immature	Brown-gray	Alkaline; calcareous	11.7	500
40	San Joaquin loam	Acid igneous	Secondary alluvial	Mature	Brown-red	Moderately acid	21.0	500
41	Tehama loam	Mixed	Secondary alluvial	Immature	Light yellow-brown	Neutral	13.6	500
42	Vina loam	Basic igneous	Secondary alluvial	Recent	Brown	Neutral	22.5	500
43	Yolo loam	Sedimentary	Secondary alluvial	Recent	Brown	Neutral	20.1	500
	Silt and clay loams							
							per cent	*gm*
44	Aiken clay loam	Basic igneous	Primary	Semimature	Red	Slightly acid	21.3	400
45	Antioch clay loam	Sedimentary	Secondary alluvial	Mature	Dark brown	Moderately acid	15.8	600
46	Arbuckle clay loam	Sedimentary	Secondary alluvial	Recent	Brown	Neutral	18.5	500
47	Chino silty clay loam	Acid igneous	Secondary alluvial	Youthful	Dark gray	Neutral	20.4	500
48	Columbia silty clay loam	Mixed	Secondary alluvial	Recent	Light gray-brown	Neutral	26.0	500
49	Mariposa silt loam	Sedimentary	Primary	Semimature	Brown-yellow	Moderately acid	20.0	500
50	Marvin silty clay loam	Mixed	Secondary alluvial	Immature	Light brown	Neutral	24.4	500
51	Ramada silt loam	Mixed	Secondary alluvial	Recent	Light yellow-brown	Neutral	19.7	500
52	Sacramento clay loam	Mixed	Secondary alluvial	Immature	Dark gray	Slightly acid	28.2	400
53	Yolo silt loam	Sedimentary	Secondary alluvial	Recent	Brown	Neutral	18.1	500
54*a*	Yolo clay loam§	Sedimentary	Secondary alluvial	Recent	Brown	Neutral	30.0	500
54*b*	Yolo clay loam§	Sedimentary	Secondary alluvial	Recent	Brown	Neutral	30.0	500

* Information from (*14*, *15*, and *16*).

† Data given in this column were taken from (*14*, *15*, and *16*). They apply to the soil types in general. No such determinations were made on the samples collected.

‡ The Fresno sandy loam used in this and in previous tests is designated as brown phase. Shaw now classifies this soil in the Dinuba series (*14*).

§ Soil 54*a* harvested December 22, 1934; soil 54*b* harvested June 4, 1935.

(Table concluded on next page.)

TABLE 1—(*Concluded*)

No.	Soil type	Origin	Mode of formation	Stage of development	Color	Remarks†	Moisture content of cultures	Soil used in each culture
				Clays				
							per cent	*gm*
55	Alamo adobe clay	Mixed	Secondary alluvial	Mature	Dark gray	Neutral	27.3	500
56	Anita adobe clay	Basic igneous	Secondary alluvial	Immature	Dark brown	Neutral	26.3	500
57	Capay adobe clay	Sedimentary	Secondary alluvial	Immature	Gray-brown	Neutral	27.9	500
58	Clear Lake adobe clay	Sedimentary	Secondary alluvial	Youthful	Gray-black	Neutral	24.4	500
59	Conejo adobe clay	Basic igneous	Secondary alluvial	Recent	Gray-black	Neutral	29.2	500
60	Diablo adobe clay	Sedimentary	Primary	Semimature	Gray-black	Neutral	23.1	500
61	Dublin adobe clay	Sedimentary	Secondary alluvial	Recent	Gray-black	Neutral	33.7	500
62	Dunnigan clay	Mixed	Secondary alluvial	Semimature	Brown-gray	Saline	28.0	500
63	Esparto clay	Sedimentary	Secondary alluvial	Youthful	Light brown	Slightly acid	22.4	500
64	Farwell adobe clay	Basic igneous	Secondary alluvial	Youthful	Chocolate-brown	Neutral	25.3	500
65	Fresno light clay	Acid igneous	Secondary alluvial	Mature	Brown-gray	Alkaline	28.0	500
66	Imperial clay	Mixed	Secondary alluvial	Recent	Light gray	Alkali	28.8	500
67	Landlow adobe clay	Basic igneous	Secondary alluvial	Mature	Dark brown	Calcareous subsoil	22.1	500
68	Madera clay	Acid igneous	Secondary alluvial	Mature	Brown	Neutral	25.0	500
69	Merced adobe clay	Acid igneous	Secondary alluvial	Semimature	Black	Neutral	49.1	500
70	Montezuma adobe clay	Sedimentary	Secondary alluvial	Semimature	Gray-black	Neutral	28.0	500
71	Montezuma adobe clay	Sedimentary	Secondary alluvial	Semimature	Gray-black	Neutral	33.0	500
72	Panoche adobe clay	Sedimentary	Secondary alluvial	Recent	Brown-gray	Calcareous	25.0	500
73	Porterville adobe clay	Basic igneous	Secondary alluvial	Immature	Chocolate-brown	Neutral	26.5	500
74	Salinas clay	Mixed	Secondary alluvial	Immature	Dark brown-gray	Neutral	20.0	500
75	Sites adobe clay	Sedimentary	Primary	Semimature	Red-brown	Moderately acid	22.5	500
76	Stockton adobe clay	Basic igneous	Secondary alluvial	Mature	Gray-black	Basic	32.0	500
77	Tulare clay	Mixed	Secondary alluvial	Immature	Light gray	Calcareous	28.0	500
78	Willows adobe clay	Sedimentary	Secondary alluvial	Semimature	Dark brown	Neutral	30.5	500
79	Yolo adobe clay	Sedimentary	Secondary alluvial	Recent	Brown	Neutral	26.6	500
80	Yolo clay	Sedimentary	Secondary alluvial	Recent	Brown	Neutral	26.3	500

† Data given in this column were taken from (*14*, *15*, and *16*). They apply to the soil types in general. No such determinations were made on the samples collected.

California soils. The range of concentrations used in these early trials was not sufficient to show what changes in toxicity take place with repeated cropping; furthermore, two of the soils used were not quite typical. The Stockton adobe clay for the first experiment was taken near a drainage ditch and proved to be mostly subsoil that behaved anomalously. The Columbia fine sandy loam was not so fertile and was coarser-textured than that used in later tests. A retest was therefore devised to correct these difficulties.

When the results, which are presented in a later section, were compared with those of the previous experiment, it was impossible to formulate general relations between toxicity and soil type suitable for prescribing dosages. Therefore a simpler test was devised that could be used simultaneously on many soils. The results of these simple comparative tests form the main subject of this report.

MATERIALS AND METHODS

Selection and Sampling of Soils.—In conjunction with the Division of Soil Technology at Davis, sampling areas for type soils were located on soil-survey maps. The samples, taken from the top 4 inches after removal of the surface débris, were collected during the summer dry season, and wherever possible, near fence lines or from similar locations where they had not recently been disturbed.

After transportation to Davis, they were pulverized to pass a ¼-inch screen and were stored in burlap bags in a dry place until used. Table 1 presents descriptive data obtained from various sources (*14, 15, 16*). A casual survey will indicate the wide variety tested. Collected throughout the length and breadth of the state, the soils illustrate almost every textural grade, mode of formation, color, and reaction; and most important agricultural soils are represented by one or more types.

Biological Testing of Toxicity.—The biological testing method used in studying arsenic toxicity in these soils has been described (*6, 9*). It consists of growing a series of cultures in No. 2 cans in the greenhouse. The air-dry soils are weighed into the cans, which have been tared, bits of coarse gravel being added to bring them to a standard weight. The arsenic is added in solution in the water used to bring the soils to field capacity. Dry soil and solution are rapidly mixed, each in 3 successive portions to insure uniform distribution. After moistening, 13 Kanota oat seeds are planted in each can; and wrapping paper is laid over the cultures to prevent drying. The paper is removed as soon as the seeds germinate, and the plants are thinned to 10 at the end of the first week of growth. There-after, they are watered as required by growth, sunshine, and humidity. After 30 days, they are cut off at the soil level. The fresh weights of the tops are recorded, and are used as a measure of toxicity of the arsenic applied.

The stock arsenic solution is prepared by mixing 4 parts of screened, dry, arsenic trioxide, 1 part of C.P. stick caustic soda, and 3 parts of water. When heated slightly, this mixture goes into solution, giving a clear sirupy liquid containing 50 per cent As_2O_3 by weight. The diluted solution for application to the soils is prepared by making up 10 grams of this to a liter. The resulting solution, containing 5,000 p.p.m. of As_2O_3, is measured out with a burette and further diluted to the appropriate strength. This concentration of 5,000 p.p.m. is particularly convenient in making up cultures in 500-gram lots of soil, since the number of cubic centimeters added, multiplied by 10, gives the p.p.m. based on the weight of the air-dry soil.

The concentration series used in the tests on the 80 soils ran as follows: 0, 15, 40, 80, 140, 220, 340, 490, 680, and 920 p.p.m. As_2O_3 in the air-dry soil. All series were run in triplicate. In determining the amount of water required to moisten these soils, a simple method has been used. When 50-gram lots of the soils have been weighed into test tubes, water is added—2.5 cc, 5.0 cc, 7.5 cc, or 10.0 cc, according to the textural grade of the soil. After 24 hours, the depth of the soil column moistened is measured, and the volume of water necessary to wet 100 grams of soil calculated. By an appropriate factor, the volume needed in the cultures is determined. This method has proved simpler and more satisfactory than determining the moisture equivalent, since it allows for the moisture present in the air-dry soil and for factors of soil preparation that must be considered in the latter method.

Data on the water-holding capacities of the soils and on the weights of soil used in the cultures are reported in table 1.

EXPERIMENTAL RESULTS

Retests on Four Soil Types.—In order to remedy some of the difficulties experienced in the initial trial, a more extended experiment was set up, with an expanding series of concentrations ending with cultures containing 3,000 p.p.m.

The soils for this retest were more carefully selected than those in the earlier experiment. The Stockton adobe clay was carefully selected from an area along a fence, undisturbed for many years and never affected except by shallow plowing. The Columbia fine sandy loam of this and later experiments was somewhat more fertile and a bit finer-textured than that of the previous tests. The Yolo clay loam and the Fresno sandy loam were the same.

TABLE 2

TOXICITY OF SODIUM ARSENITE IN 4 CALIFORNIA SOILS AS SHOWN BY GROWTH OF INDICATOR PLANTS; EFFECTS OF TIME AND CROPPING*

Sodium arsenite expressed as p.p.m. As_2O_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
First run, harvested December 29, 1933								
p.p.m.	*cm*	*gm*	*cm*	*gm*	*cm*	*gm*	*cm*	*gm*
10	36	8.5	18	1.9	29	5.1	32	6.8
30	35	8.0	16	1.7	26	3.6	32	6.7
60	35	7.8	14	1.2	20	1.9	31	5.9
100	35	7.5	12	1.0	8	0.7	30	5.5
150	33	6.6	10	0.9	7	0.5	27	4.8
210	33	6.2	9	0.8	5	0.1	20	2.6
280	31	4.9	10	0.8	0	0.0	9	0.7
360	26	3.3	8	0.6	0	0.0	7	0.5
450	16	2.0	7	0.5	0	0.0	3	0.3
550	8	0.8	5	0.4	0	0.0	0	0.0
660	8	0.6	4	0.3	0	0.0	0	0.0
780	6	0.4	5	0.3	0	0.0	0	0.0
910	4	0.2	4	0.2	0	0.0	0	0.0
1,050	3	0.1	4	0.1	0	0.0	0	0.0
Check	36	9.1	21	2.0	28	5.5	33	7.3
Third run, harvested May 31, 1934								
p.p.m.	*cm*	*gm*	*cm*	*gm*	*cm*	*gm*	*cm*	*gm*
10	34	9.6	21	3.4	26	4.4	29	5.4
30	34	9.8	21	3.2	26	4.3	28	6.1
60	34	9.8	22	3.0	25	3.9	28	5.6
100	32	8.4	20	2.3	23	3.4	26	4.5
150	30	6.2	19	2.1	20	2.7	21	2.7
210	28	5.3	15	1.4	16	1.8	18	2.0
280	24	3.5	11	1.0	13	1.5	14	1.5
360	21	2.5	9	0.5	14	1.3	12	1.2
450	18	2.1	8	0.4	9	0.8	11	0.9
550	16	1.8	8	0.3	7	0.5	10	0.6
660	13	1.3	8	0.4	6	0.2	9	0.5
780	11	0.9	8	0.4	6	0.3	8	0.3
910	11	0.9	8	0.4	5	0.1	6	0.2
1,050	11	0.6	8	0.4	0	0.0	6	0.1
1,200	10	0.5	7	0.2	0	0.0	0	0.0
1,360	9	0.5	7	0.1	0	0.0	0	0.0
1,530	8	0.2	0	0.0	0	0.0	0	0.0
1,710	7	0.1	0	0.0	0	0.0	0	0.0
Check	30	8.1	20	3.1	23	4.3	26	5.1

* Each value given is an average of 5 replicates.

TABLE 2—(*Concluded*)

Sodium arsenite expressed as p.p.m. As_2O_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 January 9, 1935								
p.p.m.	*cm*	*gm*	*cm*	*gm*	*cm*	*gm*	*cm*	*gm*
10	29	5.9	21	2.4	25	3.7	28	4.8
30	30	6.3	22	2.8	26	3.5	27	4.8
60	29	6.0	22	2.6	25	3.5	28	5.3
100	29	6.5	23	3.4	26	3.5	29	5.4
150	31	6.9	25	3.7	26	3.4	29	5.4
210	31	6.4	23	3.0	23	2.8	27	4.6
280	30	6.1	22	2.8	23	2.6	25	3.4
360	27	4.9	17	1.9	19	1.9	23	2.7
450	26	4.5	18	1.7	15	1.4	20	1.9
550	24	3.7	12	1.2	11	0.8	18	1.5
660	23	3.1	13	1.3	11	0.7	17	1.4
780	22	2.7	12	1.2	10	0.6	14	1.1
910	21	2.4	11	1.2	9	0.5	13	0.9
1,050	19	2.0	11	1.1	9	0.5	11	0.7
1,200	17	1.5	11	1.0	8	0.3	11	0.6
1,350	15	1.2	11	0.8	8	0.3	10	0.5
1,530	13	1.0	10	0.7	7	0.2	9	0.4
1,710	12	0.9	10	0.5	6	0.1	8	0.4
1,900	12	0.9	9	0.5	6	0.1	8	0.3
2,100	11	0.7	8	0.5	5	0.1	7	0.3
2,310	10	0.7	8	0.4	0	0.0	7	0.3
2,530	9	0.5	7	0.3	0	0.0	7	0.3
2,760	9	0.5	7	0.3	0	0.0	6	0.3
3,000	9	0.5	6	0.3	0	0.0	6	0.3
Check	26	5.0	20	3.0	25	3.5	26	4.5
Seventh run, harvested November 14, 1935								
p.p.m.	*cm*	*gm*	*cm*	*gm*	*cm*	*gm*	*cm*	*gm*
150	..	...	..	...	16	1.9	..	...
210	..	...	..	...	15	1.9	18	2.7
280	..	...	14	1.8	14	1.6	16	1.8
360	24	5.4	14	1.6	12	1.5	14	1.5
450	24	4.8	12	1.2	11	1.1	13	1.3
550	23	3.9	10	1.0	9	0.7	12	1.0
660	21	3.1	10	1.0	8	0.6	10	0.9
780	20	2.7	10	1.1	8	0.5	9	0.7
910	18	2.3	11	1.1	7	0.4	9	0.6
1,050	15	1.7	11	1.2	7	0.4	7	0.4
1,200	14	1.5	11	1.1	6	0.3	5	0.2
1,360	13	1.4	10	1.0	6	0.3	4	0.1
1,530	12	1.1	8	0.8	5	0.2	4	0.1
1,710	10	1.1	7	0.6	5	0.2	4	0.1
1,900	10	0.8	7	0.4	4	0.2	3	0.1
2,100	8	0.6	6	0.4	3	0.1	3	0.1
2,310	7	0.5	5	0.2	0	0.0	0	0.0
2,530	7	0.4	5	0.2	0	0.0	0	0.0
2,760	6	0.5	4	0.2	0	0.0	0	0.0
3,000	6	0.4	3	0.1	0	0.0	0	0.0
Check	21	4.2	15	2.2	16	2.3	18	3.0

When complete, this experiment contained 24 concentrations and 4 checks, each consisting of 5 replicates. Similar series were established at about the same time for sodium chlorate and borax. The first 3 crops on the chlorate series were reported earlier (*6*), as were the first, third, and fifth crops of the borax tests (*9*). The first, third, fifth, and seventh crops of the present experiment on the arsenic series are given in table 2. In each run only the cultures having growth in one or more of the soils are reported, all higher concentrations having no growth. By the fifth run all concentrations in the Yolo and Stockton soils had so greatly decreased in toxicity that plants survived in them. Since the lower concentrations were producing crops as heavy as the checks or heavier, the first 4 were not included in the seventh run in table 2; and even higher concentrations were omitted in 3 of the soils.

The most noticeable result of the retest is the difference in behavior of the Stockton soil. Though producing a low yield, the plants survived through the lowest 13 concentrations; a fact indicating a toxicity similar to that of the Yolo clay loam. The change in toxicity, furthermore, practically kept pace with that of the Yolo soil. Evidently the results reported earlier (*6*) gave an inaccurate picture of the toxicity in adobe soils.

Tests on Eighty Soils.—Yield data on the eighty soils tested are presented in table 3. Obviously the toxicity results follow a definite pattern, toxicity being highest in the sands and lowest in the clays. There are a few notable exceptions, later to be considered in detail. The general relation may be more easily scrutinized in the summary in table 4, where averages for the 5 soil groups are compiled.

The water-holding capacities of the various soil groups, as shown in these averaged results, may be correlated with textural grade; and the arsenic toxicities show a related change. Conceivably, certain factors that enable the soil to hold water against the force of gravity are involved in the availability of applied arsenic to plants.

For comparing soil groups, a series of toxicity values have been calculated, based upon the yield of the untreated checks; these results, presented in table 4, are graphed in figure 1. Although the numbers in these averages are not great enough to give perfectly smooth curves and although the exceptional results on a few individual soils tend in places to overshadow the general relations, the correlation of toxicity and textural grade is obvious. The expression of this relation, regardless of the crops produced, is the principal finding in this study.

The relation of toxicity to textural grade is further illustrated by the crops in Oakley sand, Farwell loam, and Aiken clay loam shown in figure 2. These series all contain a 5 p.p.m. culture; and all concentrations being

TABLE 3

TOXICITY OF SODIUM ARSENITE IN 80 CALIFORNIA SOILS AS SHOWN BY GROWTH OF INDICATOR PLANTS

No.	Soil type	Date of harvest	Arsenic concentration—As_2O_3 in p.p.m. basis air-dry soil									
			0	15	40	80	140	220	340	490	680	920
			Fresh weight of plants									
	Sands											
			gm	*gm*	*gm*	*gm*	*gm*	*gm*	*gm*	*gm*	*gm*	*gm*
1	Holland loamy gravelly sand	Dec. 23, 1934	1.8	2.0	1.5	1.3	0.6	0.3	*			
2	Niland gravelly sand	June 5, 1935	1.0	0.7	0.4			*				
3	Oakley sand	Jan. 10, 1936	1.9	1.6	1.3	0.8	0.4	*				
4	Rositas fine sand	June 5, 1935	1.2	1.1	0.9	0.1		*				
5	Superstition gravelly sand	June 5, 1935	1.6	1.3	1.4	0.9	0.1	*				
6	Tujunga sand	June 4, 1935	0.5	0.4	0.6	0.1	*					
	Gravelly and sandy loams											
			gm	*gm*	*gm*	*gm*	*gm*	*gm*	*gm*	*gm*	*gm*	*gm*
7	Aiken gravelly loam	Dec. 23, 1934	1.6	1.7	1.6	1.8	1.7	1.8	1.6	0.4	0.3	0.1
8	Arbuckle gravelly sandy loam	Dec. 23, 1934	2.1	2.3	1.8	1.9	0.9	0.3	*			
9	Chualar fine sandy loam	Jan. 10, 1936	5.3	4.9	2.8	1.9	0.1		*			
10	Columbia fine sandy loam	June 4, 1935	4.4	4.8	4.0	3.0	1.5	0.3	*			
11	Corning gravelly loam	Dec. 23, 1934	1.6	1.5	1.4	1.2	0.8	0.3	0.2	*		
12	Delano fine sandy loam	Jan. 10, 1936	4.5	4.5	3.9	2.6	0.9	0.7	0.1			
13	Foster fine sandy loam	Jan. 10, 1936	3.3	2.8	0.4	0.1		*				
14	Fresno sandy loam	June 4, 1935	3.0	2.2	1.4	0.1	*					
15	Greenfield coarse sandy loam	Jan. 10, 1936	4.3	3.8	1.2	0.3	0.1	*				
16	Hanford sandy loam	Jan. 10, 1936	4.3	4.0	2.5	0.7	0.2	0.1	*			
17	Hanford fine sandy loam	Jan. 10, 1936	4.0	3.4	2.9	1.0	0.2	*				
18	Meloland fine sandy loam	June 5, 1935	1.9	1.9	1.5	1.0	0.2	*				
19	Merced fine sandy loam	Jan. 10, 1936	4.4	3.8	3.1	1.7	0.4	*				
20	Oakdale coarse sandy loam	Jan. 10, 1936	3.0	2.8	2.4	0.8	0.1		*			
21	Ramona sandy loam	June 5, 1935	3.0	3.0	2.6	1.6	0.3			*		
22	Redding gravelly loam	Jan. 10, 1936	3.3	3.1	2.8	2.5	2.1	0.7	0.1	*		
23	Rocklin sandy loam	Dec. 23, 1934	1.5	1.3	1.2	0.8	0.5	0.2	0.1		*	
24	Salinas fine sandy loam	Jan. 10, 1936	3.7	3.5	3.0	1.9	1.3	0.5	*			
25	Sierra gravelly loam	Dec. 23, 1934	1.8	1.9	1.6	1.8	1.6	1.5	0.7	0.6	0.2	*
26	Sierra sandy loam	Dec. 23, 1934	3.2	3.1	2.7	2.4	1.2	0.3	0.1	*		
27	Sites fine sandy loam	Dec. 23, 1934	1.9	1.9	1.4	1.3	0.7	0.2	0.1	*		
28	Tulare fine sandy loam	Jan. 10, 1936	2.1	1.8	1.3	0.3	0.2		*			
29	Yolo fine sandy loam	Dec. 22, 1934	3.5	3.3	3.1	2.9	2.6	0.6	0.3	0.2	*	
	Loams											
			gm	*gm*	*gm*	*gm*	*gm*	*gm*	*gm*	*gm*	*gm*	*gm*
30	Egbert loam	June 4, 1935	3.9	3.4	3.2	2.7	2.2	1.6	1.0	0.2	*	
31	Farwell loam	Jan. 10, 1936	7.3	7.2	6.1	5.4	3.2	1.0	0.1	*		
32	Gridley loam	Jan. 10, 1936	2.5	2.7	2.6	2.5	2.5	0.5	0.2			*
33	Honcut loam	Jan. 10, 1936	4.1	3.8	3.4	2.5	1.3	0.3	0.1	*		
34	Madera loam	June 5, 1935	3.2	2.7	2.6	2.2	1.7	0.5	0.3		*	
35	Panoche light loam	Jan. 10, 1936	2.7	2.4	2.2	0.8	0.2	0.2		*		
36	Pinole loam	Jan. 10, 1936	1.4	1.4	1.4	1.2	0.9	0.7	0.5		*	

* Seeds in cultures at this and higher concentrations failed to germinate. 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	Arsenic concentration—As_2O_3 in p.p.m. basis air-dry soil									
			0	15	40	80	140	220	340	490	680	920
			Fresh weight of plants									
		Loams—(*Continued*)										
			gm	*gm*	*gm*	*gm*	*gm*	*gm*	*gm*	*gm*	*gm*	*gm*
37	Placentia light loam.....	June 4, 1935	2.7	2.4	2.2	1.7	0.1		*			
38	Pleasanton loam.........	Jan. 10, 1936	4.4	4.2	4.0	2.4	0.6	0.2	*			
39	Pond heavy loam.......	Jan. 10, 1936	0.0		*							
40	San Joaquin loam.......	June 5, 1935	3.4	2.6	2.7	1.8	1.3	0.6	0.2		*	
41	Tehama loam...........	Jan. 10, 1936	2.6	2.4	2.2	0.8	0.2		*			
42	Vina loam...............	Jan. 10, 1936	3.3	3.6	3.4	3.2	3.0	0.9	0.2		*	
43	Yolo loam...............	Dec. 22, 1934	3.8	3.6	3.5	3.1	2.2	0.3	0.2	0.1	*	
		Silt and clay loams										
			gm	*gm*	*gm*	*gm*	*gm*	*gm*	*gm*	*gm*	*gm*	*gm*
44	Aiken clay loam.........	Jan. 10, 1936	1.0	1.0	0.9	0.9	0.9	0.8	0.7	0.6	0.6	0.3
45	Antioch clay loam.......	Jan. 10, 1936	3.9	4.5	3.9	4.0	2.8	1.2	0.5	*		
46	Arbuckle clay loam.....	Dec. 23, 1934	2.4	2.4	1.9	1.9	1.1	1.3	0.3	0.1	*	
47	Chino silty clay loam...	June 5, 1935	1.6	1.5	1.5	1.4	0.7	0.1		*		
48	Columbia silty clay loam..................	June 5, 1935	4.2	3.8	3.7	2.8	2.7	2.4	2.4	1.5	1.1	0.3
49	Mariposa silt loam.......	Dec. 22, 1934	2.0	1.9	1.8	1.4	1.5	0.7	0.6	0.3	*	
50	Marvin silty clay loam..	Jan. 10, 1936	3.4	3.9	3.5	3.1	1.9	0.7	0.4		*	
51	Ramada silt loam.......	Jan. 10, 1936	6.5	6.3	6.2	3.8	1.6	0.3	0.1	*		
52	Sacramento clay loam...	June 5, 1935	4.1	4.2	3.9	2.7	2.0	0.8	0.5			*
53	Yolo silt loam...........	Dec. 22, 1934	8.9	8.6	6.9	6.5	3.4	0.9	0.3	0.2	*	
54*a*	Yolo clay loam..........	Dec. 22, 1934	9.8	9.4	9.5	8.8	5.1	1.4	0.4	0.2	*	
54*b*	Yolo clay loam..........	June 4, 1935	8.7	8.8	7.6	6.9	5.8	4.0	0.6	0.4	*	
		Clays										
			gm	*gm*	*gm*	*gm*	*gm*	*gm*	*gm*	*gm*	*gm*	*gm*
55	Alamo adobe clay.......	Jan. 10, 1936	1.7	1.7	1.6	1.4	1.3	0.7	0.5	0.3	0.2	0.1
56	Anita adobe clay........	Jan. 10, 1936	2.1	2.1	1.8	1.7	1.2	1.1	0.9	0.7	0.2	0.1
57	Capay adobe clay.......	Dec. 23, 1934	3.7	3.7	3.4	3.5	3.1	2.1	1.4	1.5	0.5	0.5
58	Clear Lake adobe clay...	June 4, 1935	1.6	1.5	1.4	1.1	1.1	0.7	0.4	0.2	0.1	
59	Conejo adobe clay.......	Jan. 10, 1936	1.8	1.9	1.5	1.2	0.8	0.8	0.7	0.5	0.3	0.2
60	Diablo adobe clay.......	Jan. 10, 1936	2.6	2.4	1.9	1.5	0.8	0.4	0.2	0.2	0.1	
61	Dublin adobe clay......	Jan. 10, 1936	4.7	4.9	4.6	4.4	4.3	3.7	3.2	2.0	0.5	0.3
62	Dunnigan clay..........	Dec. 23, 1934	1.8	1.8	1.6	1.1	0.3	0.3	0.2	0.2	*	
63	Esparto clay............	Dec. 22, 1934	4.4	4.5	4.0	3.9	3.2	2.5	1.4	0.5	0.1	
64	Farwell adobe clay......	Jan. 10, 1936	2.5	2.4	2.4	1.9	1.6	1.2	0.8	0.7	0.3	0.1
65	Fresno light clay........	Jan. 10, 1936	1.0	1.5	1.3	0.6	0.4	0.3	0.2	0.2		
66	Imperial clay............	June 5, 1935	3.0	2.9	2.8	2.4	2.1	1.6	0.8	0.5		
67	Landlow adobe clay.....	Jan. 10, 1936	1.8	2.2	2.1	2.0	1.7	1.6	0.8	0.6	0.2	
68	Madera clay.............	Jan. 10, 1936	2.3	2.1	1.7	1.6	1.1	0.9	0.5	0.5	0.1	
69	Merced adobe clay......	Jan. 10, 1936	1.5	1.5	1.5	1.3	1.1	1.1	0.7	0.4	0.3	0.2
70	Montezuma adobe clay..	June 4, 1935	2.3	2.1	1.8	1.2	1.1	0.9	0.5	0.3	0.2	
71	Montezuma adobe clay..	Jan. 10, 1936	2.1	2.3	2.0	2.1	1.9	1.0	0.5	0.1	*	
72	Panoche adobe clay.....	Jan. 10, 1936	8.1	8.1	6.9	6.6	5.4	3.7	2.5	0.7	0.4	0.2
73	Porterville adobe clay...	Jan. 10, 1936	4.2	3.8	3.5	2.0	0.9	0.3	0.2	0.2	*	
74	Salinas clay.............	Jan. 10, 1936	3.5	3.5	3.3	3.2	1.1	0.3	0.2		*	
75	Sites adobe clay.........	Dec. 22, 1934	2.8	3.0	2.5	2.0	1.6	1.1	0.5	0.3	0.1	0.1
76	Stockton adobe clay.....	April 24, 1936	2.9	2.3	1.8	1.8	1.5	0.8	0.6	0.4	0.1	
77	Tulare clay..............	Jan. 10, 1936	1.6	1.5	1.4	0.5	0.3	0.1	*			
78	Willows adobe clay......	Dec. 23, 1934	2.0	2.2	1.9	1.6	1.2	0.7	0.7	0.4	0.1	0.1
79	Yolo adobe clay.........	Jan. 10, 1936	1.9	1.9	1.7	1.5	0.7	0.2	0.1		*	
80	Yolo clay................	Dec. 22, 1934	4.4	4.8	4.4	4.5	4.1	3.9	2.6	2.2	1.0	0.1

* Seeds in cultures at this and higher concentrations failed to germinate. Fresh weight of plants in cultures between reported weight and point of no germination was less than 0.1 gram.

comparable in the 3 series, the heavier soils show obviously lower toxicities, while crop-producing power (table 3) varies in no regular way with textural grade.

Figure 3, showing 3 toxicity series in adobe soils, further illustrates this point. Although the crop yields vary widely, being high in the Panoche soil, intermediate in Dublin, and low in Merced (table 3), toxicities are strictly comparable in the 3 soils. These series lack the 5-p.p.m. cultures but have the 920-p.p.m. ones.

TABLE 4

SUMMARY OF RESULTS: TOXICITY OF SODIUM ARSENITE IN CALIFORNIA SOILS AS SHOWN BY GROWTH OF INDICATOR PLANTS

Soils	Water	Arsenic concentration—As_2O_3 in p.p.m. on the basis of air-dry soil									
		0	15	40	80	140	220	340	490	680	920
		Fresh weight of plants									
	per cent	*gm*	*gm*	*gm*	*gm*	*gm*	*gm*	*gm*	*gm*	*gm*	*gm*
Sands	11.4	1.33	1.18	1.02	0.53	0.18	0.05				
Gravelly and sandy loams	14.3	3.12	2.88	2.20	1.46	0.77	0.33	0.14	0.05		
Loams	17.9	3.49	3.26	3.04	2.33	1.48	0.52	0.21	0.02		
Silt and clay loams	22.7	4.71	4.69	4.28	3.68	2.46	1.22	0.57	0.28	0.14	0.05
Clays	27.6	2.82	2.79	2.50	2.18	1.70	1.23	0.81	0.52	0.18	0.08
		Results expressed as a percentage of checks									
	per cent	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*
Sands	11.4	100	88.8	76.7	30.6	13.5	3.8				
Gravelly and sandy loams	14.3	100	91.6	70.5	46.8	24.6	10.6	4.5	1.6		
Loams	17.9	100	93.5	87.1	66.8	42.4	14.9	6.0	0.6		
Silt and clay loams	22.7	100	99.5	91.0	78.1	52.3	25.9	12.1	5.9	3.0	1.1
Clays	27.6	100	99.2	88.6	77.4	60.3	43.6	28.7	18.4	6.4	2.8

A more detailed study of the data in table 3 shows many minor variations in toxicity within the groups designated on the basis of soil texture. Though the general relation shown between texture and toxicity is valuable, its usefulness would be enhanced if the exceptions could be explained and anticipated in the field, as is possible in several cases.

The soils most obviously out of agreement are Aiken gravelly loam, Aiken clay loam, and Columbia silty clay loam. The two Aiken soils—residual soils from basic igneous rock—are deep red. They have demonstrated an immense capacity to render phosphate unavailable and by analogy should do the same with arsenic. Tests in the field and greenhouse show this to be true. Earlier, the red iron oxide content of these soils was thought to explain their immense capacity to reduce arsenic toxicity (*10*). Judging from recent experiments, however, peculiar colloids at least partly account for this phenomenon. This property of rendering arsenic unavailable, though common to all red soils, is less pronounced in those from acid igneous rocks. Among the gravelly and sandy loams (in addition to the Aiken), the Corning, Delano, Redding, Rocklin, Sierra, and Sites soils all contain more or less of this material and all show relatively low toxicities. Incidentally, red iron oxide has been used to lower

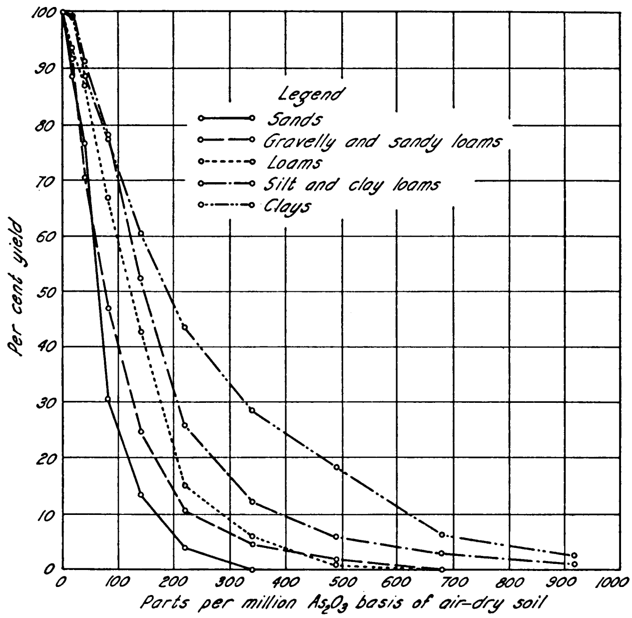

Fig. 1.—The relation between textural grade and arsenic toxicity from the summarized results of table 4.

arsenic solubility in filter beds made of soil (*10*). A great capacity for reducing arsenic toxicity is apparently characteristic of all red soils used in these tests, so that dosages must be set with this factor in mind, more arsenic being required than would ordinarily be applied on the basis of textural grade alone.

The Columbia soils, recent alluvial deposits from the floodwaters of the Sacramento River, come from a mixture of acid and basic igneous rocks from the Sierras with sedimentary rocks from the Coast Range. During deposition, the heavier particles settle out along the river banks, while the finer ones are deposited farther from the main channel. To obtain a silty clay loam it was necessary to visit the very edge of the alluvial deposits. The source of soil used in these experiments was a spot

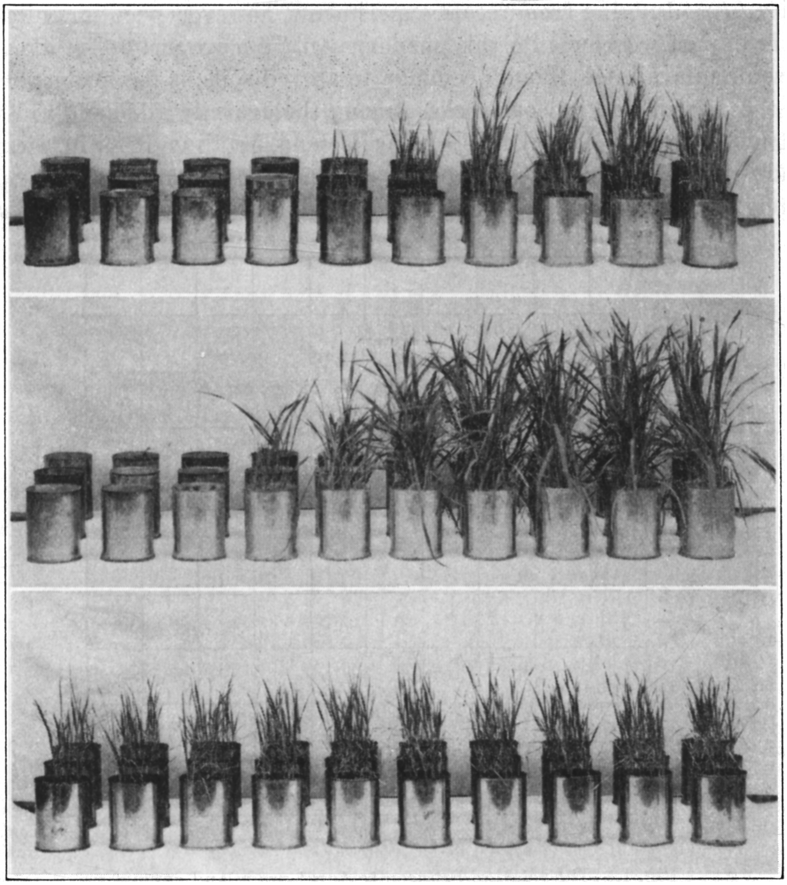

Fig. 2.—Culture series in Oakley sand, Farwell loam, and Aiken clay loam illustrating the relation between textural grade and arsenic toxicity. The As_2O_3 concentrations are 680, 490, 340, 220, 140, 80, 40, 15, 5, and 0 p.p.m., based on the air-dry soil.

about 3 miles west of Sacramento near the main highway, where the Columbia soil occurs as a thin layer about 18 inches deep, overlying an extremely heavy, black Sacramento clay. Such a soil might be expected to contain a large proportion of the colloidal fractions characteristic of the soils from the three available rock sources. Though the sample used contained considerable silt, it undoubtedly had, in addition, enough colloids from the red Aiken and Sierra soils and the brown Yolo soils to explain the low toxicity. The coarser Columbia fine sandy loam obtained only a few miles farther north consisted largely of fine sand and silt, without enough of these active colloids to give it an unusual behavior.

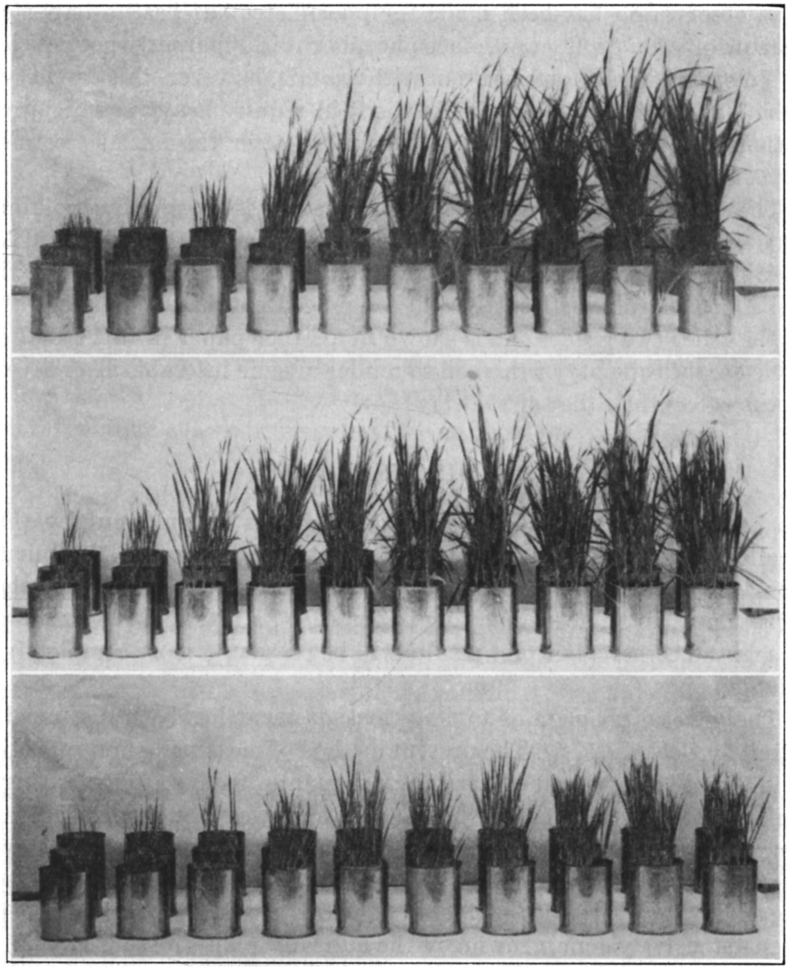

Fig. 3.—Culture series showing arsenic toxicity in Panoche adobe clay, Dublin adobe clay, and Merced adobe clay. Although fresh-weight yields of crops on these soils vary widely, the toxicity is approximately the same in all three. These series lack the 5 p.p.m. cultures. The As_2O_3 concentrations are 920, 680, 490, 340, 220, 140, 80, 40, 15, and 0 p.p.m.

Exceptional results are also shown by the Yolo soil in these experiments. Being easily obtainable, a full series of textural grades of this soil was used to show the effect of particle size within a single soil series. The choice of the Yolo series for this purpose was unfortunate in that the two lighter types act like heavy soils, whereas the adobe behaved like a lighter type. The behavior of the lighter types may be explained by their colloids, which have an extreme capacity to render arsenic unavailable.

This observation has been made for phosphates but has no important bearing on crop production, since phosphorus is apparently not deficient in Yolo soils. In soil sterilization with arsenic, however, this capacity is a critical factor, for Yolo soils in the field require heavy arsenic applications (*5*), and toxicity decreases rapidly after the initial treatment (*5, 6,* and table 2).

The abnormal behavior of the Yolo adobe clay is less readily explained. This soil required no more water for moistening than the clay and less than the clay loam. Though its colloids are of such a form as to give this soil adobe characteristics, the total colloid content may be less than that of the other two grades. As is shown in another paper in this issue (*13,* table 3), the capacity of this soil to render arsenic insoluble after several weeks is less than that of the clay.

DISCUSSION

To be widely applicable, the general relations brought out by these studies should rest upon chemical interpretation and practical confirmation through field-plot testing. Chemical studies on a number of these soils appear in an accompanying paper (*13*) ; a few field-plot tests will be mentioned here, but plot results will be presented more completely in a later paper.

The general problem of toxicity measurement has been discussed in detail by Cook (*2, 3, 4*). The present method of measuring and reporting height and fresh weight of the indicator plants 30 days after planting in soils moistened with the herbicide solutions was standardized several years ago and has proved entirely satisfactory. These values, however, are only comparative; for practical use they must be calibrated by checking against graded series of treated plots. Although this checking has not been extensively done, growing of the indicator plants on soils from plots having known degrees of sterility has shown that yields of 0.2 gram or less per can represent practical sterilization. Such comparisons seem sufficiently reliable to justify a tentative schedule of dosages, offered later in this paper.

Since fresh weight is by far the more valuable of the two toxicity criteria used, height has been omitted from tables 3, 4, and 5. Obviously, relative growth rate (*4*) cannot be used as a criterion of toxicity in the type of testing reported here, since the soil cultures could not be returned to the original weight for determination of growth increments. The work involved in repeated weighings on the large numbers of cultures run simultaneously in these tests was, furthermore, not feasible.

Before making the more practical interpretations, the errors and limitations of the biological testing methods used should be considered. Since the greenhouse in which these tests were conducted had only partial temperature control and practically no control of light, humidity, and length of day, results from culture series run at different seasons vary. Table 5 reports tests conducted at different dates upon the same soils. These data illustrate variations in toxicity resulting from the lack of constant culture conditions and, in the cases of Yolo clay loam and Stockton adobe clay, from the use of different samples. They emphasize the desirability of conducting comparative tests simultaneously on as many samples as possible. The soils in table 3 were tested in 3 lots, 2 of 20 each and 1 of 40. Though testing all 80 at one time would have been better, the work presents practical difficulties. Had it been done, the general relation shown between texture and toxicity would probably not have been appreciably changed.

The moisture conditions of the cultures are another matter for consideration. One might think that allowing the cultures to dry down periodically to the permanent wilting point would increase the arsenic concentration and hence the toxicity. In certain series, the moisture was varied in a number of soils (footnotes ¶ and ||, table 5). Judging from the results, arsenic toxicity is not seriously affected by the method of watering. This matter will be discussed more fully in a companion paper (*13*).

The biological test is definitely limited in scope by the sensitivity of the indicator plant. Since, however, the practical application of the results is in weed control, this drawback is not serious. The biological method, furthermore, gives a direct index to the availability and hence to the toxicity or crop-limiting power of the toxicant, which is impossible to obtain by chemical analysis. Considering the easy operation and the simple, inexpensive equipment needed, this method is very practical for testing toxicity of herbicides in soils.

RECOMMENDED DOSAGES OF ARSENIC FOR SOIL STERILIZATION

Clearly, these studies show that arsenic dosages for soil sterilization will vary between wide limits. Recommendations can at best be only approximate because of the complex relations between toxicity as related to availability, permanence as affected by leaching, and susceptibility as determined by the arsenic tolerance of the weed species concerned. Table 6 presents a dosage schedule based on plots and the present toxicity

TABLE 5

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

Soil type	Run No.	Date of harvest	Arsenic concentration—As_2O_3 in p.p.m. on the basis of air-dry soil									
			0	15	40	80	140	220	340	490	680	920
			Fresh weight of plants									
			gm	*gm*	*gm*	*gm*	*gm*	*gm*	*gm*	*gm*	*gm*	*gm*
Columbia fine sandy loam.	1*	June 10, 1933*. . .	4.6	4.6	4.4	4.1	3.0	1.7	0.3	0.1		
	2†	Dec. 29, 1933†	7.3	6.8	6.5	5.7	5.0	2.2	0.5	0.1		
	3‡	June 4, 1935‡	4.4	4.8	4.0	3.0	1.5	0.3				
	4§	Apr. 24, 1936§	13.5	11.1	9.9	5.5	1.4	0.2				
Delano fine sandy loam.	1‡	Jan. 10, 1936‡	4.5	4.5	3.9	2.6	0.9	0.7	0.1			
	2¶	Mar. 16, 1937¶	2.9	2.5	1.8	0.7	0.3	0.5				
	3‖	Mar. 16, 1937‖	2.6	2.2	1.7	0.6	0.3	0.2				
Fresno sandy loam. . .	1*	June 10, 1933*	2.9	2.4	1.4	0.6	0.4	0.2				
	2†	Dec. 29, 1933†	5.5	4.6	3.1	1.2	0.5	0.1				
	3‡	June 4, 1935‡	3.0	2.2	1.4	0.1						
	4§	Apr. 24, 1936§	7.2	4.0	2.6	0.5	0.2					
	5¶	Mar. 16, 1937¶	4.7	3.8	2.2	0.7	0.2	0.2				
	6‖	Mar. 16, 1937‖	4.4	4.3	2.3	0.6	0.2					
Greenfield coarse sandy loam.	1‡	Jan. 10, 1936‡	4.3	3.8	1.2	0.3	0.1					
	2¶	Mar. 16, 1937¶	3.2	2.7	1.1	0.7	0.3					
	3‖	Mar. 16, 1937‖	1.4	1.7	0.9	0.6	0.2					
Sierra sandy loam. . . .	1‡	Dec. 23, 1934‡	3.2	3.1	2.7	2.4	1.2	0.3	0.1			
	2¶	Mar. 16, 1937¶	3.0	2.5	2.3	1.6	0.7					
	3‖	Mar. 16, 1937‖	2.3	2.2	2.0	0.3	0.1					
Yolo fine sandy loam.	1‡	Dec. 22, 1934‡	3.5	3.3	3.1	2.9	2.6	0.6	0.3	0.2		
	2§	Apr. 24, 1936§	5.4	5.5	4.7	4.4	2.4	0.4				
Egbert loam.	1‡	June 4, 1935‡	3.9	3.4	3.2	2.7	2.2	1.6	1.0	0.2		
	2¶	Mar. 16, 1937¶	8.2	8.6	8.4	8.5	5.7	3.7	2.3	1.1	1.1	0.4
	3‖	Mar. 16, 1937‖	5.8	5.2	5.6	5.3	4.1	3.8	1.6	0.6	0.7	0.1
Aiken clay loam.	1‡	Jan. 10, 1936‡	1.0	1.0	0.9	0.9	0.9	0.8	0.7	0.6	0.6	0.3
	2§	Apr. 24, 1936§	3.2	3.5	3.4	2.9	2.4	2.2	2.1	1.8	1.1	0.7
Arbuckle clay loam. .	1‡	Dec. 23, 1934‡	2.4	2.4	1.9	1.9	1.1	1.3	0.3	0.1		
	2§	Apr. 24. 1936§	4.5	4.2	3.6	3.3	3.0	2.9	1.5	0.4		
Sacramento clay loam	1‡	June 5, 1935‡	4.1	4.2	3.9	2.7	2.0	0.8	0.5			
	2¶	Mar. 16, 1937¶	5.2	5.3	5.4	4.9	4.0	3.7	2.6	1.9	0.8	0.1
	3‖	Mar. 16, 1937‖	2.1	3.5	3.5	3.1	2.6	2.8	2.1	0.7	0.1	

* By interpolation from Crafts (*6*).
† By interpolation from table 2.
‡ From table 3.
§ From Crafts (*7*).
¶ From Rosenfels and Crafts (*13*); watered daily.
‖ From Rosenfels and Crafts (*13*); watered as needed.

TABLE 5—(*Concluded*)

Soil type	Run No.	Date of harvest	Arsenic concentration—As_2O_3 in p.p.m. on the basis of air-dry soil									
			0	15	40	80	140	220	340	490	680	920
			Fresh weight of plants									
			gm	*gm*	*gm*	*gm*	*gm*	*gm*	*gm*	*gm*	*gm*	*gm*
Yolo clay loam.......	1*,[a]	June 10, 1933*,[a]	8.6	8.6	7.6	7.2	5.7	4.8	2.3	1.0	0.3	
	2†,[a]	Dec. 29, 1933†,[a]	9.1	8.4	7.9	7.6	6.7	5.8	3.7	1.5	0.5	0.2
	3‡,[b]	Dec. 22, 1934‡,[b]	9.8	9.4	9.5	8.8	5.1	1.4	0.4	0.2		
	4‡,[b]	June 4, 1935‡,[b]	8.7	8.8	7.6	6.9	5.8	4.0	0.6	0.4		
	5§,[c]	Apr. 24, 1936§,[c]	18.6	17.5	14.2	12.4	8.9	5.4	0.3			
Stockton adobe clay..	1*,[a]	June 10, 1933*,[a]	2.9	2.3	2.0	1.6	0.5	0.2	0.1	0.1	0.1	
	2†,[b]	Dec. 29, 1933†,[b]	2.0	1.8	1.5	1.1	0.9	0.8	0.7	0.5	0.3	0.2
	3‡,[c]	Apr. 24, 1936‡,[c]	2.9	2.3	1.8	1.8	1.5	0.8	0.6	0.4	0.1	
Yolo clay.............	1‡	Dec. 22, 1934‡	4.4	4.8	4.4	4.5	4.1	3.9	2.6	2.2	1.0	0.1
	2¶	Mar. 16, 1937¶	4.1	3.8	3.6	3.1	2.8	2.5	0.9	1.0	0.1	
	3‖	Mar. 16, 1937‖	3.5	3.3	3.2	3.3	2.9	1.5	1.3	1.3	0.5	0.3
Yolo adobe clay......	1‡	Jan. 10, 1936‡	1.9	1.9	1.7	1.5	0.7	0.2	0.1			
	2¶	Mar. 16, 1937¶	3.2	3.3	3.3	2.8	1.6	1.1	0.1	0.1		
	3‖	Mar. 16, 1937‖	2.8	2.8	2.7	2.8	2.0	1.7	0.1			

* By interpolation from Crafts (*6*).
† By interpolation from table 2.
‡ From table 3.
§ From Crafts (*7*).
¶ From Rosenfels and Crafts (*13*); watered daily.
‖ From Rosenfels and Crafts (*13*); watered as needed.

[a] Soil sample collection in 1932.
[b] Soil sample collection in 1933.
[c] Soil sample collection in 1935.

studies in the greenhouse. The groupings are somewhat arbitrary and require liberal interpretation to meet specific problems.

In the high-toxicity group are the coarse, gritty soils having little colloidal matter. Such soils not only are common on the alluvial fans and upper flood-plain areas of the large valleys of California but also occur as surface material in many foothill and mountain regions, on old valley fills, bench lands, wind-modified areas, and heavily leached areas. Lands of this type are developed by man by the deposition of gravel and rock in roadways, railroad roadbeds, parking areas, and various yards and lots used for stacking lumber and the raw materials for manufacture. Vast areas of such lands could be profitably sterilized with arsenic with little poisoning hazard to livestock and at a great saving of hand labor.

In the intermediate-toxicity range lie the loams, silt loams, and those clay loams that are developed directly from acid igneous rocks or highly weathered from other rocks; also lighter soils from basic igneous and sedimentary rocks. Many agricultural soils of California lie in this range, and their successful sterilization requires appreciably heavier dosages than with the high-toxicity type.

The heavier soils of the clay and adobe clay types, together with the intermediate red soils from basic igneous rocks and brown soils from sedimentary rocks, demand heavy arsenic dosages; and their successful sterilization requires special technique in application.

In soil sterilization, two factors should be kept in mind: first, the immediate effect of the application; second, the persistence of the treatment. Application of a heavy dosage to sterilize the soil for a long time would on first thought seem most economical. Where, however, leaching is severe (annual precipitation of 30 inches or more) or where the soil colloids cause low toxicity, losses of arsenic will be high, and the persistence of the treatment may not meet expectations. Under these latter conditions, a light annual application, though increasing the cost, minimizes losses from leaching and other causes. Evidently soils in the low-toxicity range require this type of treatment.

TABLE 6

DOSAGE RECOMMENDATIONS FOR THE USE OF ARSENIC IN SOIL STERILIZATION ON CALIFORNIA SOILS

Soil			Toxicity group	Dosage,* As_2O_3† pounds per square rod
Texture	Type	Factors affecting arsenic availability		
Light and coarse...	Sands and gravels, sandy and fine sandy loams.....	Normal...............	High	2- 4
		Red or recent alluvial.	Intermediate	4- 8
Medium............	Loams and silt loams.......	Normal..............	Intermediate	4- 6
		Red or recent alluvial.	Low	12
Heavy.............	Clay loams‡, clays, and adobe clays..............	Normal...............	Low	8-12
		Red or recent alluvial.	Very low	12-20

* Values given in this table represent total dosages; this amount may be applied in several light treatments to meet the requirements of heavy soils or conditions of severe leaching.

† Since commercial sodium arsenite varies in As_2O_3 content, the weight of sodium arsenite required per square rod will depend upon the composition of the particular product being used.

‡ Clay loams from acid igneous rocks belong in the intermediate toxicity group and require a dosage of about 6 pounds per square rod.

Leaching is an important factor in arsenic treatment of soils. Thus, Raynor found (*12*, p. 28–29) that the depth of penetration of sodium arsenite was influenced by the date of application since this was related to the rainfall. Under constant leaching, as in the banks of an unlined irrigation ditch, soil sterilization is not effective, all of the arsenic being removed by the seeping water. In regions of heavy rainfall, sterilization upon a given soil type is less permanent than in arid regions.

In connection with sterilization methods, arsenic trioxide (white arsenic) should be mentioned. This material, already used in plot studies (*5*), promises to become more popular when its special characteristics are better understood. Being relatively insoluble, it will lie in the soil for a year or more and gradually pass into solution, becoming tied up in high concentration in the top soil. According to experiments under central California conditions, one year is required to develop an effective toxicity in the soil. After the first year it is as effective as sodium arsenite, and because of its slow solution it lasts somewhat longer. This dry material, mixed with enough chlorate to give sterilization during the first year, should be the best reagent on heavy soils. Plot tests apparently bear out this conclusion (*5*).

In contrast to the retention of arsenic in the surface layer, common on heavy soils, a 12- to 20-inch penetration of sodium arsenite solution is common in light soils (*5*). This may be advantageous in controlling shallow-rooted perennials (*5, 12*). Consequently, the form of arsenic used should be related to the problem, and its varied behavior utilized to accomplish the ends in view.

The problems posed in the Introduction may be answered, at least in part, from the results of these studies. Concerning the type of arsenic compound to use in soil sterilization, the answer has already been indicated. For immediate results and for deep penetration on sandy soils from acid igneous rocks, sodium arsenite is preferable. In many other soils, especially heavy ones, red ones, and those from sedimentary rocks, decrease in toxicity is a serious factor; and to avoid excessive loss, either light annual application of sodium arsenite or the use of the less soluble trioxide seems advisable.

RECLAMATION OF ARSENIC-TREATED SOILS

From the soil-conservation standpoint, the slow accumulation of arsenic from compounds of low solubility to a toxic level in the soil is a serious problem (*11*). It means that a large reserve of insoluble arsenic is present, and that reduction in available arsenic must depend largely upon extensive leaching or upon the supplying of additional material capable of rendering arsenic unavailable. Though the use of iron oxides, or possibly red soils like Aiken clay loam, as soil amendments to reduce such toxicity offers an interesting field for research (*1*), nevertheless the slow solution of the residual, slightly soluble arsenic in the soil presents further difficulties. Apparently the continued use of arsenicals of low solubilty as insecticides on crops should be avoided, at least on light soils, for this method seems the best for providing lasting soil sterilization.

Where crop reduction follows the application of sodium arsenite, table 2 (p. 183) indicates that the toxicity may be greatly reduced over a period of time; and if the damage is not excessive, the soil may be reclaimed for agricultural use. But crop reduction following the continued use of slightly soluble arsenicals is a different matter; for the large reserve of arsenic present constitutes a supply capable of producing a long-continued toxicity. For reasons indicated above, even the use of soil amendments may not solve this problem. Where serious sterilization occurs, leaching would seem the only answer. Arsenic applications have not been effective below the water line in unlined irrigation ditches, and apparently the slow percolation of water will carry away almost any amount of arsenic in time.

SUMMARY

Biological tests show that arsenic toxicity is high in Fresno sandy loam, intermediate in Columbia fine sandy loam, and low in Yolo clay loam and Stockton adobe clay. Variation from previous tests may be explained by differences in the soil samples.

Repeated cropping shows that arsenic toxicity decreased in all 4 of these soils until, with the seventh crop, plants in the Yolo and Stockton soils survived in cultures containing 3,000 p.p.m. As_2O_3 in the air-dry soil. In the first crop test, no plants grew in cultures having more than 1,050 p.p.m. As_2O_3.

With repeated cropping, differences between Fresno and Columbia soils diminished. Though the limiting arsenic concentrations with the first crop were 280 and 550 p.p.m. As_2O_3, respectively, plants survived in cultures having 2,100 p.p.m. or more by the seventh cropping.

According to extensive tests involving short toxicity series in 80 California soils, arsenic toxicity can be correlated with texture, being high in sandy soils and low in clays. The most notable exceptions occur among the red soils, all of which, by rendering much arsenic unavailable, act like heavier types.

Arsenic sterilization on coarse, gritty soils in California requires a dosage of 2 pounds As_2O_3 per square rod.

Loams, silt loams, and those clay loams that are developed directly from acid igneous rocks or are highly weathered from other rocks require from 4 to 6 pounds per square rod.

Clays and adobe clays and some clay loams demand applications of from 8 to 12 pounds per square rod.

Red soils or recent alluvial soils from sedimentary rocks require approximately twice as much arsenic for a given type.

Light annual applications of soluble arsenic or use of dry arsenic trioxide with the addition of about 10 per cent sodium chlorate may be less wasteful on soils that render much arsenic unavailable.

Heavy leaching tends to reduce the concentration of available arsenic in the soil.

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