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TOXICITY OF THREE 2,4-D FORMULATIONS IN CALIFORNIA SOILS¹

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INTRODUCTION

ONE OF THE most widely publicized herbicides in recent years is 2,4-dichlorophenoxy acetic acid, commonly known as 2,4-D. In 1949 the acreage of crops successfully sprayed with this chemical ran into the millions. Because of its selectivity, it has been used primarily to control broad-leaved weeds in cereal crops. It has been used to a lesser degree to control perennial weeds, brush, and trees where no crop was involved. The chemical is usually applied in solution, emulsion, or suspension as a spray to the leafy vegetation of plants.

Blackman's (1945)³ report that 2,4-D may act as a selective temporary soil sterilant suggested a new use for this chemical in the field of preemergence weed control.

De Rose (1946) confirmed the toxicity of 2,4-D in soils. Crafts (1949), using three indicator plants, studied toxicity, rate of decomposition, and displacement in eight California soils, showing clearly the selectivity between monocots and dicots even in soil applications. The fact that 2,4-D acid is only slightly water soluble has led to the manufacture of various water and oil soluble formulations, the use of which is preferred or recommended in different cases. Since with 2,4-D it is possible to obtain herbicidal action by treatment of the soil as well as by foliage application, it was important to determine the toxicity and rate of inactivation of different formulations when in contact with the soil. It was also important to know whether the effect on subsequent crops depended upon formulation or was related to some particular soil characteristic.

MATERIALS AND METHODS

Air dried and screened samples of three California soils were used: Yolo fine sandy loam, Yolo adobe clay, and Hanford fine sandy loam. All three soils are of neutral reaction. Both series are of a recent alluvial nature; the Yolo is of sedimentary origin and the Hanford of an acid igneous parent material. Three indicator plants were used: Kanota oats, sunflowers, and vetch. Because of the greater resistance of monocots, the 2,4-D concentrations used for oats are ten times greater than those added to the dicot cultures. For the oats, the series was 0.0, 0.8, 1.6, 3.2, 6.4, 12.8, 25.6, 51.2, 102.4, and 204.8 p.p.m. 2,4-D acid equivalent, air dry soil basis.

Three formulations were studied: the water soluble sodium and triethylamine salts, and the oil soluble butyl ester.

The methods followed were described in detail by Crafts (1949). The necessary amounts of 2,4-D were measured from a stock solution or emulsion, diluted to a total volume calculated to bring the soil to field capacity, and

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³ See "Literature Cited" for citations referred to in text by author and date.

seeded. Thirty days after planting, the crops were cut off at ground level, and their fresh weights determined. After allowing the soil to dry out for a period of 30 days, it was pulverized, mixed, placed in the cans on top of the dried plant material, wetted to field capacity, and reseeded to determine the rate of decomposition of the chemical. Three such croppings were obtained in all cases.

RESULTS

Results are shown in figures 1 to 7 and tables 1 to 3. The toxicity and rate of decomposition of the three formulations, as can be seen in figures 1, 2, and 3, were quite similar in Yolo fine sandy loam when oats were used as the indicator plant. Figures 4 and 5 show yields of sunflowers and vetch in Yolo fine sandy loam to which increasing quantities of a butyl ester formulation of 2,4-D were added.

Figures 6 and 7 show crop yields of first and second croppings of oats and sunflowers obtained in the three soils to which the butyl ester formulation was added. A study of tables 1 to 3 will show that no important difference was obtained by the effects of the three different formulations considered.

Perhaps it is worth mentioning again that the 2,4-D was added on an acid equivalent basis, and not on formulation weight basis.

DISCUSSION AND CONCLUSIONS

The actual toxicity and subsequent inactivation of 2,4-D acid in California soils were previously studied and reported in detail by Crafts (1949). In brief, he concluded that toxicity was sufficient to reduce growth during the first cropping in the eight soils he considered (three of which are reported in these studies), but little toxicity remained by the second cropping, and a certain stimulation was noted in the third cropping. Breakdown was apparently slower in neutral and alkaline soils than in acid ones. Moderate fixation on clay was noted, and leaching experiments using 320 surface centimeters of water did not completely rid two soils of 2,4-D.

In that same report, Crafts mentioned the anomalous behavior of Yolo adobe clay, which fixed less 2,4-D than lighter soil types. From its clay content this soil might be expected to have a high fixing power. The experiments reported here tend to confirm those reported by Crafts. Again, here, the behavior of Yolo adobe clay was anomalous; the slight difference in clay content (14.94 per cent for Yolo fine sandy loam, and 16.44 per cent for Hanford fine sandy loam) between the other two soils is not sufficient to explain the evident difference in 2,4-D toxicity. However, if the two Yolo soils are considered separately, a correlation could be found with clay content, as shown by table 4.

In addition to the fact that the initial toxicity was the same for the three formulations considered, their subsequent inactivation was also quite similar. The largest dosages—204.8 p.p.m. for the oats and 20.48 p.p.m. for the sunflowers and vetch—caused appreciable growth reduction during the second and third croppings only to the vetch.

As was pointed out by Crafts (1948) breakdown of 2,4-D is accompanied by a certain increase in growth of oats and sunflowers. However, no appreci-

able increase in yield was noted when vetch was used as the indicator plant. Such increases in growth were highest when the sodium salt was applied. It seems possible that a base exchange mechanism may be involved. Because of the minute quantities of chemicals added, it hardly seems possible that a direct nutrition of the plant is concerned. If direct nutrition did occur, the triethylamine by releasing nitrogen should give the highest yields, which it does not.

If the crop yields of the checks are taken as indices of soil fertility, no actual relation could be found between this soil characteristic and the 2,4-D toxicity or its inactivation.

On the basis of studies with these three soils, it is difficult to generalize upon the differences in behavior of various 2,4-D formulations in soils, but it is possible to state that under greenhouse conditions their action through the soil is not different.

Warren and Hernandez (1948), working sodium and amine salts and isopropyl ester formulations into the soil just before planting onions, obtained results that showed no significant difference from the effects of the formulation, except that perhaps isopropyl ester gave a little greater kill.

It should be emphasized that the results obtained in these experiments are from each of the three formulations thoroughly mixed with a given quantity of soil. Under these conditions it appears to make no difference which formulation is used. Field observations with the different materials applied to the soil surface have shown that the water soluble forms are more effective than the esters insofar as immediate effect on prevention of germination is concerned.

The experiments reported here lead to the conclusion that all three forms act alike when mixed with the soil. This would appear contrary to the theory (Crafts, 1948) that the nonpolar ester should enter through the roots more slowly or to a lesser extent than the more polar sodium or amine salts. However, it might be inferred that in the soil all three forms act alike because they all revert to the parent acid through buffering action and hydrolysis. This would be in agreement with the theory since the acid is sufficiently polar to be effective through root absorption. The field observations on the lower effectiveness of the ester applied to the surfaces of the soil would also fit this scheme since it is possible that decomposition of the acid proceeds at about the same rate as its formation from the ester by hydrolysis. If the effective form of 2,4-D in the soil is that of the acid, then for soil application the use of finely ground acid rather than other formulations should be the most economical practice.

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TABLE 1
FRESH WEIGHTS OF KANOTA OATS GROWN IN THREE CALIFORNIA SOILS
CONTAINING VARIOUS CONCENTRATIONS OF THREE DIFFERENT
FORMULATIONS OF 2,4-D

Concentration 2,4-D acid equivalent in p.p.m. (air dry soil basis)	Soils								
	Yolo fine sandy loam			Hanford fine sandy loam			Yolo adobe clay		
	Formulation			Formulation			Formulation		
	B.E.	T.E.A.	Na salt	B.E.	T.E.A.	Na salt	B.E.	T.E.A.	Na salt
First cropping									
	(wt, gm)	(wt, gm)	(wt, gm)	(wt, gm)	(wt, gm)	(wt, gm)	(wt, gm)	(wt, gm)	(wt, gm)
0.0.....	2.9	2.8	3.1	5.0	5.4	5.6	5.4	4.3	5.7
0.8.....	2.4	1.8	1.7	5.0	3.4	5.0	4.9	3.5	4.9
1.6.....	0.6	1.1	1.2	3.6	3.3	4.3	4.3	3.3	3.3
3.2.....	0.4	0.5	0.7	3.4	2.1	2.9	2.7	2.5	2.5
6.4.....	0.3	0.2	0.3	0.8	1.0	1.3	1.2	1.3	1.2
12.8.....	0.1	0.2	0.2	0.3	0.4	0.4	0.2	0.2	0.3
25.6.....	0.1	0.2	0.2	0.2	0.3	0.2	0.2	0.1	0.2
51.2.....	0.2	0.2	0.1	0.2	0.2	0.2	0.1	0.1	0.2
102.4.....	0.1	0.1	0.1	0.2	0.1	0.2	0.1	0.0	0.1
204.8.....	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.0	0.0
Second cropping									
0.0.....	5.7	3.3	3.3	7.8	6.4	6.2	4.6	3.7	4.5
0.8.....	3.4	4.1	3.8	7.1	7.7	7.5	5.1	5.1	4.9
1.6.....	3.7	3.5	3.6	7.5	8.6	6.5	5.0	5.5	4.5
3.2.....	4.7	3.2	3.9	9.1	7.4	8.1	6.7	6.2	5.3
6.4.....	2.6	3.2	4.1	9.4	7.7	9.1	7.2	6.9	5.8
12.8.....	1.8	4.0	3.8	6.7	7.2	9.4	6.1	7.0	6.4
25.6.....	2.4	4.3	2.7	7.8	6.6	8.0	6.9	6.4	6.0
51.2.....	2.3	4.0	1.6	6.6	5.5	8.8	6.5	6.5	7.3
102.4.....	2.0	3.5	3.3	5.8	5.1	...	5.4	3.1	6.3
204.8.....	1.3	0.5	3.2	6.6	6.5	9.0	3.3	2.1	5.7
Third cropping									
0.0.....	1.5	2.2	1.9	6.0	4.4	4.4	3.1	2.7	2.7
0.8.....	3.2	2.5	2.2	5.5	5.4	4.4	3.4	2.7	3.1
1.6.....	3.3	2.5	2.6	6.3	6.5	6.1	3.4	3.0	2.7
3.2.....	4.3	2.3	2.4	6.4	6.0	4.8	4.4	2.8	4.1
6.4.....	3.8	3.4	3.1	7.9	5.5	6.7	4.3	3.3	2.9
12.8.....	4.4	3.0	2.9	7.0	5.9	6.4	5.2	3.7	3.3
25.6.....	4.2	5.1	3.9	7.0	5.6	7.5	5.3	4.5	3.6
51.2.....	4.5	3.5	4.0	7.4	6.5	7.8	4.3	2.8	3.2
102.4.....	3.9	3.4	3.3	7.1	6.1	4.1	4.6	6.0	4.4
204.8.....	3.9	4.5	3.3	5.9	6.9	7.1	6.0	6.3	5.0

TABLE 2
FRESH WEIGHTS OF SUNFLOWERS GROWN IN THREE CALIFORNIA SOILS
CONTAINING VARIOUS CONCENTRATIONS OF THREE DIFFERENT
FORMULATIONS OF 2,4-D

Concentration 2,4-D acid equivalent in p.p.m. (air dry soil basis)	Soils								
	Yolo fine sandy loam			Hanford fine sandy loam			Yolo adobe clay		
	Formulation			Formulation			Formulation		
	B.E.	T.E.A.	Na salt	B.E.	T.E.A.	Na salt	B.E.	T.E.A.	Na salt
First cropping									
	(wt, gm)	(wt, gm)	(wt, gm)	(wt, gm)	(wt, gm)	(wt, gm)	(wt, gm)	(wt, gm)	(wt, gm)
0.0	5.1	2.7	2.4	10.8	10.8	13.1	8.6	8.5	9.1
0.08	1.4	1.0	4.7	11.8	10.4	11.5	8.1	8.4	9.7
0.16	0.4	1.8	1.5	9.2	11.2	10.7	8.0	8.4	7.9
0.32	0.4	1.0	2.4	10.7	11.6	10.9	7.0	7.6	6.9
0.64	0.0	0.4	0.0	8.8	10.4	9.4	5.4	4.9	5.7
1.28	0.0	0.0	0.0	9.2	4.6	7.3	1.0	3.0	0.9
2.56	0.0	0.0	0.0	5.4	1.8	2.0	0.0	0.0	0.2
5.12	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10.24	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
20.48	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Second cropping									
0.0	9.7	11.0	10.0	13.5	10.2	11.4	9.3	11.6	9.4
0.08	...	14.0	11.7	15.8	13.3	13.6	9.1	11.2	10.7
0.16	11.5	13.1	8.3	12.0	15.2	16.0	9.3	11.6	10.5
0.32	10.6	13.9	8.4	14.1	15.7	14.6	9.4	10.1	12.0
0.64	10.5	12.4	9.7	17.9	13.3	14.6	12.3	11.0	10.4
1.28	11.5	11.4	8.8	17.0	14.0	13.8	13.0	12.1	9.9
2.56	8.8	10.6	9.8	15.8	11.2	15.0	11.2	15.0	14.2
5.12	5.2	9.5	7.6	17.0	15.3	19.7	5.1	13.4	12.1
10.24	4.9	5.2	7.8	18.0	10.2	15.1	7.8	13.7	9.7
20.48	5.4	6.3	4.9	9.0	13.6	14.8	3.4	10.5	10.0
Third cropping									
0.0	7.9	9.6	5.5	10.6	11.3	13.7	8.1	7.8	8.0
0.08	...	7.7	7.8	9.2	10.7	11.0	8.7	9.3	8.5
0.16	8.2	6.3	7.9	11.5	10.3	13.4	11.2	7.2	9.0
0.32	7.8	7.9	7.9	11.7	14.1	11.1	8.4	8.4	8.1
0.64	7.9	7.2	7.4	13.5	12.9	13.1	9.4	9.8	8.8
1.28	7.8	6.1	7.6	11.3	12.5	12.2	10.0	10.5	9.9
2.56	8.4	8.6	7.6	13.0	11.6	12.3	9.3	11.5	8.4
5.12	8.9	8.6	7.8	11.4	11.6	11.2	9.5	8.3	9.6
10.24	8.5	8.0	10.8	13.7	11.6	12.9	11.1	9.9	9.4
20.48	10.7	9.6	9.9	11.7	11.1	11.6	12.5	11.8	9.5

TABLE 3
FRESH WEIGHTS OF VETCH GROWN IN THREE CALIFORNIA SOILS
CONTAINING VARIOUS CONCENTRATIONS OF THREE DIFFERENT
FORMULATIONS OF 2,4-D

Concentration 2,4-D acid equivalent in p.p.m. (air dry soil basis)	Soils								
	Yolo fine sandy loam			Hanford fine sandy loam			Yolo adobe clay		
	Formulation			Formulation			Formulation		
	B.E.	T.E.A.	Na salt	B.E.	T.E.A.	Na salt	B.E.	T.E.A.	Na salt
First cropping									
	(wt, gm)	(wt, gm)	(wt, gm)	(wt, gm)	(wt, gm)	(wt, gm)	(wt, gm)	(wt, gm)	(wt, gm)
0.0.....	0.1	0.0	0.0	0.9	0.4	1.1	0.4	0.9	1.1
0.08.....	0.1	0.0	0.0	0.1	0.1	0.5	0.1	0.3	0.2
0.16.....	0.0	0.0	0.0	0.0	0.1	0.3	0.1	0.0	0.1
0.32.....	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0
0.64.....	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1.28.....	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2.56.....	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5.12.....	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10.24.....	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
20.48.....	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Second cropping									
0.0.....	1.5	1.0	1.5	1.1	1.1	0.9	0.9	1.2	0.8
0.08.....	1.1	1.2	1.2	0.9	1.3	1.0	1.1	1.2	0.8
0.16.....	0.9	1.2	1.1	1.0	1.4	1.0	0.9	1.1	1.3
0.32.....	1.0	0.9	1.2	1.3	1.4	1.5	1.1	1.1	1.1
0.64.....	0.4	0.5	1.0	1.3	1.5	1.3	0.7	1.2	1.0
1.28.....	0.7	0.8	1.0	1.1	1.2	0.8	1.1	0.9	0.5
2.56.....	0.1	0.3	0.6	1.1	1.2	1.1	1.1	0.7	1.3
5.12.....	0.0	0.0	0.2	0.7	1.1	1.5	0.5	0.4	0.3
10.24.....	0.0	0.1	0.1	1.0	0.9	1.5	0.1	1.1	0.1
20.48.....	0.0	0.0	0.0	0.3	0.8	0.0	0.0	0.0	0.0
Third cropping									
0.0.....	1.0	1.1	1.0	1.3	1.4	1.7	1.6	1.6	0.9
0.08.....	0.9	1.2	0.9	1.4	1.6	1.4	1.7	1.7	1.5
0.16.....	1.2	1.2	1.1	1.3	1.2	1.2	1.3	1.7	1.3
0.32.....	1.4	1.3	1.4	1.4	1.6	1.5	1.5	1.6	1.1
0.64.....	1.4	1.3	1.0	1.0	1.4	1.5	1.4	1.4	1.3
1.28.....	1.9	1.2	1.0	1.3	1.2	1.1	1.5	1.2	1.0
2.56.....	1.0	1.3	0.9	1.1	1.1	1.4	1.3	1.4	1.3
5.12.....	1.2	1.3	1.1	1.4	1.4	0.7	1.5	1.5	1.2
10.24.....	1.1	1.0	0.8	1.4	0.6	1.1	1.4	1.2	1.2
20.48.....	0.8	1.1	0.7	1.3	1.7	0.5	1.3	0.8	1.1

TABLE 4
RELATION BETWEEN TOXICITY OF 2,4-D AND CLAY CONTENT OF TWO YOLO SOILS
(Values are p.p.h. 2,4-D acid at which growth was severely inhibited)

Soil	Clay	Indicator plant (first crop)	Formulation		
			B.E.	T.E.A.	Na salt
Yolo fine sandy loam	(per cent) 14.94	oats	1.60	3.20	3.20
		sunflowers	0.08	0.64	0.64
	50.80	oats	12.80	12.80	12.80
Yolo adobe clay		sunflowers	1.28	1.28	1.28

Fig. 1. Toxicity of butyl ester of 2,4-D to oats in Yolo fine sandy loam.

Fig. 2. Toxicity of triethylamine 2,4-D to oats in Yolo fine sandy loam.

Fig. 3. Toxicity of sodium salt of 2,4-D to oats in Yolo fine sandy loam.

Fig. 4. Toxicity of butyl ester of 2,4-D to sunflowers in Yolo fine sandy loam.

Fig. 5. Toxicity of butyl ester of 2,4-D to vetch in Yolo fine sandy loam.

Fig. 6. Toxicity of butyl ester of 2,4-D to oats in three California soils.

Fig. 7. Toxicity of butyl ester of 2,4-D to sunflowers in three California soils.

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