HILGARDIA

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CONTENTS

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THE HERBICIDAL PROPERTIES OF BORON COMPOUNDS[1]

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INTRODUCTION

IN THE FIELD of chemical weed control there is a constant demand for a reagent that will render the soil permanently sterile, for use on graveled driveways, parking areas, railroad right of ways, and similar areas where any plant growth is a nuisance. Although arsenic has proved most effective (*14*)[4] for this purpose, its use is always attended by a poison hazard. For this reason it seems desirable to find a soil sterilant that is nonpoisonous to man and animals. The known toxicity of boron compounds to plants suggests the possibility of their use for this purpose.

While it is recognized that toxic concentrations of boron occur in soils in certain regions in California and Nevada (*19, 23, 32*) and that the leaching of additional boron compounds into the underground waters in these regions is undesirable, there are large areas in these states, and others, where such a condition does not exist. In fact, as the data presented in this paper will show, one of the most promising uses for boron compounds is in the control of range weeds in the north-coast counties of California where the underground waters are not utilized for irrigation. It seems therefore that such materials may find extensive use in many places.

On the other hand, it is well to point out at the outset that wherever boron is present in toxic quantities in soils, and wherever crop plants may be affected, boron compounds should not be used in weed control. One of the principal objects of the work to be presented here was to determine the behavior of these substances in soils so that they might be

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

handled with safety. From the results of the leaching studies, it is obvious that they would be useless, and possibly harmful, if applied below the water line in irrigation ditches and that they must be handled with caution on walks and drives beneath which the roots of trees and shrubs are growing. They should never be used in regions devoted to growing citrus and walnuts or even on range areas where the run-off contributes to the water supply of these regions. With these definite limitations in mind the studies that have been made are presented.

REVIEW OF LITERATURE

Although the toxic nature of boron compounds has been known since 1876 (*6*), relatively few attempts have been made to utilize them as herbicides. Thompson and Robbins (*37*), who tried borax and boric acid in their experiments on barberry eradication, did not consider them satisfactory. Other tests have been made (*12, 26*), but in no instance have boron compounds been recommended for use in weed control.

The literature on the toxicity of boron as a contaminating material in commercial fertilizers gives a different view. During the World War imports of potash from Germany were cut off, and a new supply had to be found. Among the sources were certain dry lakes in the desert regions of California. Salts extracted from these lake beds contained, besides potash and other elements, rather large percentages of borax. No great effort was made in the beginning to separate the borax completely from the potash; the possible effects of borax on plants were not fully realized.

As a consequence, serious crop injury resulted in certain of the eastern states, where large amounts of fertilizer are applied in the drill with the seed of such crops as cotton, corn, and potatoes. The injury having been traced to the borax present in the fertilizer, numerous investigations of the effect of borax on plants were conducted by state experiment stations and by the United States Department of Agriculture. The reports of these investigations give much valuable information on the toxic effects of boron compounds. This work will be summarized as it relates to the use of boron in weed control.

Boron as a Plant Poison.—Judging from tests on the relative toxicity of different compounds of boron (*6, 8, 38*), it is the borate ion that produces the injury; the various compounds, therefore, are toxic in proportion to the elemental boron they carry and are comparable on that basis. Even relatively insoluble compounds of boron are toxic (*20*) if available to the plants. From this we may conclude that the toxicity of these compounds is not related to any peculiarities of chemical combination or molecular structure as is the case with chlorates and thiocyanates; consequently, boron compounds would not be subject to chemical decomposition that might tend to reduce their toxicity within the soil. Since the presence of boron in the soil solution in toxic quantities should render a soil sterile, the solubility of the compounds present will be the principal factor governing their effectiveness.

The highly toxic nature of boron is shown by many tests. Solution-culture experiments (*5, 6, 8, 20, 22, 27, 36, 38*) indicate that the lower limit of boron toxicity ranges from 1 to 10 parts per million, according to the plant species; and all cultures containing 1,000 p.p.m. or above were lethal.

Sand cultures (*6, 8*) showed critical concentrations of the same order but even lower lethal concentrations. Pot-culture tests with soils (*2, 3, 6, 8, 9, 11, 12, 20, 24, 38*) vary because of the different soil types used and the different methods of application. The critical concentrations, where they could be calculated, were in the neighborhood of 10 to 15 p.p.m. on the basis of the air-dry soil. Fifty p.p.m. definitely affected germination, and 100 p.p.m. prevented germination entirely.

Field trials reported (*6, 7, 10, 12, 29, 33, 35, 36, 38*) indicate wide differences in the susceptibility of plant species and also variations due to soil type, precipitation, and method of application. In most cases dosages of 200 pounds per acre or more of borax were lethal, and injury resulted when as little as 5 to 20 pounds was applied in the drill with the seed. In terms of elemental boron, 15 p.p.m. in the soil produced injury, and 400 p.p.m. was lethal.

The problem of the susceptibility of different cultivated plants to boron injury has received considerable attention (*4, 6, 7, 19, 20, 23, 25, 31, 32*). Scofield and Wilcox (*32*) group a number of crop plants according to their boron tolerance, using walnuts and citrus as standards. Eaton (*19*) lists 55 plants in the order of their boron tolerance. Obviously, wide differences exist in the ability of different species to tolerate boron in the soil. This factor must be considered in the use of any material for weed control; an application that fails to sterilize the soil completely is certain to cause a shift in the flora, the more tolerant species surviving. If these species are less desirable than the original mixed flora, then little or nothing is accomplished by the treatment.

Studies on the effects of the method of applying boron compounds show that the severest injury results from a concentration of the poison in the surface soil where the young absorbing roots come into direct contact with it (*34, 35*). A delay between fertilizer application and seeding, heavy rains immediately after application, or a thorough mixing of the chemical with a large mass of soil all tended to reduce boron toxicity.

These observations indicate that soluble boron compounds are leached from the soil and that they are rapidly rendered unavailable to plants upon contact with a large volume of soil. The effect of soil type upon availability of boron is also important in relation to the amount required to sterilize different soils. Previous studies on this problem (*9, 10, 18, 19, 27, 28, 32*) indicate that toxicity is greatest in coarse-textured soils. The results to be presented substantiate this conclusion and indicate the magnitude of the differences to be found.

As a number of workers (*3, 6, 7, 12, 13, 20, 35*) have observed, the toxic effects of an application of boron to the soil diminish appreciably with time. It seems evident not only that soluble boron compounds leach from the soil, as reported by Kelley and Brown (*23*), but that those remaining are gradually rendered unavailable to plants (*6*). Both these properties tend to reduce the effectiveness of boron as a soil sterilant, and they definitely limit the time that a given application will last.

The foregoing consideration of the work on boron toxicity shows why this material has not been recommended in weed control. Although very toxic to certain plants, it is much less harmful to others; it loses in potency soon after application, both by leaching and by fixation. Furthermore, it has not been promoted by any commercial agency and consequently has not been tried under a wide range of conditions.

With the proper criteria for judging the herbicidal value of a reagent and the necessary studies on its properties, it should be possible to find a place for so toxic a chemical as boron in a comprehensive program of weed control. Studies made within recent years on herbicides (*1, 14, 15, 16, 17, 21*) go far toward establishing the standards to be met by a weed killer. From their chemical nature it is evident that compounds of boron would find legitimate use only in the practice of soil sterilization where an agent nonpoisonous to man and animals is required. The studies reported herein show how closely these compounds meet the standards for such an agent.

GREENHOUSE STUDIES ON THE TOXICITY AND FIXING OF BORAX IN FOUR CALIFORNIA SOILS

Toxicity Studies.—Studies on the toxicity and fixing of borax were begun in the summer of 1933 and have continued for over two years. The present paper reports the results of a number of these. This work aimed to discover a possible use for boron compounds in the process of chemical soil sterilization and was therefore established on a basis almost diametrically opposed to that of others who have studied boron injury. Since it was hoped to make immediate and practical use of the informa-

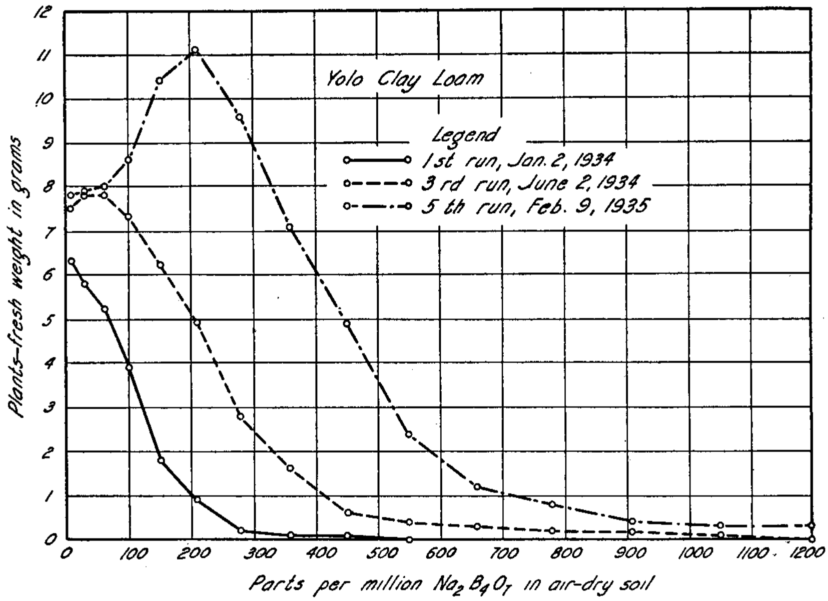

Fig. 1.—The relation of crop yield to the concentration of anhydrous borax in Yolo clay loam.

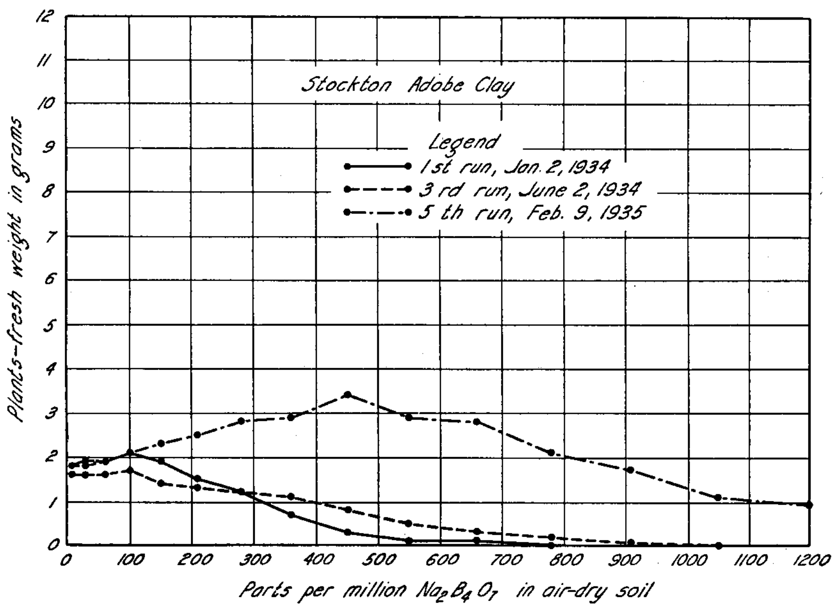

Fig. 2.—The relation of crop yield to the concentration of anhydrous borax in Stockton adobe clay.

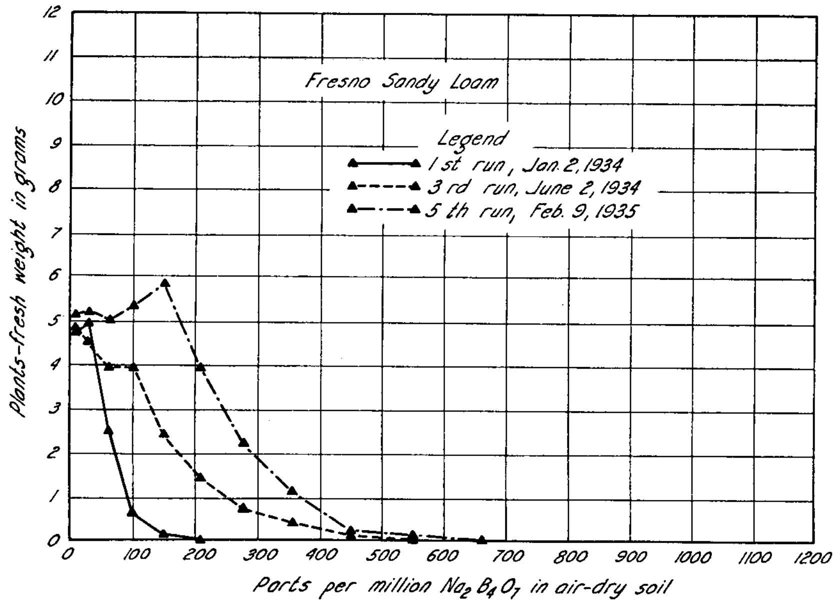

Fig. 3.—The relation of crop yield to the concentration of anhydrous borax in Fresno sandy loam.

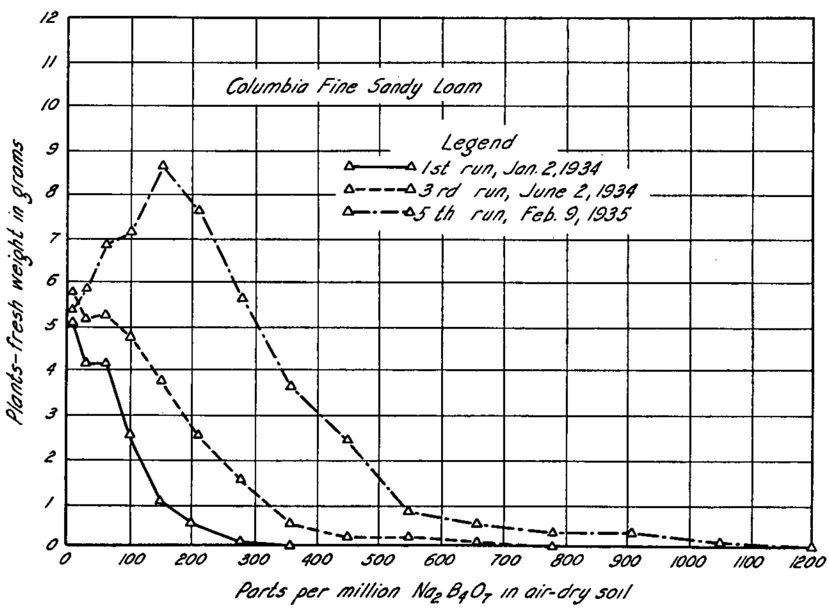

Fig. 4.—The relation of crop yield to the concentration of anhydrous borax in Columbia fine sandy loam.

TABLE 1

TOXICITY OF SODIUM BORATE IN FOUR CALIFORNIA SOILS, AS SHOWN BY GROWTH OF INDICATOR PLANTS

Sodium borate expressed as p.p.m. anhydrous borax in the air-dry soil	Yolo clay loam		Stockton adobe clay		Fresno sandy loam		Columbia fine sandy loam	
	Ht.	Wt.	Ht.	Wt.	Ht.	Wt.	Ht.	Wt.
First run, harvested January 2, 1934								
	cm	*gm*	*cm*	*gm*	*cm*	*gm*	*cm*	*gm*
10	34	6.3	20	1.8	31	4.7	31	5.0
30	34	5.8	20	1.9	30	4.9	30	4.1
60	32	5.2	21	1.9	20	2.5	29	4.1
100	28	3.9	22	2.1	7	0.6	21	2.5
150	16	1.8	20	1.9	2	0.1	12	1.0
210	9	0.9	13	1.5	0	0.0	6	0.5
280	3	0.2	11	1.2	0	0.0	1	0.1
360	1	0.1	7	0.7	0	0.0	0	0.0
450	1	0.1	4	0.3	0	0.0	0	0.0
550	0	0.0	2	0.1	0	0.0	0	0.0
660	0	0.0	1	0.1	0	0.0	0	0.0
780	0	0.0	0	0.0	0	0.0	0	0.0
910	0	0.0	0	0.0	0	0.0	0	0.0
1050	0	0.0	0	0.0	0	0.0	0	0.0
1200	0	0.0	0	0.0	0	0.0	0	0.0
1360	0	0.0	0	0.0	0	0.0	0	0.0
Check	35	6.6	19	1.8	31	5.2	31	5.0
Check	34	6.3	20	2.0	31	5.2	31	4.9
Check	33	6.4	18	1.6	28	4.4	29	4.9
Check	32	6.3	19	1.7	31	5.2	26	4.7
Third run, harvested June 2, 1934								
	cm	*gm*	*cm*	*gm*	*cm*	*gm*	*cm*	*gm*
10	35	9.7	21	2.9	26	4.3	31	7.0
30	37	10.1	22	3.0	28	4.1	32	6.3
60	39	10.1	22	3.0	27	3.5	33	6.4
100	39	9.5	23	3.1	26	3.5	34	5.8
150	36	8.0	22	2.5	24	2.2	31	4.5
210	33	6.4	22	2.3	16	1.2	27	3.1
280	27	3.6	23	2.2	13	0.6	21	1.8
360	24	2.1	22	2.0	10	0.4	15	0.6
450	15	0.8	19	1.4	7	0.1	10	0.3
550	14	0.5	17	0.8	0	0.0	8	0.2
660	12	0.3	11	0.5	0	0.0	7	0.1
780	10	0.2	10	0.3	0	0.0	0	0.0
910	10	0.2	8	0.2	0	0.0	0	0.0
1050	6	0.1	6	0.1	0	0.0	0	0.0
1200	0	0.0	0	0.0	0	0.0	0	0.0
1360	0	0.0	0	0.0	0	0.0	0	0.0
Check	33	8.2	23	3.4	25	4.3	29	6.2
Check	35	9.9	23	3.3	27	4.8	28	6.8
Check	29	7.7	20	3.2	25	4.0	29	5.7
Check	29	7.4	21	3.2	29	4.9	29	5.3

TABLE 1—*Concluded*

Sodium borate expressed as p.p.m. anhydrous borax in the air-dry soil	Yolo clay loam		Stockton adobe clay		Fresno sandy loam		Columbia fine sandy loam	
	Ht.	Wt.	Ht.	Wt.	Ht.	Wt.	Ht.	Wt.
Fifth run, harvested February 9, 1935								
	cm	*gm*	*cm*	*gm*	*cm*	*gm*	*cm*	*gm*
10	28	4.6	15	1.6	22	2.8	23	3.6
30	29	4.7	15	1.6	23	2.8	25	3.9
60	29	4.7	15	1.6	23	2.7	28	4.5
100	31	5.1	16	1.8	24	2.9	30	5.0
150	33	6.2	17	2.0	27	3.1	34	5.7
210	35	6.6	19	2.2	24	2.1	34	5.1
280	34	5.7	21	2.5	17	1.2	31	3.7
360	32	4.2	23	2.5	13	0.6	25	2.4
450	28	2.9	24	3.0	7	0.2	22	1.6
550	20	1.4	22	2.5	5	0.1	13	0.5
660	13	0.7	22	2.4	0	0.0	10	0.5
780	11	0.5	18	1.9	0	0.0	7	0.2
910	8	0.2	16	1.5	0	0.0	6	0.2
1050	7	0.2	13	0.9	0	0.0	5	0.1
1200	7	0.2	12	0.8	0	0.0	0	0.0
1360	5	0.1	10	0.4	0	0.0	0	0.0
Check	26	4.0	15	1.7	23	2.7	24	3.7
Check	26	4.0	14	1.7	22	2.9	23	3.6
Check	23	3.4	14	1.4	21	2.6	21	2.8
Check	25	3.5	14	1.5	21	2.5	21	2.9

tion gained, a biological testing method was used which measured the toxicity of the applied chemical directly without resort to chemical analysis and subsequent interpretation. The results, therefore, are not so strictly quantitative as might be desired by some; but they have nevertheless provided valuable information and have aided greatly in the interpretation of field-plot data.

The method used has been described in a paper on the toxicity of sodium arsenite and sodium chlorate in California soils (*17*). Briefly, it consists of series of pot cultures grown in the greenhouse set up in No. 2 cans and containing increasing amounts of borax within each series. The soils used were Yolo clay loam, Stockton adobe clay, Fresno sandy loam, and Columbia fine sandy loam. Each culture in the Fresno sandy loam contained 600 grams of soil, and each in the other three soils contained 500 grams.

In making up the cultures the necessary amount of borax was applied, dissolved in a volume of water sufficient to bring the soil to field capacity. The actual moistening was done in three rapid stages so that the moisture was distributed within one minute or less. Previous tests with arsenic and chlorate had shown this to be a satisfactory method, giving a uniform distribution of the chemical.

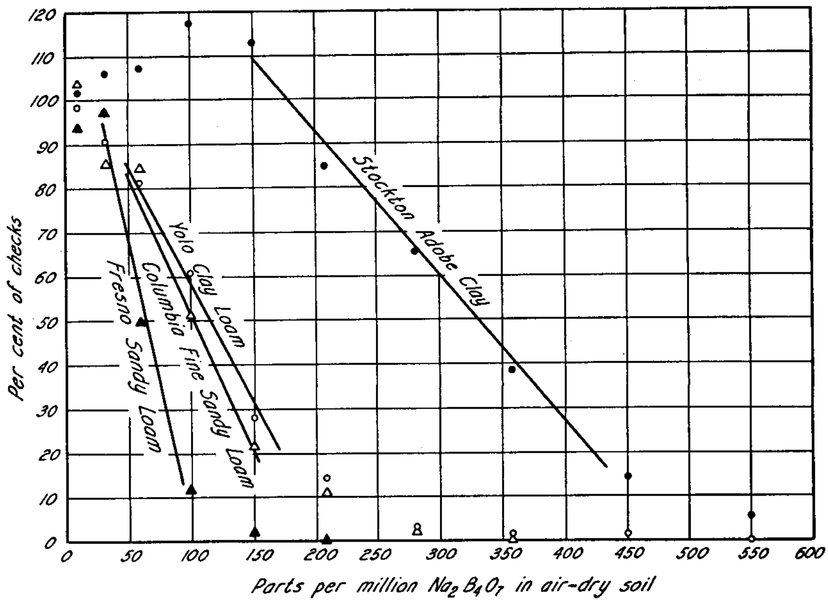

Fig. 5.—The relation of crop yield, expressed as per cent of the checks, to the concentration of anhydrous borax in four soils.

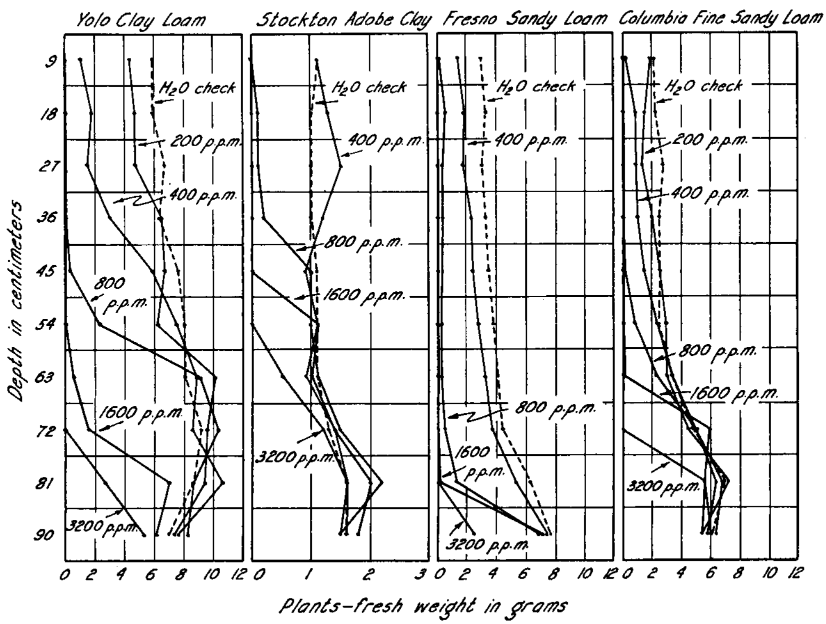

Fig. 6.—The relation of crop yield to penetration of borax into columns of four California soils, showing their power to retain this chemical.

The moistened soil was planted with Kanota oats, 13 seeds to a can. After about ten days the seedlings were thinned to 10 in each can. Thirty days from planting they were harvested, the fresh weight of tops being taken as a measure of the effect of the chemical upon growth. After harvest the tops were returned to the cans and were dried along with the soil for thirty days. The soils were then repulverized and returned to the cans, the dried tops being included under the soils. After moistening, the cultures were planted and carried along as in the first cropping. Five croppings are reported in this paper. The cultures are still on hand and will be cropped several more times. From the standpoint of weed control, the more important results are probably included in this report.

TABLE 2

THE FIXING POWER OF YOLO CLAY LOAM FOR SODIUM BORATE, AS SHOWN BY GROWTH OF INDICATOR PLANTS

(Harvested December 15, 1934)*

Fraction of soil column	H_2O check		$Na_2B_4O_7$, 100 p.p.m.		$Na_2B_4O_7$, 200 p.p.m.		$Na_2B_4O_7$, 400 p.p.m.		$Na_2B_4O_7$, 800 p.p.m.	
	Ht.	Wt.	Ht.	Wt.	Ht.	Wt.	Ht.	Wt.	Ht.	Wt.
cm	*cm*	*gm*	*cm*	*gm*	*cm*	*gm*	*cm*	*gm*	*cm*	*gm*
0–9	24	5.9	28	5.2	24	4.3	11	1.0	0	0.0
9–18	24	5.9	26	5.4	27	4.7	17	1.8	0	0.0
18–27	24	6.7	27	5.9	26	4.7	17	1.4	0	0.0
27–36	24	6.3	24	5.9†	29	6.5	20	2.9	0	0.0
36–45	25	7.6	25	6.6	27	6.7†	28	5.9†	5	0.3
45–54	26	8.0	24	6.7	26	6.2	29	7.5	21	2.2
54–63	27	8.1	30	9.7	29	10.1	28	8.9	32	9.1†
63–72	27	9.2	28	11.4	27	9.6	28	8.6	27	10.4
72–81	26	8.7	28	11.2	28	9.5	30	10.7	27	8.7
81–90	24	7.0	28	7.8	24	7.4	25	7.7	27	8.2

Fraction of soil column	$Na_2B_4O_7$, 1,600 p.p.m.		$Na_2B_4O_7$, 3,200 p.p.m.		$Na_2B_4O_7$, 100 p.p.m.‡		$Na_2B_4O_7$, 400 p.p.m.‡		$Na_2B_4O_7$, 1,600 p.p.m.‡	
	Ht.	Wt.	Ht.	Wt.	Ht.	Wt.	Ht.	Wt.	Ht.	Wt.
cm	*cm*	*gm*	*cm*	*gm*	*cm*	*gm*	*cm*	*gm*	*cm*	*gm*
0–9	0	0.0	0	0.0	26	4.0	8	0.5	0	0.0
9–18	0	0.0	0	0.0	26	4.5	19	1.7	0	0.0
18–27	0	0.0	0	0.0	28	4.6	14	1.3	0	0.0
27–36	0	0.0	0	0.0	25	4.1†	19	2.1	0	0.0
36–45	0	0.0	0	0.0	27	4.6	24	3.8	0	0.0
45–54	0	0.0	0	0.0	21	3.2	24	4.0†	0	0.0
54–63	5	0.5	0	0.0	19	4.1	17	2.2	0	0.0
63–72	17	1.6	0	0.0	19	2.3	17	2.3	12	0.8
72–81	26	7.0†	21	2.7	19	3.0	18	2.9	21	2.4
81–90	25	6.1	21	5.4†	20	3.3	20	3.1	23	3.8†

* Average weight of plants in 10 untreated checks = 9.8 gm.

† Boron injury present to this depth.

‡ Soil in the last three columns moistened before the sodium borate was applied.

All cultures were replicated five times; and the points given in figures 1, 2, 3, and 4 on toxicity represent the average of the five. The figures mentioned present the data of the first, third, and fifth crops representative of the results on these soils; and table 1 gives the yields of these crops. The relative toxicities in the four soils, and the loss of toxicity with time and cropping are shown. The curves for each soil have been reduced to a common base by multiplying values in the third and fifth runs by the average weight of first-run checks and dividing by the average weight of checks for the respective run.

TABLE 3

THE FIXING POWER OF STOCKTON ADOBE CLAY FOR SODIUM BORATE, AS SHOWN BY GROWTH OF INDICATOR PLANTS

(Harvested January 14, 1935)*

Fraction of soil column	H_2O check		$Na_2B_4O_7$, 100 p.p.m.		$Na_2B_4O_7$, 200 p.p.m.		$Na_2B_4O_7$, 400 p.p.m.		$Na_2B_4O_7$, 800 p.p.m.	
	Ht.	Wt.	Ht.	Wt.	Ht.	Wt.	Ht.	Wt.	Ht.	Wt.
cm	*cm*	*gm*	*cm*	*gm*	*cm*	*gm*	*cm*	*gm*	*cm*	*gm*
0– 9	14	1.1	14	1.1	14	1.3	11	1.1	0	0.0
9–18	13	1.0	14	1.0	14	1.1	12	1.3	3	0.1
18–27	13	1.0	13	0.9†	13	1.0	14	1.5	3	0.1
27–36	12	1.0	13	1.0	13	0.8†	13	1.2	4	0.2
36–45	13	1.1	12	1.0	14	1.1	13	0.9†	11	1.0
45–54	14	1.1	15	1.1	14	1.1	14	1.1	14	1.0†
54–63	14	1.1	14	1.2	14	1.2	12	0.9	14	1.1
63–72	15	1.3	17	1.9	15	1.3	16	1.4	16	1.5
72–81	16	1.6	16	1.6	19	2.0	16	1.6	18	2.2
81–90	16	1.6	17	1.8	17	1.8	17	1.5	18	1.5

Fraction of soil column	$Na_2B_4O_7$, 1,600 p.p.m.		$Na_2B_4O_7$, 3,200 p.p.m.		$Na_2B_4O_7$, 100 p.p.m.‡		$Na_2B_4O_7$, 400 p.p.m.‡		$Na_2B_4O_7$, 1,600 p.p.m.‡	
	Ht.	Wt.	Ht.	Wt.	Ht.	Wt.	Ht.	Wt.	Ht.	Wt.
cm	*cm*	*gm*	*cm*	*gm*	*cm*	*gm*	*cm*	*gm*	*cm*	*gm*
0– 9	0	0.0	0	0.0	17	1.4	16	1.5	0	0.0
9–18	0	0.0	0	0.0	15	1.0	14	1.4	0	0.0
18–27	0	0.0	0	0.0	14	1.1†	13	1.4	0	0.0
27–36	0	0.0	0	0.0	14	1.1	16	1.4	0	0.0
36–45	0	0.0	0	0.0	13	1.0	16	0.9†	0	0.0
45–54	12	1.2	0	0.0	14	1.1	15	1.0	8	0.3
54–63	14	1.0†	7	0.5	14	1.0	13	0.9	13	1.3
63–72	16	1.4	15	1.2	14	1.0	14	0.9	15	1.0†
72–81	18	2.0	15	1.6†	14	1.2	12	0.8	14	1.0
81–90	17	1.8	17	1.6	15	1.2	14	1.1	13	0.9

* Average weight of plants in 10 untreated checks = 1.5 gm.

† Boron injury present to this depth.

‡ Soil in the last three columns moistened before the sodium borate was applied.

In the coarser soils, evidently, borax is very toxic. The oat plant, being located at about the middle of the list of plants given by Eaton (*19*), is intermediate in susceptibility to boron injury. The results of these tests show that boron, expressed as anhydrous borax, ranks in effectiveness with trivalent arsenic and sodium chlorate. The most pronounced difference occurs in Stockton adobe clay, where the toxicity of borax is notably low and the loss of toxicity with time and cropping very great. To study

TABLE 4

THE FIXING POWER OF FRESNO SANDY LOAM FOR SODIUM BORATE, AS SHOWN BY GROWTH OF INDICATOR PLANTS

(Harvested February 20, 1935)*

Fraction of soil column	H_2O check		$Na_2B_4O_7$, 100 p.p.m.		$Na_2B_4O_7$, 200 p.p.m.		$Na_2B_4O_7$, 400 p.p.m.		$Na_2B_4O_7$, 800 p.p.m.	
	Ht.	Wt.	Ht.	Wt.	Ht.	Wt.	Ht.	Wt.	Ht.	Wt.
cm	*cm*	*gm*	*cm*	*gm*	*cm*	*gm*	*cm*	*gm*	*cm*	*gm*
0– 9	26	2.9	25	2.3	24	2.5	18	1.4	3	0.1
9–18	23	3.2	23	2.6	25	2.5	22	1.9	10	0.5
18–27	25	3.0	26	2.9	26	2.8	21	1.8	8	0.3
27–36	25	3.2	26	2.9	27	3.0	26	2.3	8	0.3
36–45	26	3.4	26	3.2†	28	3.1	24	2.4	8	0.3
45–54	28	3.8	27	3.2	27	3.2	25	2.7	5	0.2
54–63	27	4.1	28	3.4	29	3.7	27	3.2	5	0.2
63–72	28	4.3	29	4.0	29	3.9†	29	3.7	9	0.4
72–81	31	6.2	31	4.5	31	5.6	31	5.3†	17	1.3†
81–90	33	7.6	36	6.9	35	7.5	34	7.4	33	6.8

Fraction of soil column	$Na_2B_4O_7$, 1,600 p.p.m.		$Na_2B_4O_7$, 3,200 p.p.m.		$Na_2B_4O_7$, 100 p.p.m.‡		$Na_2B_4O_7$, 400 p.p.m.‡		$Na_2B_4O_7$, 1,600 p.p.m.‡	
	Ht.	Wt.	Ht.	Wt.	Ht.	Wt.	Ht.	Wt.	Ht.	Wt.
cm	*cm*	*gm*	*cm*	*gm*	*cm*	*gm*	*cm*	*gm*	*cm*	*gm*
0– 9	0	0.0	0	0.0	26	2.3	19	1.4	0	0.0
9–18	0	0.0	0	0.0	23	2.2	24	2.2	0	0.0
18–27	0	0.0	0	0.0	23	2.1	22	1.8	0	0.0
27–36	0	0.0	0	0.0	25	2.4	22	2.1	0	0.0
36–45	0	0.0	0	0.0	25	2.7†	23	2.3	0	0.0
45–54	0	0.0	0	0.0	27	2.9	26	2.5	0	0.0
54–63	0	0.0	0	0.0	28	3.4	23	2.3	0	0.0
63–72	0	0.0	0	0.0	27	3.7	27	2.7	0	0.0
72–81	3	0.1†	0	0.0	22	3.0	23	2.0†	9	0.3
81–90	30	7.2	27	2.5†	23	2.9	23	2.4	23	2.3†

* Average weight of plants in 10 untreated checks = 4.8 gm.

† Boron injury present to this depth.

‡ Soil in the last three columns moistened before the sodium borate was applied.

the relation of toxicity and textural grade of the soil, the curves of the first runs have been reproduced, expressed on the basis of percentage of their checks. These curves appear in figure 5. Apparently a rough correlation exists between toxicity and particle size, as shown by the slopes of these curves. Considering the difference in the water-holding capacity of these soils, it seems that the differences in the three coarser soils may be explained on the basis of differences in the concentration of borax in the soil solution. In the Stockton adobe clay, some other factor reduces the toxicity. This soil is highly colloidal but, under the conditions of this experiment, not particularly productive. Evidently it renders much of the applied borax unavailable to plants.

TABLE 5

THE FIXING POWER OF COLUMBIA FINE SANDY LOAM FOR SODIUM BORATE, AS SHOWN BY GROWTH OF INDICATOR PLANTS

(Harvested February 4, 1935)*

Fraction of soil column	H_2O check		$Na_2B_4O_7$, 100 p.p.m.		$Na_2B_4O_7$, 200 p.p.m.		$Na_2B_4O_7$, 400 p.p.m.		$Na_2B_4O_7$, 800 p.p.m.	
	Ht.	Wt.	Ht.	Wt.	Ht.	Wt.	Ht.	Wt.	Ht.	Wt.
cm	*cm*	*gm*	*cm*	*gm*	*cm*	*gm*	*cm*	*gm*	*cm*	*gm*
0– 9	16	2.1	16	1.9	18	1.9	4	0.2	0	0.0
9–18	16	2.1	17	2.2	14	1.4	10	0.8	0	0.0
18–27	16	2.7	16	2.1	13	1.2	12	0.9	0	0.0
27–36	16	2.4	17	2.3†	17	2.0	13	0.9	0	0.0
36–45	16	2.5	17	2.4	20	2.4†	16	1.4	2	0.1
45–54	16	2.4	17	3.0	17	2.9	19	2.3†	10	0.7
54–63	19	3.3	17	3.0	17	2.9	19	3.3	19	2.3†
63–72	24	4.7	23	4.3	24	4.4	24	4.9	25	4.8
72–81	28	6.9	27	6.8	28	7.2	28	6.7	28	6.3
81–90	27	6.1	28	7.0	26	5.4	26	6.3	26	5.7

Fraction of soil column	$Na_2B_4O_7$, 1,600 p.p.m.		$Na_2B_4O_7$, 3,200 p.p.m.		$Na_2B_4O_7$, 100 p.p.m.‡		$Na_2B_4O_7$, 400 p.p.m.‡		$Na_2B_4O_7$, 1,600 p.p.m.‡	
	Ht.	Wt.	Ht.	Wt.	Ht.	Wt.	Ht.	Wt.	Ht.	Wt.
cm	*cm*	*gm*	*cm*	*gm*	*cm*	*gm*	*cm*	*gm*	*cm*	*gm*
0– 9	0	0.0	0	0.0	14	1.5	6	0.4	0	0.0
9–18	0	0.0	0	0.0	14	1.4	9	0.7	0	0.0
18–27	0	0.0	0	0.0	15	1.6†	12	0.9	0	0.0
27–36	0	0.0	0	0.0	14	1.8	15	1.6	0	0.0
36–45	0	0.0	0	0.0	14	1.5	16	1.8	0	0.0
45–54	0	0.0	0	0.0	13	1.4	15	1.4	0	0.0
54–63	2	0.1	0	0.0	15	1.6	15	1.5	0	0.0
63–72	27	5.9†	0	0.0	15	1.8	15	1.6†	6	0.2
72–81	25	5.5	26	5.5†	15	1.5	15	1.9	11	0.9
81–90	27	5.4	28	6.0	18	2.0	16	1.8	17	1.6†

* Average weight of plants in 10 untreated checks = 6.5 gm.

† Boron injury present to this depth.

‡ Soil in the last three columns moistened before the sodium borate was applied.

Another interesting feature of these tests is the large loss of toxicity in the later runs. In every soil, by the fifth run, concentrations which had initially rendered the soil sterile have produced crops as good as the checks or better. In every soil also there is a noticeable stimulation of growth in the lower concentrations. After the harvest of the third run on June 2, 1934, the cultures stood in the greenhouse at Davis until September 18. During this time the loss of available borax was particularly noticeable.

Soil-Tube Studies.—To study the fixing or retention of borax in an available form by soils, tests were made using a special type of soil tube.

TABLE 6

RESULTS OF LEACHING SODIUM BORATE IN YOLO CLAY LOAM, AS SHOWN BY GROWTH OF INDICATOR PLANTS

(Harvested March 23, 1935)*

Fraction of soil column	Check		$Na_2B_4O_7$, 800 p.p.m.					
	10 cm H_2O		0 cm H_2O		2.5 cm H_2O		5.0 cm H_2O	
	Ht.	Wt.	Ht.	Wt.	Ht.	Wt.	Ht.	Wt.
cm	*cm*	*gm*	*cm*	*gm*	*cm*	*gm*	*cm*	*gm*
0– 9	19	4.4	0	0.0	0	0.0	0	0.0
9–18	21	4.6	0	0.0	0	0.0	4	0.2
18–27	22	5.5	0	0.0	0	0.0	3	0.2
27–36	22	5.5	0	0.0	0	0.0	0	0.0
36–45	22	6.1	8	0.5	0	0.0	4	0.2
45–54	23	6.5	16	1.6	17	1.3	9	0.8
54–63	22	6.1	24	6.8†	23	4.8†	17	1.6
63–72	22	4.9	23	8.5	22	8.8	27	7.1†
72–81	22	4.7	21	8.7	29	10.1	26	9.3
81–90	19	4.3	22	8.0	25	9.5	24	7.3

Fraction of soil column	$Na_2B_4O_7$, 800 p.p.m.							
	10 cm H_2O		20 cm H_2O		40 cm H_2O		80 cm H_2O	
	Ht.	Wt.	Ht.	Wt.	Ht.	Wt.	Ht.	Wt.
cm	*cm*	*gm*	*cm*	*gm*	*cm*	*gm*	*cm*	*gm*
0– 9	22	3.1	22	3.6	20	3.3	21	3.4
9–18	15	1.4	20	3.5	21	4.3	21	4.4
18–27	6	0.4	20	3.4	22	4.1	22	3.4‡
27–36	0	0.0	18	2.4	21	3.8	21	4.3
36–45	0	0.0	7	0.5	21	2.5	21	4.5
45–54	0	0.0	4	0.2	23	3.1	19	3.0
54–63	5	0.2	6	0.3	21	3.4	19	2.7
63–72	28	5.2	8	0.6	22	2.9	19	2.6
72–81	24	5.1†	18	1.8	11	0.7	20	2.7
81–90	22	5.0	18	2.2†	7	0.3†	20	2.9

* Average weight of plants in 10 untreated checks = 8.2 gm.
† Boron injury present to this depth.
‡ Boron injury present below this depth.

This consists of a sheet of celluloid bent to form a hollow cylinder. It is supported on the outside with a sheet of ½-inch-mesh hardware cloth bent around it and wired in place. The tube, filled with air-dry soil, is moistened slowly by dripping a given solution on the soil through a small glass jet. The jets are adjusted to deliver 12 drops per minute, and the tubes are usually moistened in 24 to 36 hours, according to the field capacity of the soil being studied. The solutions used in these tests contained 100, 200, 400, 800, 1,600, and 3,200 p.p.m. anhydrous borax, respectively; and the same four soils were used. A check tube moistened with water was included in each set.

TABLE 7

RESULTS OF LEACHING SODIUM BORATE IN STOCKTON ADOBE CLAY, AS SHOWN BY GROWTH OF INDICATOR PLANTS

(Harvested April 22, 1935)*

Fraction of soil column	Check		$Na_2B_4O_7$, 800 p.p.m.					
	10 cm H_2O		0 cm H_2O		2.5 cm H_2O		5.0 cm H_2O	
	Ht.	Wt.	Ht.	Wt.	Ht.	Wt.	Ht.	Wt.
cm	*cm*	*gm*	*cm*	*gm*	*cm*	*gm*	*cm*	*gm*
0– 9	16	1.7	9	0.2	10	0.5	20	1.3
9–18	16	2.0	10	0.3	8	0.4	10	0.7
18–27	16	1.7	12	0.5	8	0.4	6	0.3
27–36	16	1.8	19	1.2	7	0.6	8	0.4
36–45	18	2.2	18	1.1	18	1.0	12	0.8
45–54	19	2.1	19	1.5	19	1.2	18	1.2
54–63	18	2.2	16	1.4†	18	1.6	20	1.7
63–72	18	1.9	17	1.6	20	1.7†	17	1.9†
72–81	18	2.1	19	1.9	20	2.6	19	2.5
81–90	17	2.3	19	2.6	19	2.4	20	2.5

Fraction of soil column	$Na_2B_4O_7$, 800 p.p.m.							
	10 cm H_2O		20 cm H_2O		40 cm H_2O		80 cm H_2O	
	Ht.	Wt.	Ht.	Wt.	Ht.	Wt.	Ht.	Wt.
cm	*cm*	*gm*	*cm*	*gm*	*cm*	*gm*	*cm*	*gm*
0– 9	15	1.0	16	1.4	17	1.7	15	1.8
9–18	18	1.1	15	1.3	15	1.4	14	1.5‡
18–27	11	0.5	16	1.2	16	1.5	13	1.4
27–36	12	0.7	16	1.1	17	1.4	14	1.2
36–45	12	0.7	16	1.2	18	1.3	16	1.5
45–54	14	0.9	18	1.4	17	1.3	16	1.2
54–63	19	1.3	19	1.5	19	1.2	19	1.4
63–72	19	1.6	17	1.2	19	1.2	20	1.3
72–81	19	2.3	19	1.5	17	1.2	19	1.2
81–90	17	2.1†	16	1.2†	16	1.0†	16	1.1

* Average weight of plants in 10 untreated checks = 1.8 gm.
† Boron injury present to this depth.
‡ Boron injury present below this depth.

After moistening, the tubes were allowed to stand for 48 hours to approach equilibrium. Then, while lying in a horizontal position, each tube was opened, the soil column divided into 10 fractions of equal length, and each fraction mixed and placed in a No. 2 can. These cultures were seeded and handled as were those of the previous experiments. Ten cans of air-dry soil were moistened and seeded with each set of soil tubes. The average yield of these untreated checks is given at the foot of each table. The results of these tests are presented in tables 2, 3, 4, and 5. The more characteristic data are shown graphically in figure 6.

TABLE 8

RESULTS OF LEACHING SODIUM BORATE IN FRESNO SANDY LOAM, AS SHOWN BY GROWTH OF INDICATOR PLANTS

(Harvested April 12, 1935)*

Fraction of soil column	Check		$Na_2B_4O_7$, 800 p.p.m.					
	10 cm H_2O		0 cm H_2O		2.5 cm H_2O		5.0 cm H_2O	
	Ht.	Wt.	Ht.	Wt.	Ht.	Wt.	Ht.	Wt.
cm	*cm*	*gm*	*cm*	*gm*	*cm*	*gm*	*cm*	*gm*
0–9	21	3.1	9	0.2	20	1.1	20	1.8
9–18	18	2.7	10	0.2	15	0.6	18	1.2
18–27	18	2.7	0	0.0	6	0.1	14	0.7
27–36	20	3.3	5	0.1	6	0.5	7	0.6
36–45	20	3.1	4	0.1	7	0.4	6	0.4
45–54	21	3.6	4	0.2	4	0.2	4	0.2
54–63	21	3.4	3	0.1	4	0.2	11	0.7
63–72	22	3.8	9	0.5	6	0.3	7	0.6
72–81	21	4.2	23	2.0†	10	0.9	8	0.8
81–90	22	3.2	25	4.7	14	1.0†	10	0.6†

Fraction of soil column	$Na_2B_4O_7$, 800 p.p.m.							
	10 cm H_2O		20 cm H_2O		40 cm H_2O		80 cm H_2O	
	Ht.	Wt.	Ht.	Wt.	Ht.	Wt.	Ht.	Wt.
cm	*cm*	*gm*	*cm*	*gm*	*cm*	*gm*	*cm*	*gm*
0–9	21	1.7	17	2.3‡	19	2.7	18	2.4
9–18	22	2.5	22	2.8	19	2.6	18	2.5
18–27	21	2.0	21	2.4	19	2.4	19	2.6
27–36	22	1.5	20	2.3	18	2.5‡	17	2.4
36–45	7	0.5	21	2.1	17	1.8	17	2.1
45–54	4	0.1	24	2.1	17	1.9	18	2.1
54–63	7	0.5	24	2.5	19	2.2	16	2.1
63–72	0	0.0	24	2.4	20	2.1	19	2.4
72–81	0	0.0	8	0.6	19	1.8	19	2.7
81–90	0	0.0†	10	0.5	22	2.4	23	2.9

* Average weight of plants in 10 untreated checks = 5.4 gm.
† Boron injury present to this depth.
‡ Boron injury present below this depth.

Evidently, borax is held in the soil in an available form and tends to accumulate in the upper portion of the tube to which it is applied. Comparison with results of similar tests on sodium chlorate and sodium arsenite places borax between these other two chemicals in the firmness with which it is held.

As borax is somewhat less toxic than chlorate under the conditions of this experiment, the accumulation from the lower concentrations is less noticeable. In the higher concentrations, however, the results are more clear-cut. Probably the most outstanding difference occurs in the

TABLE 9

RESULTS OF LEACHING SODIUM BORATE IN COLUMBIA FINE SANDY LOAM, AS SHOWN BY GROWTH OF INDICATOR PLANTS

(Harvested May 9, 1935)*

Fraction of soil column	Check		$Na_2B_4O_7$, 800 p.p.m.					
	10 cm H_2O		0 cm H_2O		2.5 cm H_2O		5.0 cm H_2O	
	Ht.	Wt.	Ht.	Wt.	Ht.	Wt.	Ht.	Wt.
cm	*cm*	*gm*	*cm*	*gm*	*cm*	*gm*	*cm*	*gm*
0– 9	19	2.6	0	0.0	0	0.0	21	1.2
9–18	19	2.6	0	0.0	0	0.0	0	0.0
18–27	21	3.7	0	0.0	0	0.0	0	0.0
27–36	22	3.5	0	0.0	0	0.0	0	0.0
36–45	24	3.8	9	0.3	0	0.0	0	0.0
45–54	23	4.0	16	1.0	15	0.5	8	0.2
54–63	23	3.4	25	4.3	20	1.2	18	0.8
63–72	24	3.9	25	5.4†	26	5.1†	24	3.0†
72–81	26	5.2	30	8.9	29	6.8	30	7.6
81–90	28	6.7	28	8.0	28	6.1	27	7.7

Fraction of soil column	$Na_2B_4O_7$, 800 p.p.m.							
	10 cm H_2O		20 cm H_2O		40 cm H_2O		80 cm H_2O	
	Ht.	Wt.	Ht.	Wt.	Ht.	Wt.	Ht.	Wt.
cm	*cm*	*gm*	*cm*	*gm*	*cm*	*gm*	*cm*	*gm*
0– 9	23	1.8	21	2.3	20	2.2	18	1.8
9–18	20	1.2	18	1.6	17	1.8	18	1.9
18–27	16	0.5	19	1.6	17	1.5	19	1.9
27–36	0	0.0	21	1.9	17	1.7	19	2.1‡
36–45	0	0.0	19	1.0	18	1.3	19	2.0
45–54	0	0.0	8	0.2	19	1.4	19	2.0
54–63	0	0.0	0	0.0	19	1.4	18	1.7
63–72	15	0.5	0	0.0	19	1.1	18	1.9
72–81	24	2.0†	0	0.0	13	0.4	21	2.0
81–90	29	6.3	9	0.2†	9	0.3†	19	1.9

* Average weight of plants in 10 untreated checks=8.9 gm.
† Boron injury present to this depth.
‡ Boron injury present below this depth.

Stockton adobe clay. Chlorate was not retained at a concentration above that of the moistening solution by this soil. Borax, on the other hand, is definitely accumulated in the upper fractions from the three more concentrated solutions. As with arsenic, the quantity held (at least in this one soil) was greater with the higher concentrations of the moistening solutions.

Leaching Studies.—The effect of leaching upon the movement of borax within the soil columns is shown in the next set of experiments. In these tubes the initial moistening solution contained 800 p.p.m. of anhydrous borax. Seven tubes of each soil were moistened with this solution; an eighth tube was moistened with distilled water as a check. After moistening, the tubes were leached with different volumes of distilled water expressed in the tables as surface centimeters, and, after standing 48

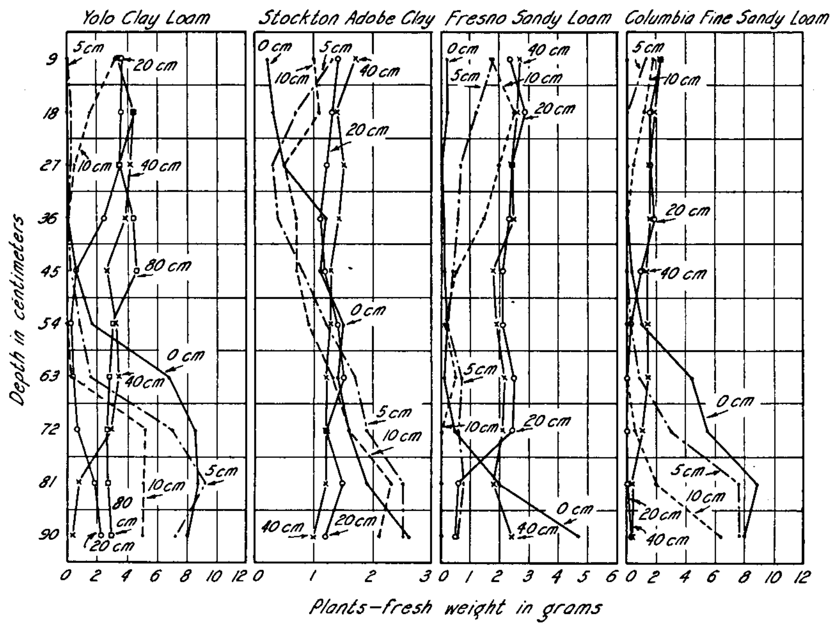

Fig. 7.—The effect of leaching upon the location of borax in soil columns as shown by crop yield.

hours, were divided into ten fractions, planted, and handled as in the previous experiments.

The data on these tests are presented in tables 6, 7, 8, and 9 and shown in the form of curves in figure 7. Comparison with the results obtained with chlorate and arsenic (*17*) indicate again that the borax is more firmly held than the former and less firmly than the latter. In the Yolo soil, borax was present in toxic amounts in the lower fractions of the column leached with 80 cm of water.

In the Stockton adobe clay the low toxicity of borax somewhat obscures the effects of leaching. The results would have been more clear-cut had the moistening solution contained more borax. Nevertheless, the chemical tended to remain in the top of the column and was reduced in concentration below the limits of visible toxicity by the increased leaching instead of being displaced toward the bottom of the tube as in the other soils.

In the coarser soils the borax was readily displaced by leaching, the columns being left relatively free of chemical by the larger volumes of water.

The range of concentrations in the soil that can be tested by this method is very definitely limited by the sensitivity of the indicator plant used. Not only is the range limited, but it varies with the different soils and with the time elapsed between application and the growth of the crop. For these reasons chemical studies are needed to substantiate and extend these results. Analyses of these treated soils should give a much more accurate picture of the concentrations and the distribution of borax under the different experimental conditions.

PLOT TESTS WITH BORON COMPOUNDS

Davis Plots.—As shown by the toxicity tests reported, borax is a very toxic chemical on many soils, ranking with sodium chlorate and sodium arsenite in its ability to render the soil sterile immediately after application. It loses its toxicity rather rapidly, however, under the conditions of plant growth and, furthermore, is not firmly held in available form in the coarser soils in which it is most toxic. It is likely, therefore, to have only a limited usefulness in weed control, being effective on light soils in regions of low rainfall or upon plants especially susceptible to boron injury.

The first plots to be treated with boron compounds at Davis were established in the winter of 1933–34. They were located on the banks of an abandoned irrigation ditch on a Yolo fine sandy loam. A mixed growth of grasses and various winter annuals covered the soil at the time the applications were made. The plots were each 1 square rod in area and were treated with a number of chemicals, including borax in solution, borax in combination with sodium arsenite in solution, dry powdered borax, and mixtures of dry borax and arsenic trioxide. A few plots received colemanite, a mixed borate of sodium and calcium, somewhat less soluble than borax; others received colemanite with dry arsenic trioxide. Two plots were treated with a mixture of colemanite and sodium chlorate. The results on these plots, shown in table 10, are visual estimates of the surviving plants at the dates indicated. Check plots with arsenic and chlorate alone (*14*) were included, but are not reported in the table.

Evidently straight borax either dry or in solution is much less toxic in the field than sodium chlorate or arsenic. When mixed with arsenic,

TABLE 10

EFFECTS OF VARIOUS SOIL STERILANTS UPON WEED GROWTH; PLOTS AT DAVIS
(Applications made in December, 1933, and January, 1934)

Plot No.	Chemicals applied, pounds per square rod				Per cent weed stand on dates given		
	Chemical	Dosage	Chemical	Dosage	April 5, 1934	July 16, 1934	April 12, 1935
1	Borax in solution	2	....	..	90	90	100
2		3	....	..	80	90	100
3		4	....	..	30	80	100
4		8	....	..	40	80	95
5		12	....	..	7	15	30
6	Borax in solution	1	Sodium acid arsenite in solution expressed in terms of As_2O_3	4	30	70	90
7		2		4	25	60	90
8		3		4	2	10	60
9		1		6	10	20	90
10		2		6	15	40	75
11		3		6	10	20	90
12		1		8	2	5	40
13		2		8	7	10	25
14		3		8	1	5	10
15	Borax, dry	2	....	..	100	100	100
16		4	....	..	100	100	100
17		6	....	..	100	100	100
18		8	....	..	60	75	90
19		10	....	..	40	40	90
20		12	....	..	10	10	30
21	Borax, dry	2	Arsenic trioxide, dry	4	90	90	10
22		4		4	90	100	15
23		6		4	20	40	5
24		2		6	90	100	20
25		4		6	30	45	2
26		6		6	40	50	1
27		2		8	40	50	1
28		4		8	50	90	2
29		6		8	10	15	1
30	Colemanite, dry	4	....	..	100	100	100
31		6	....	..	100	100	90
32		8	....	..	100	100	100
33		12	....	..	75	90	60
34	Colemanite, dry	2	Arsenic trioxide, dry	4	100	100	90
35		4		4	100	100	20
36		6		4	100	100	5
37		8		4	75	75	5
38		12		4	75	100	10
39	Colemanite, dry	4	Sodium chlorate, dry	1	25	50	100
40		8		1	2	10	50

furthermore, the borax added little or nothing to the effectiveness of the treatment. In the case of the dry mixtures with arsenic the treatments were more effective the second year, probably because of a slow dissolving of the arsenic and retention in an available form in the top soil. The borax failed to improve the results of this type of application.

Arsenic, either in the form of sodium arsenite or as the dry trioxide, is very effective in soil sterilization. Its principal drawback is its poisonous nature. Sodium chlorate, though also effective, is costly, is hazardous to handle, and rapidly loses its toxicity by decomposition and leaching. For these reasons boron compounds would be preferable if they were more effective.

Probably the most promising result obtained the first season was that of the colemanite-chlorate plots listed at the bottom of table 10. These plots were relatively free of vegetation throughout the first winter and spring and for much of the second winter. The mixture of one pound of sodium chlorate with 8 pounds of colemanite would be relatively low in cost, nonpoisonous, and practically free of fire hazard.

The second season's plots were treated to test the relative effectiveness of the borate-chlorate mixtures. A portion of the same abandoned ditch was used, and applications were made in December, 1934. Results on these plots are shown in table 11.

The total seasonal rainfall during the winter of 1934–35 was 18.71 inches. At the time of application in December, 1934, 4.94 inches had fallen, leaving a difference of 13.77 inches received by the plots, much of which came in March and April. These heavy spring rains explain to a certain extent the poor results on these plots. Plots with only a scattering of weak chlorotic plants in early March later developed a fairly heavy growth. Experience indicates that the applications would have been far more effective had the spring been dry.

On the other hand, the boron compounds used in these experiments were not nearly so effective as the greenhouse results would seem to promise. Only when mixed with sodium chlorate were they satisfactory. The colemanite mixtures gave the best results under conditions at Davis.

During this same season a number of applications were made on different areas on the University Farm in an attempt to control miscellaneous weeds. These trials were made on fence lines, roadsides, graveled parking areas, graveled walks, and other places usually hoed during the spring. Most of the applications were light—from 1 to 4 pounds per square rod. Some of the treatments were repeated several times as weed growth seemed to warrant.

As the season advanced it became very evident that the treatments

TABLE 11

EFFECTS OF CHLORATE-BORATE MIXTURES UPON WEED GROWTH; PLOTS AT DAVIS
(Applications made in December, 1934)

Plot No.	Chemicals applied, pounds per square rod				Per cent weed stand on dates given	
	Chemical	Dosage	Chemical	Dosage	April 12, 1935	October 5, 1935*
1	Borax, dry	2	Sodium chlorate	½	70	90
2		4		1	60	80
3		6		1½	50	70
4		8		2	15	50
5		4		½	60	90
6		8		1	50	75
7		12		1½	20	40
8		16		2	10	20
9	Borax, dry	4	....	...	100	100
10		8	....	...	100	100
11		12	....	...	90	100
12		16	....	...	80	100
13	Kramer ore, dry	2	Sodium chlorate	½	80	100
14		4		1	70	90
15		6		1½	60	90
16		8		2	40	75
17		4		½	75	100
18		8		1	35	70
19		12		1½	25	50
20		16		2	15	30
21	Kramer ore, dry	4	....	...	100	100
22		8	....	...	100	100
23		12	....	...	100	100
24		16	....	...	100	100
25	Colemanite, dry	2	Sodium chlorate	½	75	100
26		4		1	30	100
27		6		1½	15	90
28		8		2	5	75
29		4		½	50	100
30		8		1	15	100
31		12		1½	5	90
32		16		2	0	50
33	Colemanite, dry	4	....	...	100	100
34		8	....	...	100	100
35		12	....	...	100	100
36		16	....	...	100	100
37	....	..	Sodium chlorate	½	80†	100†
38	....	..		1	70†	100†
39	....	..		1½	60†	90†
40	....	..		2	60†	90†

* Winter and spring annuals on these plots were mature at the time the data were taken in April. The difference in stand in October was due to a growth of *Kickxia elatine*, a prostrate summer annual with a high salt tolerance.

† Average of 2 plots.

where two or three light applications were made were much more satisfactory than those in which the total dose was applied at one time.

Considering all of the results so far obtained with boron compounds in soil sterilization, on the fertile alluvial soils of the interior valleys of California colemanite appears to be the most effective material. Mixed with sodium chlorate at a rate of 8 parts to 1 by weight, it makes an effective sterilant if properly used. The above-mentioned experiments indicate that several light applications of the mixture through the season as the weed growth warrants are more effective than one heavy application of a like total amount. Graveled areas yield much more satisfactory results than bare soil. Dosages must be far heavier under the latter conditions. Results of using the mixture on deep-rooted perennials do not differ from those obtained by applying the chlorate which it contains alone. Borates applied to the top soil have no effect below the top few inches upon such weeds as morning-glory and creeping mallow.

Humboldt County Plots.—The results obtained with boron compounds in the control of Klamath weed on the more heavily leached soils of Humboldt County differ considerably from those that have just been presented.

Klamath weed (*Hypericum perforatum*), a weed pest on range lands in parts of northern California (*30*), is a perennial with a root system that may extend to a depth of 3 feet. It has no feed value and frequently grows in stands so dense as to crowd out desirable plants.

Experimental plot studies with soil sterilants in stands of Klamath weed in southern Humboldt County have been carried on for the past year and a half. The soil sterilants include borax, colemanite, Kramer ore (a crude sodium borate), and mixtures of these with sodium chlorate, sodium arsenite, and arsenic trioxide.

The first applications of borax and mixtures of borax with other chemicals were made near Blocksburg in March, 1934. Rainfall amounting to 8.86 inches fell between the date of application and July 1, the end of the season. These plots now have also had the 1934–35 season's rainfall of 49.23 inches—a total of 58.09 inches up to July 1, 1935. Results on these plots are given in table 12, expressed in terms of percentage stand of Klamath weed surviving the treatment. The field in which these plots are located had practically a solid stand of Klamath weed, with a small percentage of annual grasses. Removal of Klamath weed by mechanical means or by temporary soil sterilants usually results in a dense stand of annual grasses in the second year. Very little grass grew on any of the borax plots during the spring and summer of 1934. By the summer of 1935 some grass and annual weeds appeared on all plots

TABLE 12

EFFECTS OF VARIOUS CHEMICALS UPON KLAMATH WEED; SOIL STERILIZATION PLOTS AT BLOCKSBURG

(Applications made in March, 1934)

Plot No.	Chemicals applied, pounds per square rod				Per cent weed stand on dates given		
	Chemical	Dosage	Chemical	Dosage	May 8, 1934	August 15, 1934	May 2, 1935
1	Borax, dry	2	....	..	100	90	70
2	Borax, dry	4	....	..	75	70	50
3	Borax, dry	6	....	..	60	60	40
4	Borax, dry	8	....	..	50	60	25
5	Borax, dry	12	....	..	25	15	10
6	Borax, dry	2	Arsenic trioxide, dry	4	100	80	75
7	Borax, dry	4	Arsenic trioxide, dry	4	100	90	90
8	Borax, dry	6	Arsenic trioxide, dry	4	40	30	40
9	Borax, dry	2	Arsenic trioxide, dry	8	90	70	80
10	Borax, dry	4	Arsenic trioxide, dry	8	75	75	40
11	Borax, dry	6	Arsenic trioxide, dry	8	35	40	25
12	Borax, dry	2	Arsenic trioxide, dry	12	75	40	25
13	Borax, dry	4	Arsenic trioxide, dry	12	50	25	20
14	Borax, dry	6	Arsenic trioxide, dry	12	50	30	70
15	Borax, dry	4	Sodium chlorate, dry	1	25	2	5
16	Borax, dry	4	Sodium chlorate, dry	2	25	2	3
17	Borax, dry	4	Sodium chlorate, dry	3	20	1	1
18	Borax, dry	8	Sodium chlorate, dry	1	10	3	5
19	Borax, dry	8	Sodium chlorate, dry	2	5	1	1
20	Borax, dry	8	Sodium chlorate, dry	3	5	1	0
21	Borax, dry	12	Sodium chlorate, dry	1	3	1	1
22	Borax, dry	12	Sodium chlorate, dry	2	3	0	0
23	Borax, dry	12	Sodium chlorate, dry	3	2	0	0
24	....	..	Sodium chlorate, dry	1	75	60	40
25	....	..	Sodium chlorate, dry	2	60	100	100
26	....	..	Sodium chlorate, dry	3	30	40	50
27	....	..	Sodium chlorate, dry	4	10	3	5
28	....	..	Sodium chlorate, dry	6	10	1	0
29	Borax in solution	1	Sodium acid arsenite in solution expressed in terms of As_2O_3	4	10	25	35
30	Borax in solution	2	Sodium acid arsenite in solution expressed in terms of As_2O_3	4	10	15	25
31	Borax in solution	1	Sodium acid arsenite in solution expressed in terms of As_2O_3	6	5	20	60
32	Borax in solution	2	Sodium acid arsenite in solution expressed in terms of As_2O_3	6	3	5	25
33	Borax in solution	1	Sodium acid arsenite in solution expressed in terms of As_2O_3	8	0	1	1
34	Borax in solution	2	Sodium acid arsenite in solution expressed in terms of As_2O_3	8	0	1	1
35	....	..	Sodium acid arsenite in solution	4	10	25	30
36	....	..	Sodium acid arsenite in solution	6	1	5	20
37	....	..	Sodium acid arsenite in solution	8	1	5	15

except those treated with arsenic trioxide and sodium arsenite. All borax-treated plots had a reduced stand of grasses. Four pounds of borax per square rod reduced the stand of grasses and annual weeds by about 50 per cent; 8 pounds, by about 75 per cent.

Of this series of treatments, the mixtures of borax and sodium chlorate were the most effective against Klamath weed. The mixture of 4 pounds borax and 1 pound sodium chlorate per square rod gave satisfactory control.

The mixtures of borax with arsenic trioxide and sodium arsenite gave results no better than those of the arsenic compounds applied alone.

Another set of plots was laid out in another field in the same general locality and treated during the winter of 1934–35. Conditions of soil, topography, and plant cover were similar in the two fields. Each treatment was repeated several times between November, 1934, and April, 1935. The results of these treatments are reported in table 13. The results as stated are for Klamath weed only.

Best results with borax, both dry and in solution, were obtained from applications made about February 1. These applications had 16.22 inches of rain up to the end of the season. Eight pounds per square rod gave satisfactory control of Klamath weed under these conditions.

The dry borax-chlorate mixtures were most effective in the March 30 application. The rainfall between that date and the end of the season was 7.68 inches. This is not far from the 8.86 inches received by the series of plots treated the previous March, and the results are equally satisfactory. Again the combination treatment gave better results than either of the ingredients applied alone.

In general, results of treatments combining sodium chlorate and borax in solution are of the same order as for the corresponding dry treatments. None of the solution applications received the amount of rainfall that proved to be optimum for the dry treatments. The February 9 applications had 16.64 inches; the April 22 application but 0.84.

The November and April applications of colemanite and Kramer ore gave better results than the corresponding dry-borax treatments; but the January and February applications were not as effective as the corresponding borax application.

Combinations of colemanite with sodium chlorate, and Kramer ore with sodium chlorate were better than the corresponding combinations of sodium chlorate and borax applied on the same dates, and in general the Kramer-ore combinations appeared better than those with colemanite, though the differences may not be significant. Unfortunately, no colemanite or Kramer-ore combinations were applied on March 30,

TABLE 13

EFFECTS OF VARIOUS CHEMICALS UPON KLAMATH WEED; SOIL STERILIZATION PLOTS AT CASTERLIN, 1934–35

Plot No.	Chemicals applied, pounds per square rod				Per cent weed stand observed on Sept. 10, 1935, from applications made on dates given					
	Chemical	Dosage	Chemical	Dosage						
					Nov. 15	Dec. 8	Jan. 30	Feb. 2	Mar. 30	April 11
1	Borax, dry	4	....	..	100	50	40	20	40	80
2		8	....	..	100	40	10	1	30	50
3		12	....	..	90	20	1	1	30	50
4		16	....	..	80	15	0	1	25	50
5		20	....	..	30	10	0	5	15	60
					Nov. 22	Dec. 7	Feb. 4	Feb. 9	April 18	
6	Borax in solution	2	....	..	50	100	80	40	60	..
7		4	....	..	30	80	60	60	60	..
8		6	....	..	30	60	15	2	60	..
9		8	....	..	20	40	1	40	40	..
10		12	....	..	10	25	0	50	30	..
11		16	....	..	1	10	0	..	..	..
					Nov. 15	Dec. 9	Jan. 30	Feb. 2	Mar. 30	April 12
12	Borax, dry	2	Sodium chlorate, dry	1	100	25	..	..	..	..
13		2		2	100	25	..	..	..	..
14		4		1	100	40	40	50	2	80
15		4		2	70	40	50	60	2	70
16		6		1	..	..	25	40	8	50
17		6		2	..	..	20	60	3	20
18		8		1	65	50	10	60	3	50
19		8		2	40	30	10	50	3	40
					Nov. 25	Dec. 7	Feb. 5	Feb. 9	April 22	
20	Borax in solution	2	Sodium chlorate in solution	1	15	40	100	..	..	..
21		2		2	15	30	90	..	..	..
22		4		1	10	30	60	75	70	..
23		4		2	5	25	30	90	70	..
24		6		1	..	..	25	70	50	..
25		6		2	..	..	30	50	15	..
26		8		1	0	40	..	30	40	..
27		8		2	0	20	..	30	15	..
					Nov. 15	Dec. 8	Jan. 30	Feb. 2	Mar. 30	April 11
28	....	..	Sodium chlorate, dry	1	80	30	100	20	10	40
29	....	..		2	75	25	80	40	15	40
30	....	..		3	80	25	60	40	10	40
31	....	..		4	70	20	60	50	3	40
32	....	..		6	75	15	25	20	2	10

TABLE 13—*Concluded*

Plot No.	Chemicals applied, pounds per square rod				Per cent weed stand observed on Sept. 10, 1935, from applications made on dates given					
	Chemical	Dosage	Chemical	Dosage						
					Nov. 22	Dec. 7	Feb. 4	Feb. 9	April 18	
33	....	..	Sodium chlorate in solution	1	50	100	25	50	75	..
34	....	..		2	70	70	30	35	50	..
35	....	..		3	40	60	40	40	20	..
36	....	..		4	20	40	40	40	15	..
37	....	..		6	5	50	40	50	20	..
					Nov. 20	Feb. 3	April 11			
38	Colemanite, dry	4	....	..	80	90	70	..	..	..
39		8	....	..	80	50	15	..	..	..
40		12	....	..	80	20	15	..	..	..
41		16	....	..	30	2	15	..	..	..
42		20	....	..	30	5	10	..	..	..
					Nov. 20	Feb. 3	April 11			
43	Kramer ore, dry	4	....	..	70	50	40	..	..	..
44		8	....	..	70	40	15	..	..	..
45		12	....	..	30	10	15	..	..	..
46		16	....	..	5	2	10	..	..	..
47		20	....	..	5	20	10	..	..	..
					Nov. 20	Feb. 3	April 17			
48	Colemanite, dry	2	Sodium chlorate, dry	1	75	..	..	..	..	..
49		2		2	75	..	..	..	..	..
50		4		1	80	30	15	..	..	..
51		4		2	35	50	5	..	..	..
52		6		1	..	60	5	..	..	..
53		6		2	..	50	5	..	..	..
54		8		1	50	50	8	..	..	..
55		8		2	30	40	3	..	..	..
					Nov. 20	Feb. 3	April 18			
56	Kramer ore, dry	2	Sodium chlorate, dry	1	70	..	..	..	..	..
57		2		2	50	..	..	..	..	..
58		4		1	50	15	10	..	..	..
59		4		2	30	60	5	..	..	..
60		6		1	..	30	8	..	..	..
61		6		2	..	30	5	..	..	..
62		8		1	50	15	3	..	..	..
63		8		2	50	10	2	..	..	..

the date that gave the best results with the borax combinations. The applications of April 17 and 18 received but 0.84 inch of rain; and though the results are significantly better than from the ores alone or chlorate alone, the treatments would probably have been still more effective had they received more rainfall.

DISCUSSION AND SUMMARY

Although boron compounds are extremely toxic to some plants and may reduce growth and produce characteristic symptoms when present in relatively low concentrations in the soil, in chemical weed control they will find only limited use. The high toxicity indicated in the greenhouse tests is less evident in the field. These compounds, furthermore, are not retained in the soil against the leaching power of moving water to the same extent as arsenic. For complete sterilization, in consequence, dosages must be heavy and applications frequent. The discrepancy between the toxicity expressed in the greenhouse tests and that observed on field plots seems somewhat anomalous until one considers the time effect. As shown by figures 1, 2, 3, and 4, borax loses rapidly in toxicity when held in a given mass of soil. In the field this action is superimposed on the effects of the loss by leaching from the surface soil, and together these losses reduce the effective concentration until seedlings are permitted to develop. When these seedlings are of a tolerant species they grow, and the plots become reinfested. Evidently, therefore, the use of boron in soil sterilization will be limited both by the species existent on the areas and by the amount and distribution of the seasonal rains.

The results on the Davis plots are given in terms of the effects of boron compounds upon growth of the common winter annuals of that region. Most of these plants, adapted to growing in regions of medium to low rainfall, thrive in soils containing a fairly high level of soluble salts. They are all fairly tolerant of boron, and relatively high concentrations in the soil solution are required to kill them. Klamath weed (*Hypericum perforatum*), a native of northern Europe, grows only in regions of medium to high rainfall, where soils are heavily leached and contain relatively little soluble material. Klamath weed, therefore, is injured by high concentrations of salts in the soil solution and is highly susceptible to boron poisoning. Therefore boron compounds should be useful in controlling Klamath weed, especially when combined with sodium chlorate to increase the toxicity. Their low solubility should result in some residual effect, reducing the probability of reinfestation by seedlings. Their nonpoisonous and fire-deterrent properties should appreciably reduce the hazard over that of sodium chlorate or arsenic.

Against more tolerant plants and in regions of fertile, recent alluvial soils the use of boron compounds seems limited to the coarser soils or to graveled areas; and where rainfall exceeds 10 inches annually, applications will be needed one or more times each year.

Again it should be emphasized that boron compounds must be used with caution close to ornamental plants, around orchards or groves of such susceptible species as citrus and walnuts, and in regions where there is a possibility of contamination of water supplies used for irrigation.

With these obvious drawbacks, however, the combination of sodium chlorate with some one of the cheap boron ores should find wide use in such places as school grounds, parking areas, airports, and graveled walks and driveways, where a nonpoisonous soil sterilant is desirable.

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