TB 281 (1932)   USDA TECHNICAL BULLETINS   UPDATA
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NEWCOMER, E.J.; YOTHERS, M.A.   1 OF 1

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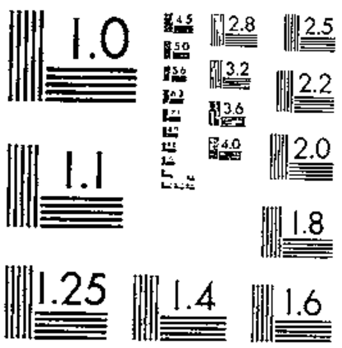

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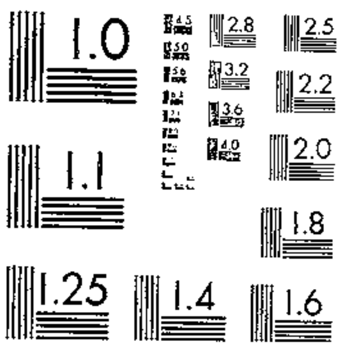

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EXPERIMENTS WITH INSECTICIDES FOR CODLING-MOTH CONTROL

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CONTENTS

INTRODUCTION

The codling moth (*Carpocapsa pomonella* L.) is one of the most serious insect enemies of apples and pears in the United States. The numerous investigations of this pest that have been made have long ago shown the chief factors to be considered in its control. The introduction of new insecticides and the necessity for avoiding objectionable spray residues, as well as the demand for more economical and more effective treatments, however, have made continuous experimentation imperative.

Laboratory and orchard experiments in controlling the codling moth with sprays have been conducted by the Bureau of Entomology at Yakima, Wash., from 1919 to 1929, inclusive.[1] Some of the experiments are of only local or transient interest; the results of many others have a wider and more permanent application. The more important of these latter are brought together in this bulletin.

METHODS

The laboratory experiments with larvae were made in the manner already described by one of the writers (*5*).[2] Experiments with insecticides for destroying the eggs were made by thoroughly spraying pear leaves or apples upon which eggs had been deposited, hanging them out of doors under a roof in a free circulation of air, and examining them after unsprayed eggs of the same age had hatched.

[1] This work was done under the direction of A. L. Quaintance, at that time in charge of the Division of Deciduous Fruit Insects, Bureau of Entomology. From 1919 to 1922 the senior writer was assisted in these experiments by W. D. Whitcomb, formerly of the Bureau of Entomology, and from 1923 to 1929 by M. A. Yothers, of the bureau. The orchard experiments were made in several commercial apple orchards near Yakima through the generous cooperation of the owners of these orchards.

[2] Italic numbers in parenthesis refer to Literature Cited, p. 28.

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The results of the experiments with egg-destroying compounds in the laboratory are given as percentage of eggs dead. With larvicides, the results are given in terms of percentage of worms entering the fruit, percentage causing only stings, total percentage causing blemishes, and ratio of stings to total blemishes. The latter is used merely as a general indication of the relative value of the treatments. In the combination experiments with eggs and larvae, the percentage of worms entering the fruit is based on the total number of eggs in the experiment rather than on the total number of larvae hatching.

For the orchard experiments, plats containing from 12 to 75 trees were used. The spraying was done with a type of gasoline power sprayer commonly employed in commercial work. Spray guns and two lines of hose were used for most of the experiments. In some of the earlier work the pressure was kept at from 250 to 300 pounds at the pump; later, pressures of from 300 to 350 pounds were maintained.

Biological observations were made each season to determine the proper times for spraying. The same number of applications was given all the plats in any one year, but the number varied somewhat in different years, owing to variations in seasons and in the different orchards used. Ordinarily one calyx spray and four or five cover sprays were applied. In most of the experiments results were estimated by examining all of the fruit from 6 to 10 trees in the center of the plat. In a few cases, where small plats were used, the fruit from only two or four trees was examined.

The results of the orchard experiments are given, for the most part, in terms of percentage of fruit wormy, percentage of fruit stung, percentage of sound fruit, which is the fruit that is neither wormy nor stung, and ratio of stings to total blemishes; that is, to total entrances and stings. In the tables the two classes wormy and stung fruit will be found to overlap, as many apples having both types of injury will be counted in both classes. The percentage of wormy fruit is the most important criterion, but percentage of stung fruit is also important. This percentage is usually much lower when egg-destroying sprays are used than when the treatment consists only of larvicides, since few of the latter are able to kill the larva before it has started to feed. The percentage of sound fruit is a rather practical indication of the value of the treatment. A valuable guide also to the efficacy of the material used consists of a ratio. Melander (*4*) suggested using the ratio of worms to stings. In this bulletin it seems preferable to employ the ratio of stings to total blemishes. When strictly stomach poisons are used this ratio is higher for the more effective materials, as a larger percentage of larvae are killed after having fed long enough to produce a sting. In most cases comparison is made with a standard treatment of lead arsenate, 1 pound to 50 gallons, and also with an unsprayed check if one is available.

LEAD ARSENATE

The experiments with lead arsenate have included tests of lead-arsenate sprays of different strengths and tests of lead arsenate with spreaders and stickers.

One pound of powdered lead arsenate to 50 gallons of water has been used for many years and has become almost a standard dilution. The question is often raised whether a larger quantity would not produce results sufficiently better to warrant its use. In 1919 a field test of lead arsenate at a dilution of 3 pounds to 50 gallons was made. The fruit used in this test turned out to be 3.2 per cent wormy, as compared with fruit 5.4 per cent wormy in a test of lead arsenate at a dilution of 1 pound to 50 gallons. There were more than twice as many stings and about twice as many calyx worms in the latter test as in the former. This indicated an advantage in the larger quantity of lead arsenate.

Laboratory experiments were then made in 1923 and 1924, the results of which have already been published (*5, Table 4*), but which are shown graphically by the solid line in Figure 1. These results

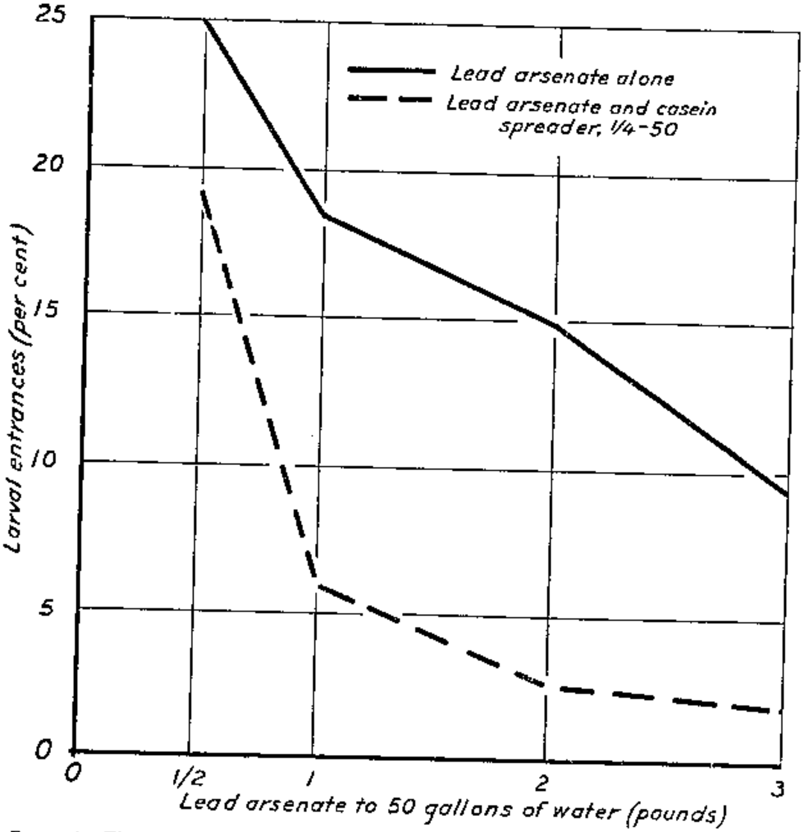


FIGURE 1.—The effect of lead arsenate at various dilutions, with and without casein spreader, on entrances of codling-moth larvae into fruit, Yakima, Wash., 1924

are a measure only of the freshly applied material, and show a very definite negative correlation between the degree of infestation and the strength of the lead arsenate.

Following these experiments orchard tests were made in 1927 and 1928. It was evident from the laboratory experiments that less than 1 pound of lead arsenate to 50 gallons would be ineffective, and, on account of the necessity of keeping the amount of arsenical residue at a minimum, there was no practical advantage in experimenting with more than 2 pounds to 50 gallons. Therefore, the orchard tests included only a comparison of 1 pound and 2 pounds of lead arsenate to 50 gallons of water. The results of these tests are shown in Table 1.

TABLE 1.—*Orchard experiments with lead arsenate for the codling moth, Yakima, Wash., 1927 and 1928*

Test No.	Applications	Dilution	Total apples	Wormy apples [1]		Stung apples [1]		Sound apples	Total blemishes	Total stings	Ratio of stings to total blemishes	Quantity of arsenic trioxide per pound of harvested fruit
	Number	*Pounds to gallons*	*Number*	*Number*	*Per cent*	*Number*	*Per cent*	*Per cent*	*Number*	*Number*		*Grain*
1927												
1	6	1 to 50	17,789	120	0.7	938	5.3	94.2	1,203	1,070	0.89	0.041
2	5	1 to 50	12,190	153	1.3	1,139	9.3	89.8	1,583	1,400	.88	.035
3	4	1 to 50	6,593	382	5.8	740	11.2	84.5	1,361	890	.65	.018
4	5	2 to 50	13,247	99	.7	589	4.4	95.0	798	689	.86	.044
5	4	2 to 50	11,236	195	1.7	788	7.0	91.7	1,176	948	.81	.033
1928												
6	7	1 to 50	30,645	3,531	11.5	10,142	33.1	62.2	24,581	18,911	0.77	0.026
7	7	2 to 50	22,710	1,102	5.2	5,599	24.7	72.6	10,569	8,770	.83	.044

[1] In this and in the succeeding tables that refer to orchard experiments all apples having both stings and entrances are recorded twice, the same apple being recorded as wormy and again as stung.

Doubling the strength of the material obviously improves the degree of control. As 3 per cent of an average crop of apples will pay for the additional material used in the double-strength treatment, it is apparent that this treatment would have been an economical one in two of the three comparisons in Table 1. The amount of arsenical residue is increased, however. It is also indicated in this table that an additional application of the single-strength lead arsenate may produce results as good as the smaller number of applications of the double-strength material without increasing the arsenical residue over that left by the latter treatment. The cost of this additional application would be less than the cost of the additional material in the other applications.

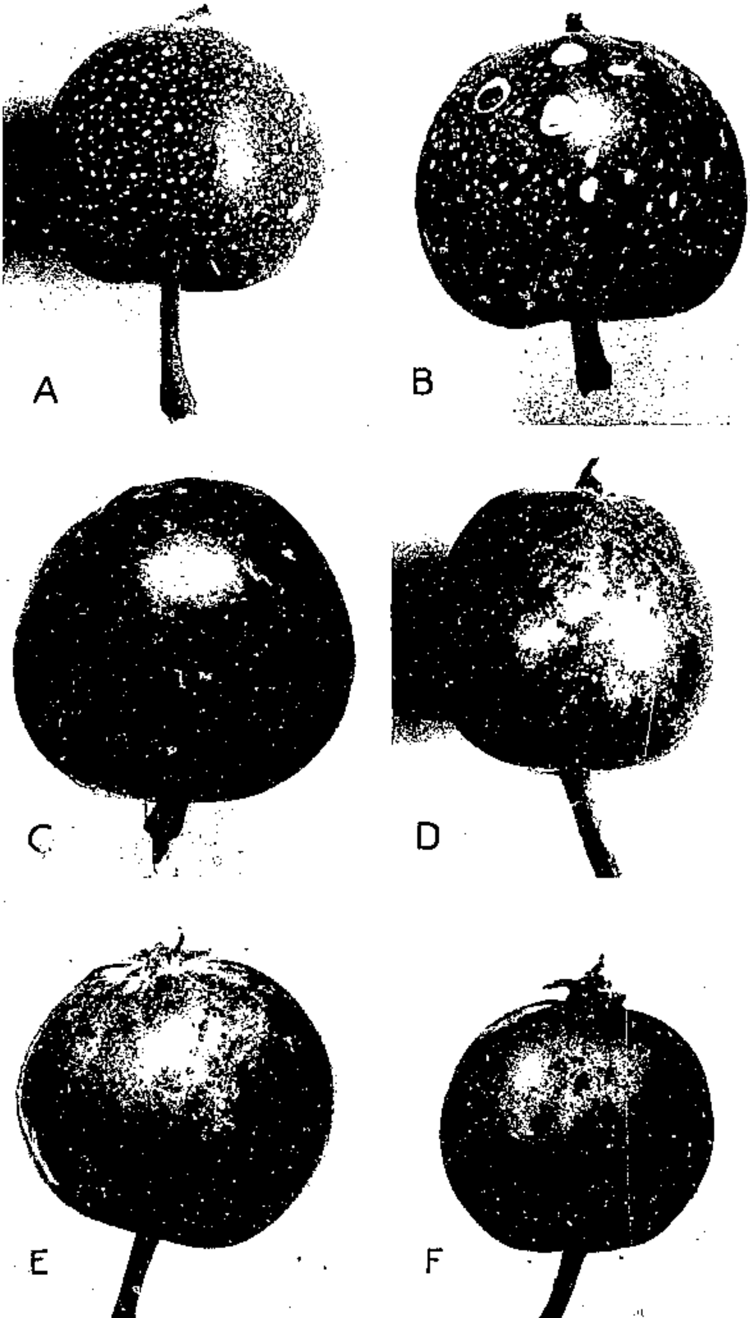
SPREADERS AND STICKERS

CASEIN

The value of adding spreaders to lead arsenate has been a much-debated question. A spreader is a material that lowers the surface tension of the spray liquid sufficiently to produce a continuous coating or film of lead arsenate on the surface of the fruit or foliage. (Pl. 1, B.) Theoretically, such a spray liquid should be more protective than one which contains no spreader and which forms droplets of irregular size on the surface with unprotected areas between. (Pl. 1, A, and 2, A.) Smith (7) did not get very much better results with the film type of coverage when he used a casein spreader containing 25 per cent casein and 75 per cent calcium hydrate in the proportion of 1 pound to 100 gallons of liquid than with the spotted type. In experiments made by the senior writer in 1923 and 1924 with the same material the results were similar to Smith's when the same proportion of spreader was used (*5, Table 2*). (Fig. 2.) The writers are in accord with Smith's conclusions that this may have been due primarily to a coating of poison that was thinner but that was also smoother and more adherent, giving the larva less opportunity for accumulating

TYPES OF SPRAY DEPOSIT

A, Apple sprayed with lead arsenate alone; B, apple sprayed with lead arsenate to which casein spreader has been added.



A, Apple sprayed with lead arsenate alone; B, lead arsenate and flour paste; C, lead arsenate and soap; D, lead arsenate and glue; E, apple burned by nicotine oleate; F, apple burned by derris extract particles of poison before beginning to feed. Spuler (*8, p. 31*) got slightly better results with lead arsenate alone than with lead arsenate and casein spreader, but he shows that the difference is too small to be significant. In a letter Mr. Spuler stated that the casein spreader was used in the proportion of 1 pound to 200 gallons.

In the writers' experiments it was found that there was a positive correlation between the quantity of spreader used and the degree of infestation. (Fig. 2.) In order to explain the increased protection afforded by decreasing the quantity of spreader used, it is reasonable to assume that the larger quantity of spreader causes a greater run-off and consequently results in a thinner coat of lead arsenate on the fruit. This assumption has not yet been proved, and the facts in regard to the experiments are given here as an indication of some such cause. Reference to the senior writer's previous publication on this subject (*5*) will show that these results were obtained in two

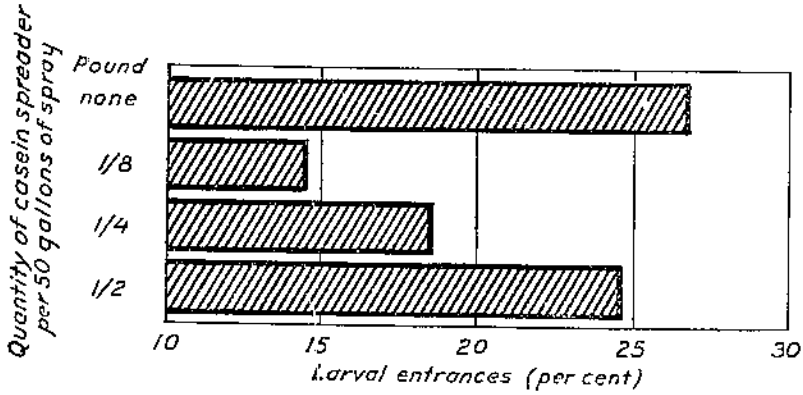


FIGURE 2.—Effect of quantity of spreader used with lead arsenate on larval entrances of the codling moth, Yakima, Wash., 1924

successive years. Similar results were obtained in 1925 and 1926, the only exception being in test 6. (Table 2.)

TABLE 2.—*Laboratory experiments with lead arsenate and casein spreader on the larvae of the codling moth, Yakima, Wash., 1925 and 1926*

Test No.	Material used [1]	Worms entering fruit		Worms causing stings		Total blemishes	Ratio of stings to total blemishes
		Number	*Per cent*	*Number*	*Per cent*	*Per cent*	
	1925						
1	Lead arsenate, 1-50, no spreader	35	10.0	77	22.0	32.0	0.69
2	Lead arsenate, 1-50, casein spreader ⅛-50	7	3.5	27	13.5	17.0	.79
3	Lead arsenate, 1-50, casein spreader ¼-50	9	4.5	31	15.5	20.0	.78
4	Check (unsprayed)	121	40.3	55	18.3	58.6	.31
	1926						
5	Lead arsenate, 1-50, no spreader	12	8.0	33	22.0	30.0	0.73
6	Lead arsenate, 1-50, casein spreader 1/16-50	16	10.7	30	20.0	30.7	.65
7	Lead arsenate, 1-50, casein spreader ½-50	13	8.7	21	14.0	22.7	.62
8	Lead arsenate, 2-50, no spreader	7	4.7	29	19.3	24.0	.81
9	Lead arsenate, 2-50, casein spreader 1/16-50	3	2.0	31	20.7	22.7	.91
10	Lead arsenate, 2-50, casein spreader ½-50	4	2.7	33	22.0	24.7	.89
11	Check (unsprayed)	80	53.3	10	6.7	60.0	.11

[1] Proportions, pounds to gallons.

This laboratory work merely shows the effect of the addition of casein spreader when the spray has been freshly applied. It is necessary to carry these experiments to the orchard to find out whether the use of casein spreader has any practical value. Such experiments were made in four different years, 4 or 5 ounces of casein being used to 200 gallons of spray, the casein being dissolved in water by means of borax, sodium bicarbonate, or calcium hydrate. The results of the use of lead arsenate alone and with casein spreader are very similar, whether a comparison is made of the percentage of wormy, stung, or sound fruit, or of the ratio of stings to total blemishes. (Table 3.) There is generally a consistent slight difference in favor of the lead arsenate and spreader, but this is so slight that it can not be said that the addition of 4 or 5 ounces of casein to 200 gallons of spray is of any benefit other than in preventing blotching of the fruit.

TABLE 3.—*Orchard experiments with lead arsenate and casein spreader for the codling moth, Yakima, Wash., 1919–1923*

Material used	Year	Total apples	Wormy apples [1]		Stung apples [1]		Sound apples	Total blemishes	Total stings	Ratio of stings to total blemishes
		Number	*Number*	*Per cent*	*Number*	*Per cent*	*Per cent*	*Number*	*Number*	
Lead arsenate, 1 pound to 50 gallons	1919	13,968	749	5.4	1,926	13.8	82.5	3,516	2,043	0.75
	1921	23,217	781	3.4	1,868	8.0	89.2	3,177	2,303	.72
	1922	15,021	1,634	10.9	4,858	32.3	62.6	11,743	9,623	.82
	1923	6,276	485	7.7	1,324	21.1	74.2	2,672	1,987	.74
Total or average				[2] 6.9		[2] 18.8	[2] 77.1	21,108	16,556	[3] .78
Lead arsenate, 1 pound to 50 gallons, plus casein spreader	1919	15,937	533	3.3	1,400	8.8	88.7	2,358	1,750	.74
	1921	19,670	518	2.6	1,266	6.4	91.3	2,117	1,537	.73
	1922	9,721	1,008	10.4	3,018	31.0	64.2	6,980	5,718	.82
	1923	6,546	420	6.4	1,746	26.7	69.9	3,305	2,753	.83
Total or average				[2] 5.7		[2] 18.3	[2] 78.5	14,760	11,758	[3] .80
Check (unsprayed)	1919	9,608	5,524	57.5	1,132	11.8	39.3	13,043	1,421	.11
	1921	25,512	10,710	42.0	1,891	7.4	56.3	25,720	2,327	.09
	1922	6,084	3,927	64.5	460	7.6	34.5	10,957	542	.05
	1923	3,621	2,537	70.1	290	8.0	27.8	7,317	331	.05
Total or average				[2] 58.6		[2] 8.7	[2] 39.5	57,037	4,621	[3] .08

[1] All apples having both stings and entrances are recorded twice, the same apple being recorded as wormy and again as stung.
[2] Simple average.
[3] Percentage of total.

The quantity of casein used in these experiments is approximately what occurs in 1 pound of casein spreader. Therefore, these results are similar to those obtained in the laboratory with one-fourth pound of casein spreader to 50 gallons of spray. (Fig. 2.) In 1928 an orchard experiment was made in which only one-half pound of casein spreader to 200 gallons of spray was used. In this experiment the fruit sprayed with lead arsenate alone became wormier than that sprayed with lead arsenate and casein spreader, indicating an advantage in the smaller amount of spreader. The detailed results are shown in Table 4.

TABLE 4.—*Results of application of lead arsenate with and without spreader in orchard tests for the control of the codling moth, Yakima, Wash., 1928*

Test No.	Material used	Total apples	Wormy apples		Stung apples[1]		Sound apple	Total blemishes	Total stings	Ratio of stings to total blemishes
		Number	*Number*	*Per cent*	*Number*	*Per cent*	*Per cent*	*Number*	*Number*	
1	Lead arsenate, 1 pound to 50 gallons	20,020	418	2.1	637	3.2	95.2	1,318	786	0.60
2	Lead arsenate, 1 pound, plus casein spreader, ½ pound, to 50 gallons	21,782	303	1.4	569	2.6	96.3	1,029	675	.66

[1] All apples having both stings and entrances are recorded twice, the same apple being recorded as wormy and again as stung.

FISH OIL

Fish oil has been used successfully by Hood (*2*) as a sticker for lead arsenate to keep the latter from being washed from foliage by heavy rains. Although rains are infrequent in the arid regions of Washington, better adherence of the lead arsenate was considered desirable, and some experiments with a salmon oil were made. Spuler (*8, p. 33*) had obtained definitely better results with the addition of fish oil in field tests in 1927. The writers tested this material both in the laboratory and in the orchard in 1928. In the laboratory, when 1 pound of lead arsenate was used to 50 gallons of water, and fish oil in the proportion of one-half pint to 50 gallons, 10.7 per cent of the larvae entered the fruit as compared with 20.0 per cent when the lead arsenate was used alone.

In the orchard test an attempt was made to show whether the addition of fish oil to the lead arsenate would make it possible to discontinue spraying at an earlier date than if the fish oil were not used. Therefore, the plat on which the fish oil was used was not sprayed after the fourth application, although three more applications were made to the trees receiving lead arsenate alone. In other words, the fish-oil plat was sprayed only for the first brood of codling-moth larvae. This was done because it had been found that the use of fish oil with lead arsenate made the removal of the arsenical residue from the mature fruit very difficult. As shown in Table 5, better results were obtained with seven applications of lead arsenate alone than with four of lead arsenate and fish oil, although the difference is not so great as would be expected if no fish oil had been used, judging from the results obtained with only two applications of lead arsenate. It is evident that fish oil could be used to obtain better control of the codling moth if it were not for the subsequent difficulty of removing the residue.

TABLE 5.—*Orchard experiments with lead arsenate and fish oil for the codling moth, Yakima, Wash., 1928*

Test No.	Material used	Total apples	Wormy apples[1]		Stung apples[1]		Sound apples	Total blemishes	Total stings	Ratio of stings to total blemishes
		Number	*Number*	*Per cent*	*Number*	*Per cent*	*Per cent*	*Number*	*Number*	
1	Lead arsenate, 1 pound to 50 gallons; 7 sprays	11,144	704	6.3	2,353	21.1	75.1	4,190	3,258	0.78
2	Lead arsenate, 1 pound to 50 gallons; first 2 sprays only	5,444	2,103	38.7	1,538	28.3	49.5	7,741	2,531	.33
3	Lead arsenate, 1 pound to 50 gallons, plus fish oil, ⅛ per cent; first 2 sprays only	11,701	2,242	19.2	3,014	25.8	62.2	7,837	4,475	.57

[1] All apples having both stings and entrances are recorded twice, the same apple being recorded as wormy and again as stung.

OTHER SPREADERS

Experiments were also made with other materials including glue, flour paste, and soap. The glue was added to the lead-arsenate spray in the proportions of one-fourth pound and one-half pound to 100 gallons, flour paste was used in the proportion of 1½ pounds to 100 gallons, and linseed oil and fish oil soap were used at the rate of 1½ and 4 pounds to 100 gallons, respectively. It is unnecessary to present detailed results of these experiments, but the percentages of wormy apples are given in Table 6.

TABLE 6.—*Experiments with glue, flour paste, and soap added as stickers to lead arsenate for the control of the codling moth, Yakima, Wash., 1920–1922*

Material used	Percentages of wormy apples in—		
	1920	1921	1922
Lead arsenate	4.2	3.4	18.5
Lead arsenate plus glue	5.2	5.3	
Lead arsenate plus flour paste		16.0	31.8
Lead arsenate plus soap	8.6		29.6

The results with the flour paste and the soap were decidedly unsatisfactory. The paste dried, cracked, and peeled off, taking much of the lead arsenate with it (pl. 2, B), and the soap apparently left too thin a coating of poison on the apples. (Pl. 2, C.) Only the glue (pl. 2, D) gave results approaching those obtained from the lead arsenate alone, but it is apparent that there is no advantage in adding the glue.

OTHER ARSENICALS

In 1927 a number of nonlead arsenicals were tested with the hope of finding something that might replace lead arsenate. Although some of these had previously been found to be inferior, it was thought that improvements might have been made by new methods of manufacture. In the laboratory experiments were made with 11 arsenates and 2 arsenites, in comparison with lead arsenate, at dilutions of 1 pound and 2 pounds to 50 gallons. The results of these experiments are detailed in Table 7.

TABLE 7.—*Laboratory experiments with nonlead arsenicals for the larvae of the codling moth, Yakima, Wash., 1927*

DILUTED, 1 POUND TO 50 GALLONS

Test No.	Material used	Worms entering fruit		Worms causing stings		Total blemishes	Ratio of stings to total blemishes
		Number	*Per cent*	*Number*	*Per cent*	*Per cent*	
1	Lead arsenate	50	33.3	20	13.3	46.0	0.29
2	Calcium arsenate (A)	75	50.0	5	3.3	53.3	.06
3	Calcium arsenate (B)	70	46.7	17	11.3	58.0	.20
4	Tricalcium arsenate	63	42.0	13	8.7	50.7	.17
5	Aluminum arsenate	86	57.3	4	2.7	60.0	.04
6	Barium arsenate	53	35.3	19	12.7	48.0	.26
7	Ferric arsenate	87	58.0	5	3.3	61.3	.05
8	Zinc arsenate	54	36.0	19	12.7	48.7	.26
9	Copper arsenate	72	48.0	1	.7	48.7	.01
10	Titanium arsenate	86	57.3	1	.7	58.0	.01
11	Magnesium arsenate	91	60.7	6	4.0	64.7	.06
12	Manganese arsenate	54	36.0	19	12.7	48.7	.26
13	Check (unsprayed)	116	77.3	0	0.0	77.3	.00
27	Lead arsenate	45	30.0	21	14.0	44.0	.32
28	Calcium arsenite	70	46.7	10	6.7	53.3	.13
29	Zinc arsenite	62	41.3	12	8.0	49.3	.16
30	Check (unsprayed)	109	72.7	3	2.0	74.7	.03

DILUTED, 2 POUNDS TO 50 GALLONS

Test No.	Material used	Worms entering fruit		Worms causing stings		Total blemishes	Ratio of stings to total blemishes
		Number	*Per cent*	*Number*	*Per cent*	*Per cent*	
14	Lead arsenate	28	28.0	7	7.0	35.0	0.20
15	Calcium arsenate (A)	32	32.0	2	2.0	34.0	.06
16	Calcium arsenate (B)	46	46.0	4	4.0	50.0	.08
17	Tricalcium arsenate	36	36.0	5	5.0	41.0	.12
18	Aluminum arsenate	56	56.0	2	2.0	58.0	.03
19	Barium arsenate	35	35.0	4	4.0	39.0	.10
20	Ferric arsenate	45	45.0	0	0.0	45.0	.00
21	Zinc arsenate	22	22.0	13	13.0	35.0	.37
22	Copper arsenate	39	39.0	3	3.0	42.0	.07
23	Titanium arsenate	59	59.0	0	0.0	59.0	.00
24	Magnesium arsenate	56	56.0	2	2.0	58.0	.03
25	Manganese arsenate	39	39.0	2	2.0	41.0	.05
26	Check (unsprayed)	80	80.0	0	0.0	80.0	.00
31	Lead arsenate	28	28.0	8	8.0	36.0	.22
32	Calcium arsenite	30	30.0	4	4.0	34.0	.12
33	Zinc arsenite	22	22.0	12	12.0	34.0	.35
34	Check (unsprayed)	76	76.0	0	0.0	76.0	.00

None of the arsenates tried equaled lead arsenate in these tests. The barium, zinc, and manganese arsenates were the best, considering both dilutions. The two arsenites, at double strength, were also good.

All of these materials, with the exception of the copper and titanium arsenates and the calcium arsenite, were tested in the orchard, and, as shown in Table 8, none of them gave as good control as lead arsenate.

Some very interesting information on the injury caused by these arsenicals was obtained from the orchard plats of 1927. The rainfall in September was unusually heavy, and, although the precipitation for the month was only about an inch, it was distributed over the first third of the month, and was accompanied by cloudy, moist weather. Soon after this injury began to appear in most of the plats on both fruit and foliage. A little was found even in the lead-arsenate plat, although usually lead arsenate does not cause any noticeable injury. Injury to the fruit consisted chiefly of sunken black areas about the calyx end where the greatest quantity of arsenical collected (pl. 3, A); foliage injury took the form of a typical arsenical burn appearing in patches of various sizes. (Pl. 3, B.)

TABLE 8.—*Orchard experiments with nonlead arsenicals for the codling moth, Yakima, Wash., 1927*

Test No.	Material used	Quantity used per 50 gallons [1]	Total apples	Wormy apples [2]		Stung apples [2]		Sound apples	Total blemishes	Total stings	Ratio of stings to total blemishes	Quantity of arsenic trioxide per pound of harvested fruit [3]
		Lbs.	*Number*	*Number*	*Per cent*	*Number*	*Per cent*	*Per cent*	*Number*	*Number*		*Grain*
1	Lead arsenate	1.00	17,780	120	0.7	938	5.3	94.2	1,203	1,070	0.89	0.041
2	Calcium arsenate (A)	.76	2,840	136	4.8	487	17.1	80.2	957	787	.82	.025
3	Calcium arsenate (B)	1.00	2,523	111	4.4	394	15.6	81.3	721	584	.81	.030
4	Tricalcium arsenate	.76	2,560	160	6.3	509	19.9	76.7	954	730	.77	.025
5	Aluminum arsenate	.88	1,980	238	12.0	461	23.2	69.1	1,052	707	.67	.020
6	Barium arsenate	1.00	2,446	172	7.0	588	24.0	72.8	1,128	880	.78	.043
7	Ferric arsenate	1.57	1,489	282	18.9	317	21.3	67.6	936	502	.54	.025
8	Zinc arsenate	.88	2,307	112	4.9	343	14.9	82.2	598	456	.76	.007
9	Magnesium arsenate	1.00	2,635	467	17.7	587	22.3	67.7	1,526	877	.57	.077
10	Manganese arsenate	.76	1,985	59	3.0	270	13.6	84.7	420	340	.82	.044
11	Zinc arsenite	.75	2,117	73	3.4	391	18.5	79.4	643	545	.85	.090
12	Check		1,843	679	36.8	486	26.4	49.5	1,823	730	.40	

[1] Quantity of each material used contained amount of As_2O_3 equal to that in 1 pound of lead arsenate, except that ferric arsenate was used at double strength.
[2] All apples having both stings and entrances are recorded twice, the same apple being recorded as wormy and again as stung.
[3] Analyses by J. O. Palmer, Food and Drug Administration.

The injury to the fruit was determined by actual count, and the leaf injury was estimated on October 18 by carefully examining the trees in each plat. A determination was also made of the percentage of water-soluble arsenic in the total quantity of arsenic present on the leaves from most of the plats. These determinations are given in Table 9, along with a statement of the water-soluble arsenic in the original arsenicals. Injury to the fruit occurred only in the aluminum arsenate and zinc-arsenite plats, but foliage injury was found in all of the plats. There was no positive correlation between the degree of injury and the percentage of water-soluble arsenic in the arsenicals. Both ferric arsenate and aluminum arsenate, with high original water-soluble arsenic content, produced relatively little foliage injury, whereas several materials originally free of water-soluble arsenic, or nearly so, caused severe burning. The degree of injury is more nearly correlated with the percentage of water-soluble arsenic found on the leaves after the injury occurred. These results suggest that some of these materials were less stable than others, and that consequently varying quantities of water-soluble arsenic were formed after the spraying was done, without regard to the original water-soluble content.

The poor control obtained with these nonlead arsenicals and the relatively high degree of injury resulting from their use practically eliminated all of them from consideration. However, experiments with two of these materials were continued in 1928. The aluminum arsenate was tested at double strength with one-eighth of 1 per cent fish oil in an effort to make it adhere better; and the zinc arsenate was also used at double strength, with the addition of an equal amount of hydrated lime for the purpose of preventing injury. When used in this manner, in laboratory tests, these materials were not so effective as single-strength lead arsenate (Table 10), the aluminum arsenate being the poorer of the two. In an orchard test, under very wormy conditions, the use of aluminum arsenate resulted in nearly twice as much wormy fruit as when lead arsenate was used, and spraying with zinc arsenate resulted in 50 per cent more wormy fruit than spraying with lead arsenate. (Table 11.) This was in spite of the apparent adherence of a greater quantity of the aluminum arsenate and zinc arsenate to the fruit than of the lead arsenate, the number of grains per pound of harvested fruit being 0.043, 0.044, and 0.036, respectively.[3] No injury occurred in 1928.

TABLE 9.—*Injury to apple fruit and foliage from applications of nonlead arsenicals, Yakima, Wash., 1927*

Test No.	Material used	Water-soluble arsenic pentoxide in original material [1]	Fruit injured [2]	Leaves dropped Oct. 18 [3]	Leaves injured (of those remaining) [3]	Percentage of the arsenic trioxide on the leaves that was water-soluble [4]
		Per cent	*Per cent*	*Per cent*	*Per cent*	
1	Lead arsenate	0.12	0	0	1	0.007
2	Calcium arsenate (A)	Free.	0	0	30	.029
3	Calcium arsenate (B)	do.	0	1	65	.051
4	Tricalcium arsenate	do.	0	0	86	----------
5	Aluminum arsenate	3.80	7.1	0	10	.016
6	Barium arsenate	.16	0	0	80	----------
7	Ferric arsenate [5]	2.86	0	0	2	.038
8	Zinc arsenate	.16	0	15	50	----------
9	Magnesium arsenate	.23	0	0	5	----------
10	Manganese arsenate	.50	0	0	10	.031
11	Zinc arsenite	.03	42.3	40	90	.142

[1] As given by manufacturer.
[2] By actual count.
[3] Estimated.
[4] Analyses by C. D. Dolman, chemist, State of Washington Division of Horticulture.
[5] Double strength.

TABLE 10.—*Laboratory experiments with nonlead arsenicals on the larvae of the codling moth, Yakima, Wash., 1928*

Test No.	Material used [a]	Worms entering fruit		Worms causing stings		Total blemishes	Ratio of stings to total blemishes
		Number	*Per cent*	*Number*	*Per cent*	*Per cent*	
1	Lead arsenate 1–50	30	20.0	31	20.7	40.7	0.51
2	Aluminum arsenate 2–50, fish oil, 1 quart–200 gallons	65	43.3	15	10.0	53.3	.19
3	Zinc arsenate 2–50, lime 2 pounds	40	26.7	25	16.7	43.4	.38
4	Check (unsprayed)	81	54.0	9	6.0	60.0	.10

[a] Proportions, with exception of fish oil, are pounds to gallons.

[3] Analyses by C. R. Gross, Bureau of Chemistry and Soils.

TABLE 11.—*Orchard experiments with nonlead arsenicals for the codling moth, Yakima, Wash., 1928*

Test No.	Material used [1]	Total apples	Wormy apples [2]		Stung apples [2]		Sound apples	Total blemishes	Total stings	Ratio of stings to total blemishes
		Number	*Number*	*Per cent*	*Number*	*Per cent*	*Per cent*	*Number*	*Number*	
1	Lead arsenate 1-50	5,502	1,251	22.7	1,333	24.2	60.1	3,630	1,780	0.49
2	Aluminum arsenate 2-50, fish oil, 1 quart to 200 gallons in first four sprays	2,738	1,151	42.0	631	23.1	46.1	2,636	802	.30
3	Zinc arsenate 2-50, lime 2 pounds	3,516	1,161	33.0	680	19.3	55.0	2,517	811	.32

[1] Proportions, excepting fish oil, are pounds to gallons.
[2] All apples having both stings and entrances are recorded twice, the same apple being recorded as wormy and again as stung.

LUBRICATING OILS

LABORATORY EXPERIMENTS

Mineral oils of the lubricating type were first thought of in connection with codling-moth control as egg destroyers. Laboratory experiments were made from 1923 to 1927 primarily to determine the percentage of codling-moth eggs that would fail to hatch when sprayed with an oil emulsion. Other experiments were made to determine the effect on eggs deposited after spraying, as well as the influence on the oviposition of the moths.

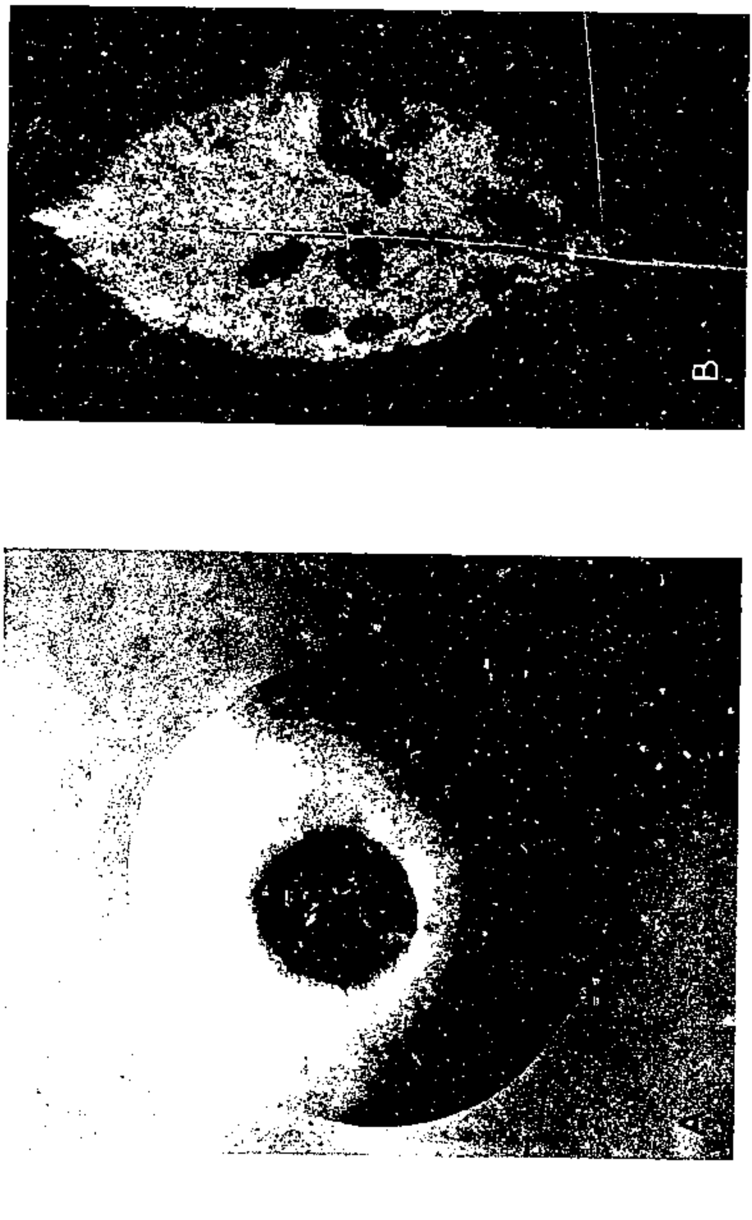
EFFECT OF OIL SPRAYS APPLIED TO THE EGGS

In a preliminary test in 1923 with an emulsion of red engine oil,[4] 75 per cent of the eggs sprayed with 1 per cent oil failed to hatch, and 97.6 per cent of those sprayed with 2 per cent oil failed to hatch, as compared with 26 per cent of the unsprayed eggs. In 1924, 1925, and 1926 more extensive experiments were made with various oils, such as red engine,[4] brown neutral [5] and crystal [6] oils. The effect of these oils was similar, except that the heavier oils caused a somewhat higher mortality of eggs than the lighter ones. In order to show these effects the results of some tests of a medium oil are given in Table 12. Apparently a high mortality can be obtained with less than 1 per cent of oil. The addition of casein spreader or lead arsenate, as in tests 10 and 11, lowered the effectiveness of the spray, probably because these materials absorbed some of the oil.

In 1927 tests were made with more highly refined oils of the types now employed in commercial-oil emulsions intended for summer spraying. The relatively light mineral seal oil destroyed fewer eggs than the less highly refined oils previously tested, while the heavy oil resulted in a complete mortality. There was little difference between the oil emulsion and the miscible oil. (Table 12.)

In many of these tests, eggs of different ages were used, ranging from eggs less than a day old to those almost ready to hatch. If the data from 15 experiments, representing over 8,000 eggs, are arranged according to the interval between oviposition and spraying, a definite negative correlation is found to exist between the interval and the percentage failing to hatch. (Fig. 3.)

[4] No. 1 (see p. 27). [5] No. 2. [6] No. 3.



INJURY BY ZINC ARSENITE SPRAY

A, To fruit; B, to foliage.

TABLE 12.—*Laboratory experiments with lubricating-oil sprays on the eggs of the codling moth, Yakima, Wash., 1924 and 1927*

Test No.	Material used	Dilution of oil	Total eggs	Eggs dead	
		Per cent	*Number*	*Number*	*Per cent*
1924					
1	Lubricating-oil [1] emulsion (casein-lime emulsifier)	2	312	311	99.7
2	do	1	545	525	96.3
3	do	.67	340	327	96.2
4	Check		495	73	14.7
5	Lubricating-oil [1] emulsion (casein-lime emulsifier)	1	422	395	93.6
6	do	.67	476	428	89.9
7	do	.5	519	384	74.0
8	Check		637	111	17.4
9	Lubricating-oil [1] emulsion (casein-lime emulsifier)	.67	415	362	87.2
10	Material used in test 9, plus casein spreader 1 to 200 [2]	.67	436	328	75.2
11	Materials used in test 10, plus lead arsenate 1 to 50 [2]	.67	202	121	59.9
12	Check		33	1	3.0
1927					
1	Lubricating-oil [3] emulsion (casein-lime emulsifier)	1.5	71	63	88.7
2	do	.75	81	58	71.6
3	Miscible oil [3]	1.5	106	90	84.9
4	do	.75	154	104	67.5
5	Lubricating-oil [4] emulsion (casein-lime emulsifier)	1.5	101	101	100.0
6	do	.75	111	111	100.0
7	Miscible oil [4]	1.5	65	65	100.0
8	do	.75	160	160	100.0
9	Check		611	98	16.0

[1] Brown neutral oil, No. 2 (see p. 27).
[2] Pounds to gallons.
[3] Mineral seal oil No. 4 (see p. 27).
[4] Technical oil No. 5.

THE EFFECT ON EGGS DEPOSITED AFTER SPRAYING

The first experiments on the effect of oil emulsions on eggs deposited after spraying were made in 1924. Pear leaves were sprayed with an emulsion containing 1 per cent of red engine oil,[7] and equal numbers of sprayed and unsprayed leaves were placed before the moths in oviposition jars at intervals of from a few hours to eight days after spraying, each lot being left in the jars 24 hours. The mortality of eggs deposited on the sprayed leaves was high for the first three days, and considerably lower after that, as is shown in Table 13.

TABLE 13.—*Effect of oil emulsion covering foliage on codling-moth eggs laid at various intervals after spraying, Yakima, Wash., 1924*

Interval between spraying and deposition of eggs	Total eggs	Eggs dead		Interval between spraying and deposition of eggs	Total eggs	Eggs dead	
	Number	*Number*	*Per cent*		*Number*	*Number*	*Per cent*
0 [1] days	980	924	94.3	4 days	805	534	66.3
1 day	962	760	79.0	8 days	203	127	62.6
2 days	815	736	90.3	Check	3,219	850	26.4
3 days	784	720	91.8				

[1] Eggs deposited a few hours after spraying.

It was thought that the use of leaves might not give a fair test, because of drying during the course of the experiment, so in 1926

[7] No. 1 (see p. 27).

apples were sprayed with emulsions containing 1 and 2 per cent of heavy crystal[8] oil. The first test was made in May, eggs being deposited within two days after spraying. With the 2 per cent oil, of 461 eggs sprayed, 87 per cent failed to hatch; with the 1 per cent oil, of 137 eggs, 73 per cent failed to hatch; and in a check sprayed with lead arsenate, of 429 eggs, 26.3 per cent failed to hatch. In August, when the weather was warmer, another test was made, and it was found that the 2 per cent oil was much more effective than the 1 per cent, and the percentage of eggs failing to hatch decreased as the interval between spraying and deposition increased. This is shown in Table 14.

TABLE 14.—*Effect of crystal oil emulsion covering apples on codling-moth eggs laid at various intervals after spraying, Yakima, Wash., August, 1926*

Interval between spraying and deposition of eggs	1 per cent crystal oil			2 per cent crystal oil		
	Total eggs	Eggs dead		Total eggs	Eggs dead	
	Number	*Number*	*Per cent*	*Number*	*Number*	*Per cent*
3 days	44	16	36.4	80	64	80.0
5 days	92	30	32.6	191	136	71.2
7 days	263	100	38.0	54	35	64.8
9 days	265	69	26.0	26	12	46.2
Check				392	46	11.7

Similar tests were made in 1927, both the heavy crystal oil and the light mineral seal oil being used. In spite of some discrepancies that appear in Table 15, it is evident that only a relatively low percentage of eggs are killed, when deposited on oil-sprayed surfaces, unless a heavy oil is used and the deposition occurs within a few days after spraying.

TABLE 15—*Effect of various oil emulsions covering apples on codling-moth eggs laid at various intervals after spraying, Yakima, Wash., 1927*

Interval between spraying and deposition of eggs	Eggs dead (per cent) following use of—				Average
	Mineral seal oil		Crystal oil		
	¾ per cent	1½ per cent	¾ per cent	1½ per cent	
3 days	26.4	34.7	36.6	58.0	43.0
6 days	12.2	11.7	2.7	48.1	16.9
9 days	39.2	13.7	17.1	70.7	35.4
Average	26.8	21.4	21.9	60.9	33.5
Check					4.2

THE EFFECT OF AN OIL DEPOSIT ON OVIPOSITION

Experiments were also made to determine what effect spraying with oil might have on oviposition. In other words, would the presence of an oil spray on leaves and fruit deter the moths from depositing eggs?

In May, 1924, fresh pear leaves were throughly sprayed with an emulsion containing 1 per cent of red engine[9] oil. Equal numbers

[8] No. 3 (see p. 27). [9] No. 1 (see p. 27).

of sprayed and unsprayed leaves were placed with the moths in oviposition jars within two days after spraying. Of 5,693 eggs deposited on these leaves, 3,210, or 56.4 per cent, were deposited on the oil-sprayed leaves.

In May, 1926, apples and leaves from oil-sprayed trees were placed in oviposition jars within two days after spraying. In one test material sprayed with an emulsion containing 1 per cent of a heavy crystal oil[10] was compared with material sprayed with lead arsenate. Of 204 eggs, 76.5 per cent were deposited on the oil-sprayed leaves and fruit. In another test 2 per cent oil was compared with lead arsenate, and of 1,287 eggs, 45.7 per cent were deposited on the oil-sprayed material. In a third test, comparing the 2 per cent oil with the 1 per cent oil, of 161 eggs, 55.3 per cent were on the material sprayed with the 2 per cent oil.

In June, 1926, fresh pear leaves were thoroughly sprayed with emulsions containing 1 and 2 per cent of crystal oil, respectively. Leaves from each lot were placed in oviposition jars with equal quantities of unsprayed leaves within three days after spraying. In the test comparing the 1 per cent oil-sprayed leaves with unsprayed leaves, of 1,277 eggs, 45.7 per cent were deposited on the oil-sprayed leaves. In the test of 2 per cent oil, of 1,565 eggs, 37.4 per cent were deposited on the oil-sprayed leaves.

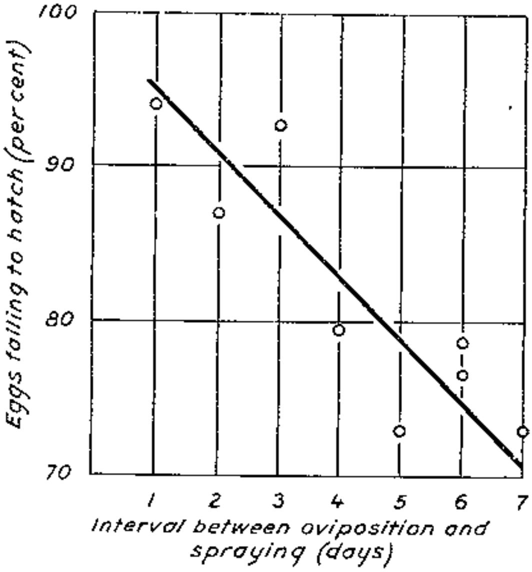


FIGURE 3.—Percentage of mortality in codling-moth eggs sprayed with an oil emulsion at various numbers of days after date of oviposition, Yakima, Wash., 1926 and 1927

The conclusion to be drawn from these experiments is that, under laboratory conditions, the oil does not especially deter the codling moth from ovipositing. Orchard trees sprayed with oil emulsion alone become wormier than those sprayed with lead arsenate alone, and it may be inferred from this and from the results of these laboratory experiments that spraying with oil will not particularly reduce the number of eggs deposited.

THE EFFECT OF AN OIL DEPOSIT ON LARVAL ENTRANCE

In order to find out whether the oil sprays prevented larvae from entering apples an experiment was made in 1926, a crystal oil[11] emulsion being used at dilutions of 1 and 2 per cent and worms placed on the fruit at intervals after spraying. Table 16 shows the number of larvae that succeeded in entering the fruit and the number making stings only.

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[10] No. 3 (see p. 27).

[11] No. 3 (see p. 27).

TABLE 16.—*Record of larval attacks on apples sprayed with oil emulsion and with lead arsenate, Yakima, Wash., 1926*

Material used	Interval after spraying	Larvae entering fruit	Larvae making stings	Total blemishes
	Days	*Per cent*	*Per cent*	*Per cent*
1 per cent crystal oil	4	62	2	64
	6	64	4	68
	8	48	2	50
	10	58	4	62
	12	68	0	68
2 per cent crystal oil	2	26	2	28
	4	38	12	50
	6	36	4	40
	8	66	0	66
	10	52	4	56
Lead arsenate, 1 pound to 50 gallons [1]		19	16	35
Check (unsprayed) [1]		63	1	64

[1] Average of 2 tests.

These experiments indicated that the 1 per cent oil had practically no effect, and that the 2 per cent oil was ineffective after a few days.

In an experiment in 1927 with 1½ per cent mineral seal oil,[12] the percentage of total blemishes after three days was 72, as compared with 42 on fruit sprayed with lead arsenate and 74 on unsprayed fruit.

ORCHARD EXPERIMENTS

Some preliminary orchard tests in 1924 and 1925 had indicated that there might be an advantage in adding an oil emulsion to some of the lead-arsenate applications. In 1926, therefore, a test was made in which a calyx spray and five cover sprays of lead arsenate were used, and in certain plats 1, 2, and 4 per cent technical oil, respectively, was added in the form of an emulsion. Table 17 shows that a very definite improvement in control resulted in the plats where oil was used, the percentage of both wormy and stung apples decreasing as the percentage of oil was increased. However, considerable injury resulted from the use of this heavy oil. The oil reduced the size of the fruit, the number of apples per box increasing as the amount of oil increased. (Fig. 4.) In the Rome Beauty variety a very decided darkening of the area about the calyx was caused by the oil. (Pl. 4, A.) Other varieties were injured in various ways, the Jonathan, for example, developing irregular brown spots (pl. 4, B), and the Yellow Newtown becoming russetted about the calyx end. (Pl. 4, C.)

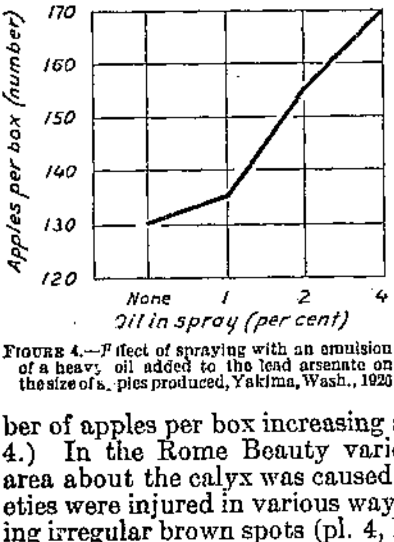
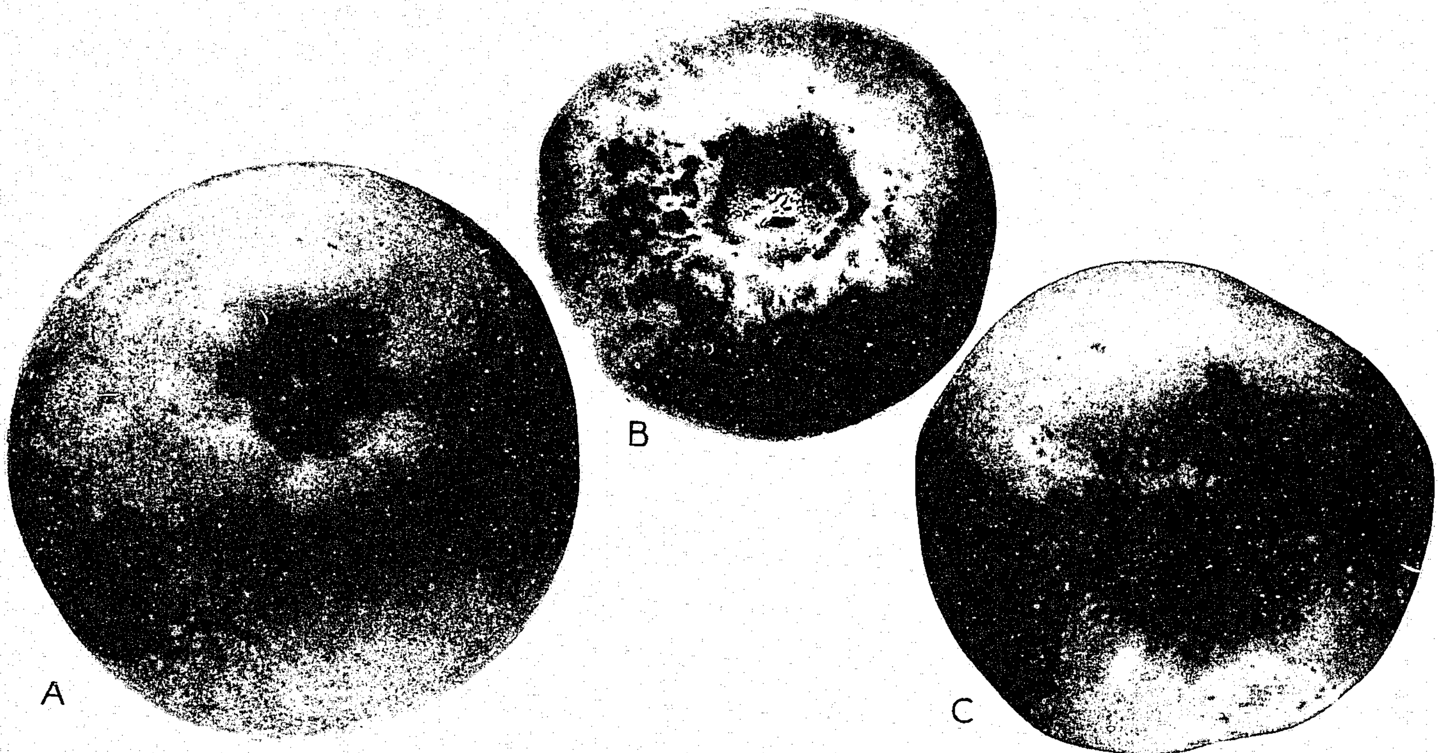


FIGURE 4.—Effect of spraying with an emulsion of a heavy oil added to the lead arsenate on the size of apples produced, Yakima, Wash., 1926

In 1927, therefore (see Table 17), experiments were made with the lighter mineral seal oil, in comparison with the technical oil, both alone and in combination with lead arsenate. The heavy dosage of the technical oil (Table 17, 1927, test 4) was apparently given in a wormier portion of the orchard than the other plats, but aside from this these tests show that the light oil is not so effective as the heavy oil. They also indicate that the addition of oil to the cover sprays of

[12] No. 4 (see p. 27).



EXAMPLES OF INJURY TO APPLES FROM THE USE OF A HEAVY OIL IN SPRAYING

A, Rome Beauty showing "Calyx ring"; B, Jonathan apple burned by spray; C, yellow Newtown showing russeting caused by spray.

lead arsenate results in better control and that the use of oil alone results in poorer control than the use of lead arsenate alone, although the fact that the crop was light in 1927 reduces somewhat the conclusiveness of these experiments.

TABLE 17.—*Orchard experiments with lubricating-oil emulsions, alone and in combination with lead arsenate, for the codling moth, Yakima, Wash., 1926 and 1927*

1926

Test No.	Material used and number of applications	Total apples	Wormy apples [1]		Stung apples [1]		Sound apples	Total blemishes	Total stings	Ratio of stings to total blemishes
		Number	*Number*	*Per cent*	*Number*	*Per cent*	*Per cent*	*Number*	*Number*	
1	Lead arsenate 1-50, calyx and 5 cover sprays	15,022	714	4.8	1,253	8.3	88.0	2,505	1,621	0.65
2	The same as in test 1, plus 1 per cent technical oil [3] (emulsified), in first 4 cover sprays	6,384	105	1.6	210	3.3	95.4	375	255	.68
3	The same as in test 1, plus 2 per cent technical oil (emulsified), in first 4 cover sprays	9,333	94	1.0	203	2.2	96.9	345	237	.69
4	The same as in test 1, plus 4 per cent technical oil (emulsified), in first 4 cover sprays	4,521	20	.4	63	1.4	98.2	92	71	.77

1927

Test No.	Material used and number of applications	Total apples	Wormy apples (Number)	Wormy apples (Per cent)	Stung apples (Number)	Stung apples (Per cent)	Sound apples (Per cent)	Total blemishes	Total stings	Ratio of stings to total blemishes
1	Lubricating-oil (mineral seal) [2] emulsion, 0.75 per cent of oil [4]	2,941	162	5.5	339	11.5	84.4	648	429	0.66
2	Lubricating-oil (mineral seal) [2] emulsion, 1.5 per cent of oil [4]	5,835	181	3.1	345	5.9	91.8	672	429	.64
3	Lubricating-oil (technical) [3] emulsion, 0.75 per cent of oil [4]	2,636	34	1.3	102	3.9	95.0	166	127	.77
4	Lubricating-oil (technical) [3] emulsion, 1.5 per cent of oil [4]	4,303	169	3.0	358	8.3	86.8	715	497	.70
1	Lubricating-oil emulsion [5] used alone in 3 cover sprays	4,672	136	2.9	287	6.1	91.6	556	365	.66
2	Lubricating-oil emulsion [5] plus lead arsenate 1-50 used in 3 cover sprays	3,708	40	1.1	222	5.9	93.5	316	266	.84
3	Lead arsenate, 1 pound to 50 gallons	2,627	66	2.5	216	8.2	90.0	368	283	.77

[1] All apples having both stings and entrances are recorded twice, the same apple being recorded as wormy and again as stung.
[2] No. 6 (see p. 27).
[3] No. 4 (see p. 27).
[4] Oil emulsions used for calyx, first, second, and third cover sprays; lead arsenate, 1 pound to 50 gallons added to calyx spray and used alone in fourth cover spray.
[5] The figures include both mineral seal and technical oils at ¾ per cent and 1½ per cent dilutions. Lead-arsenate and oil emulsion used in calyx spray; lead arsenate alone in fourth cover spray.

There was a definite difference in the degree of injury produced by the two oils, the size of the fruit not being reduced by the light oil, and the percentage of fruit showing a dark calyx ring being less. These effects of the use of oil are shown in Table 18.

Again in 1928 experiments showed that oil used in several cover sprays alone resulted in more wormy fruit than a schedule of lead arsenate alone. (Table 19.)

In 1929 orchard experiments with oil were confined to the addition of the oil to some other material. Adding oil to all of the cover sprays of lead arsenate improved the control somewhat, except in the case of the three-fourths of 1 per cent light oil. (Table 19.) A medium oil (tests 2 and 4, 1929) was used that was considerably better than the light mineral seal oil, and this did not cause any reduction in size or the discoloration of the calyx end such as resulted from the use of a heavy oil. The addition of oil to only two cover sprays (test 5, 1929) also resulted in somewhat cleaner fruit than was obtained with lead arsenate alone. The use of oil with other materials than lead arsenate is discussed elsewhere in this bulletin.

TABLE 18.—*Effect of the use of oil in sprays on the size of and injury to apples, Yakima, Wash., 1927*

Material used	Apples per box	Apples showing calyx ring	Material used	Apples per box	Apples showing calyx ring
	Number	*Per cent*		*Number*	*Per cent*
Lead arsenate alone	68.8	0	Technical oil,[2] ¾ per cent	69.2	44.4
Mineral seal oil,[1] ¾ per cent	64.5	12.7	Technical oil,[2] 1½ per cent	80.4	53.0
Mineral seal oil,[1] 1½ per cent	61.4	22.3			

[1] No. 4 (see p. 27). [2] No. 5 (see p. 27).

TABLE 19.—*Orchard experiments with lubricating-oil emulsions for the codling moth, Yakima, Wash., 1928 and 1929*

Test No.	Material used [1]	Total apples	Wormy apples [2]		Stung apples [2]		Sound apples	Total blemishes	Total stings	Ratio of stings to total blemishes
		Number	*Number*	*Per cent*	*Number*	*Per cent*	*Per cent*	*Number*	*Number*	
	1928									
1	Lead arsenate 1-50 alone	4,878	401	8.2	539	11.0	83.1	1,240	716	0.58
2	Lead arsenate 1-50, calyx and fourth cover spray; lubricating-oil (mineral seal)[3] emulsion 1½, first three cover sprays	7,856	792	10.1	771	9.8	80.0	2,016	968	.48
3	The same as test No. 2 except that technical oil[4] was used	4,090	391	9.6	433	10.6	81.8	1,108	597	.54
	1929									
1	Lead arsenate 1-50, plus mineral seal oil[3] (emulsified) (0.75 per cent of oil) added to all cover sprays	6,332	1,025	16.2	894	14.1	73.1	2,576	1,155	0.45
2	Lead arsenate 1-50, plus summer oil[5] (emulsified) (0.75 per cent of oil) added to all cover sprays	7,830	816	10.4	874	11.2	80.7	2,312	1,139	.49
3	Lead arsenate 1-50, plus mineral seal oil[3] (emulsified) (1.5 per cent of oil) added to all cover sprays	13,300	647	4.9	1,160	8.7	87.4	2,393	1,525	.64
4	Lead arsenate 1-50, plus summer oil[5] (emulsified) (1.5 per cent of oil) added to all cover sprays	9,746	344	3.5	561	5.8	91.4	1,140	701	.61
5	Lead arsenate 1-50, plus summer oil[5] (emulsified) (0.75 per cent of oil) added to second and fifth cover sprays only	11,720	1,552	13.2	1,990	17.0	73.2	4,778	2,063	.50
6	Lead arsenate 1-50	12,211	1,897	15.5	2,126	17.4	70.8	5,504	2,869	.52
7	Check (unsprayed)	3,408	2,450	71.9	485	14.2	24.0	5,686	587	.10

[1] Proportions are pounds to gallons.
[2] All apples having both stings and entrances are recorded twice, the same apple being recorded as wormy and again as stung.
[3] No. 4 (see p. 27). [4] No. 5 (see p. 27). [5] No. 6 (see p. 27).

It is concluded from all of these tests that for effective control of the codling moth without significant injury to the fruit or trees a medium oil, having a Saybolt viscosity of from 65 to 75 seconds, and a high sulphonation test, should be used in the proportion of slightly less than 1 per cent. It should be added to not more than three or four of the lead-arsenate cover sprays, in those applications occurring when the highest percentage of eggs is on the trees.[13] This is in accord with the findings of the western cooperative oil-spray project (*9*).

NICOTINE

In 1915 and 1916 De Sellem (*1*), working at Yakima, experimented with nicotine sulphate for codling-moth control and obtained some very good results, although the orchards used were not particularly wormy in 1916. Lovett (*3, p. 50*) reported a very high mortality of codling-moth eggs when sprayed with nicotine, the number of eggs used in his tests, however, being very limited.

LABORATORY EXPERIMENTS

A test was made with codling-moth eggs by the writers in 1923, using 40 per cent nicotine sulphate at 1 to 800, with casein spreader, 1 pound to 200 gallons. Thirty per cent of the sprayed eggs failed to hatch as compared with 26 per cent of the unsprayed eggs. This was so unpromising that no further tests were made until 1927. At that time more thorough tests (Table 20) indicated that in warm weather 40 per cent nicotine sulphate, at a dilution of 1 to 800, would kill over 50 per cent of the eggs, whether or not soap was added; and that although the mortality dropped in cool weather, this drop was offset by the addition of sodium bisulphate. The effect of temperature was examined further, and a graph of all of the tests of nicotine sulphate and soap (fig. 5) shows a definite increase in mortality with an increase in temperature. There was no indication of a difference in mortality dependent on the age of the eggs.

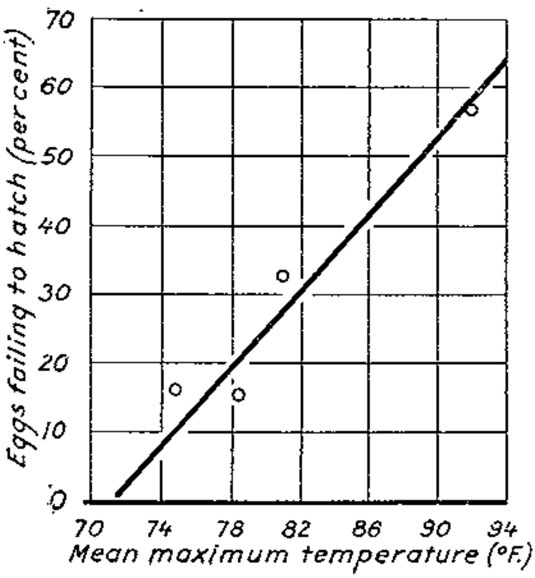


FIGURE 5.—Effect of temperature on the value of nicotine sulphate and soap when used to destroy codling-moth eggs, Yakima, Wash., 1927

[13] Experiments by H. C. Diehl, Bureau of Plant Industry, not yet published, have shown that oil used in this manner does not materially interfere with spray-residue removal.

TABLE 20.—*Laboratory experiments with nicotine sulphate on the eggs and larvae of the codling moth, Yakima, Wash., 1927 and 1928*

1927

Test No.	Material used	Total eggs	Eggs dead		Total eggs producing larvae that entered fruit
		Number	*Number*	*Per cent*	*Per cent*
1	Nicotine sulphate (40 per cent) 1-1,600	188	70	37.2	37.2
2	Nicotine sulphate (40 per cent) 1-800	59	30	50.8	27.1
3	Nicotine sulphate (40 per cent) 1-800, plus fish-oil soap, 3 pounds to 100 gallons	102	57	55.9	24.5
4	Check	118	21	17.8	72.0
5	Nicotine sulphate (40 per cent) 1-800, plus fish-oil soap, 3 pounds to 100 gallons	342	54	15.8	18.7
6	Nicotine sulphate (40 per cent) 1-800, plus casein spreader, ½ pound to 100 gallons	168	38	22.6	13.7
7	Nicotine sulphate (40 per cent) 1-800, plus sodium bisulphate, 1½ pounds to 100 gallons	294	165	56.1	2.4
8	Check	191	8	4.2	55.0

1928

Test No.	Material used	Total eggs	Eggs dead		Total eggs producing larvae that entered fruit
		Number	*Number*	*Per cent*	*Per cent*
1	Nicotine sulphate (40 per cent) 1-1,600	381	228	59.8	16.3
2	Nicotine sulphate (40 per cent) 1-1,600, plus sodium bisulphate, ½ pound to 100 gallons	382	149	39.0	14.9
3	Nicotine sulphate (40 per cent) 1-1,600, plus aluminum sulphate, ½ pound to 100 gallons	365	220	60.3	10.4
4	Nicotine sulphate (40 per cent) 1-1,600, plus ¾ per cent mineral seal oil [1] (emulsified)	521	449	86.2	4.8
5	Check	335	39	11.6	72.8
6	Nicotine sulphate (40 per cent) 1-1,600	124	88	71.0	8.1
7	Free nicotine (50 per cent) 1-800	251	136	54.2	12.4
8	Free nicotine (50 per cent) 1-1,600	162	57	35.2	32.1
9	Free nicotine (50 per cent) 1-1,600, plus aluminum sulphate, ½ pound to 100 gallons	272	106	39.0	27.9
10	Check	413	60	14.5	57.4

[1] No. 4 (see p. 27).

NOTE.—In the 1927 tests 1 to 4, the mean maximum temperature between spraying and the hatching of the eggs was 92° F.; in tests 5 to 8, it was 75°. In tests of 1928 the mean maximum temperature for one week after spraying was 85° F.

As these tests were made with eggs deposited on apples, it was possible to carry them further and determine the percentage of the total number of eggs that produced larvae able to enter the fruit. These percentages are given in the final column of Table 20. In no case did the total of the dead eggs and of the larvae entering the fruit equal the total number of eggs used, some larvae being lost. The number lost was invariably greater on the sprayed apples than on those unsprayed, indicating that the nicotine is toxic to some of the larvae after they hatch, and before they begin to feed. Observations have shown this to be the case, many larvae placed on apples recently sprayed with nicotine becoming apparently paralyzed and dropping from the fruit without feeding. More eggs hatched on both sprayed and unsprayed apples in cool weather than in warm weather, but fewer of the larvae were able to enter the apples, probably owing to the slower volatilization of the nicotine in cool weather. The results with nicotine sulphate and sodium bisulphate were particularly good.

TESTS WITH NICOTINE IN COMBINATIONS

In 1928, during warm weather, nicotine sulphate was tested at a concentration of 1–1,600, alone and with sodium bisulphate, aluminum sulphate, and an oil emulsion. (Table 20.) The best results were obtained with the combination of nicotine sulphate and oil, since the oil has a lethal effect on the eggs which the other two materials do not have. The sodium bisulphate, used one-third as strong as in 1927, seemed to have little direct value, but both it and the aluminum sulphate apparently prolonged the action of the nicotine and thus prevented many larvae from entering the fruit. Free nicotine was also tried, and its toxicity was found to be less than that of nicotine sulphate. (Table 20, 1928, tests 7 to 9.)

A direct comparison was made of nicotine sulphate and lead arsenate (Table 21), sprayed on apples on which eggs had been deposited one or two days previously. A smaller percentage of the eggs sprayed with nicotine hatched than of those sprayed with lead arsenate, the latter having no effect on hatching. Of the larvae that did emerge, approximately the same percentage entered the fruit in the two tests, indicating that the two treatments were equally effective in preventing entrance, even though this occurred 10 days after spraying. The net result was that the percentage of larvae entering the fruit, based on the original number of eggs, was twice as high in the lead arsenate test as in the nicotine sulphate test.

TABLE 21.—*Laboratory experiments comparing the effect of nicotine sulphate and lead arsenate on the eggs and larvae of the codling moth, Yakima, Wash., 1928*

Test No.	Material used	Total eggs	Eggs hatched		Eggs producing larvae that entered fruit, based on number that hatched	Eggs producing larvae that entered fruit based on total number of eggs in test
		Number	*Number*	*Per cent*	*Per cent*	*Per cent*
1	Nicotine sulphate 1-1,600	182	78	42.9	25.6	11.0
2	Lead arsenate 1-50	197	173	87.8	25.4	22.3
3	Check	63	50	79.4	82.0	65.0

In 1927, during very warm weather, a test was made also of the toxic effect of nicotine sulphate on codling-moth eggs deposited from two to six days after spraying. Even under these conditions more eggs failed to hatch and fewer larvae entered the fruit than in the check (Table 22), but the difference is not so great as in the case of apples sprayed after the deposition of eggs. (Compare test No. 1, Table 22, with No. 3, 1927, Table 20.) In this test the addition of sodium bisulphate did not increase the mortality of eggs but did reduce the percentage of larvae entering the fruit, indicating that the nicotine is retained better by the sodium bisulphate than by the soap.

These results suggested that sodium bisulphate or aluminum sulphate might be of value in retarding the volatilization of the nicotine. Since for codling-moth control it is necessary to retain the toxicity for two or three weeks, an experiment was made in which nicotine sulphate with soap and with sodium bisulphate were directly compared under similar conditions of temperature, treatment, etc. Apples were sprayed with the two combinations, and at intervals codling moth larvae were placed on them, 10 apples being used each time for each combination, and 10 larvae being placed on each apple. The percentage of larvae surviving the nicotine-soap combination rose much

TABLE 22.—*Laboratory experiments with nicotine sulphate on eggs of the codling moth deposited after spraying, Yakima, Wash., 1927*

Test No.	Material used	Interval between spraying and deposition of eggs	Total eggs	Eggs dead		Eggs producing larvae that entered fruit based on total number of eggs in test
		Days	*Number*	*Number*	*Per cent*	*Per cent*
1	Nicotine sulphate 1-800, plus fish-oil soap, 3 pounds to 100 gallons	2-6	577	155	26.9	39.2
2	Nicotine sulphate 1-800, plus sodium bisulphate, 1½ pounds to 100 gallons	6	216	59	27.3	15.3
3	Check		619	111	17.9	72.0

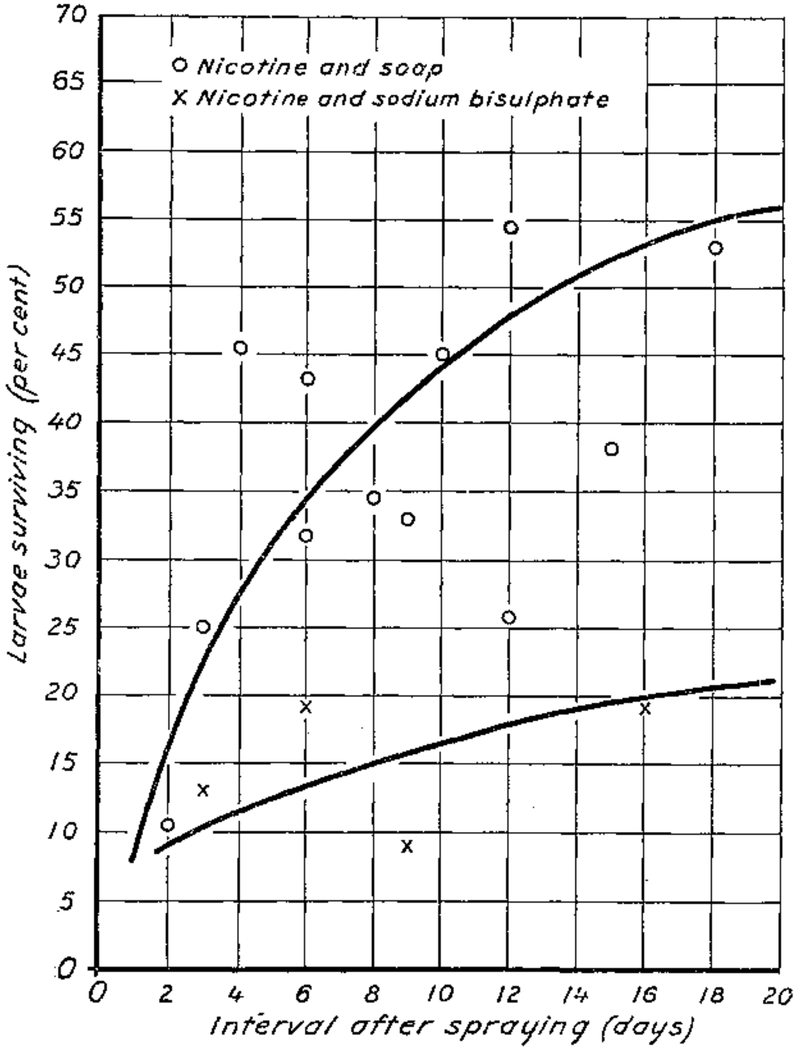


FIGURE 6.—Percentages of codling-moth larvae surviving after being placed at intervals on apples sprayed with nicotine sulphate in combination with soap and with sodium bisulphate, Yakima, Wash., 1927

more rapidly than that of the larvae surviving the mixture of nicotine sulphate and sodium bisulphate. (Fig. 6.) For comparison the percentages of larvae surviving after being placed on apples sprayed with lead arsenate and on unsprayed apples were 42 and 66, respectively, regardless of the time.

ORCHARD EXPERIMENTS

Orchard tests are necessary to show the true value of a spray containing nicotine, because the varying weather conditions and the growth of the fruit can not be reproduced in the laboratory. In 1921 and 1922 the addition of nicotine sulphate and fish-oil or linseed-oil soap to all of the cover sprays of a regular lead-arsenate schedule had been tried, and although the control was improved by this addition, the improvement was not sufficient to warrant the added expense. The experiment was tried again in 1927, except that no lead arsenate was used after the first cover spray. Results in a lightly infested orchard were fair, but not so good as from the use of lead arsenate alone. In a heavily infested orchard a similar experiment was tried, lead arsenate being used for the first two sprays and nicotine sulphate (1–800) with nothing added for the remaining cover sprays. Twice as much fruit became wormy in this plat as in an adjoining plat sprayed throughout the season with lead arsenate. It was evident that these combinations were not successful.

TABLE 23.—*Orchard experiments with nicotine sulphate, alone and in combination with glycerine and oil, for the codling moth, Yakima, Wash., 1928 and 1929*

Test No.	Material used [1]	Dilution of nicotine	Total apples	Wormy apples [2]		Stung apples [2]		Sound apples	Total blemishes	Total stings	Ratio of stings to total blemishes
			Number	*Number*	*Per cent*	*Number*	*Per cent*	*Per cent*	*Number*	*Number*	
1928											
1	Nicotine sulphate	1–800	13,591	1,146	8.4	363	2.7	89.6	1,801	410	0.23
2	do	1–1,600	15,241	1,708	11.2	649	4.3	88.1	3,015	767	.25
3	The same as in test 2, plus aluminum sulphate, 1 pound to 200 gallons.	1–1,600	11,032	822	7.5	373	3.4	90.0	1,530	432	.28
4	The same as in test 2, plus ¾ per cent mineral seal oil [3] (emulsified).	1–1,600	10,160	550	5.5	320	3.2	91.0	1,030	376	.37
1929											
1	Nicotine sulphate (40 per cent), plus ½ per cent glycerin.	1–800	9,556	5,041	52.8	1,868	19.5	40.2	12,775	2,557	0.20
2	Nicotine sulphate (40 per cent), plus ¾ per cent summer oil [4] (emulsified).	1–800	10,484	2,245	21.4	1,280	12.2	70.7	5,211	1,584	.30
3	Nicotine sulphate (40 per cent), plus ¾ per cent summer oil [4] (emulsified).	1–1,600	11,582	3,742	32.3	1,518	13.1	60.9	8,507	1,964	.23
4	Lead arsenate 1 pound to 50 gallons; nicotine sulphate and ¾ per cent summer oil [4] added to second and fifth cover sprays.	1–1,600	11,856	1,971	16.6	2,397	20.2	68.1	6,485	3,472	.54
5	Lead arsenate, 1 pound to 50 gallons.		12,749	3,247	25.5	4,598	36.1	50.7	14,261	8,024	.56

[1] Lead arsenate, 1 pound to 50 gallons, used alone for calyx and first cover sprays in all tests. In all subsequent applications only the materials shown were used.

[2] All apples having both stings and entrances are recorded twice, the same apple being recorded as wormy and again as stung.

[3] No. 4 (see p. 27).

[4] No. 6 (see p. 27).

In 1928, therefore, orchard experiments were made with aluminum sulphate and with oil emulsion added to the nicotine sulphate in comparison with the nicotine used alone. Those materials were used in all applications following a calyx spray and a first cover spray of lead arsenate. Direct comparison could not be made with plats that were

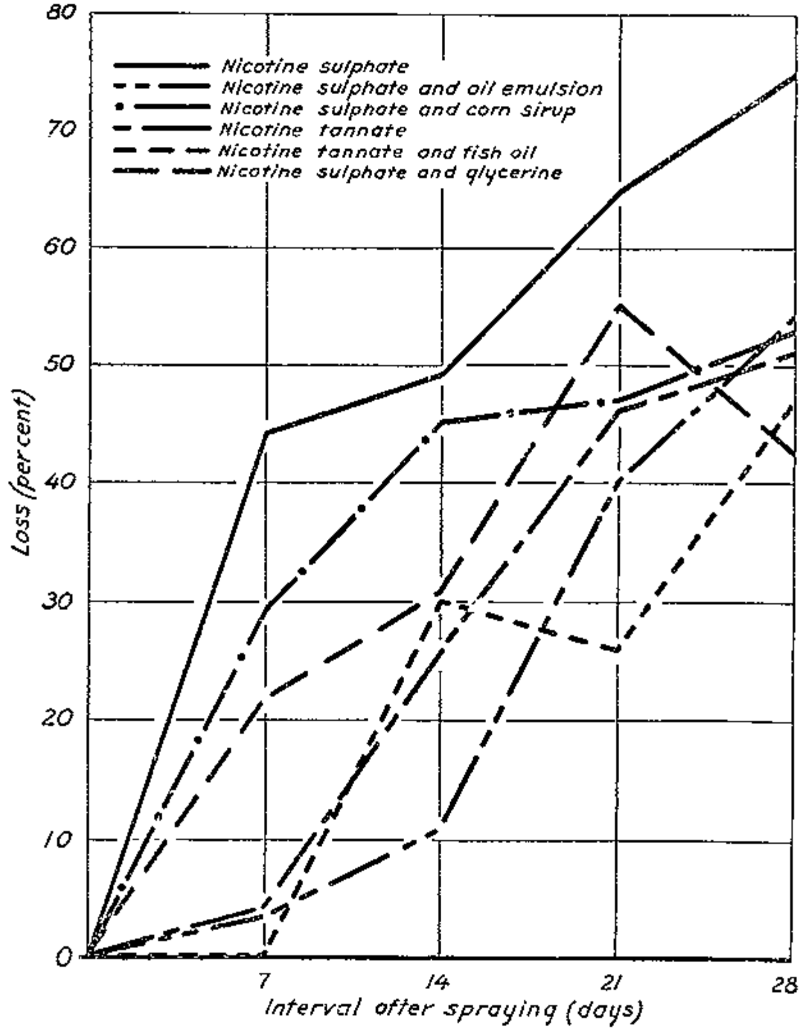


FIGURE 7.—Percentage of nicotine lost from apple foliage at intervals after spraying, Yakima, Wash., 1929

being sprayed with lead arsenate because of a difference in infestation, but much better control resulted from the addition of either of these materials to the nicotine (Table 23) than from the nicotine alone. The oil was the better of the two, probably on account of its effect on the eggs.

Variations in the use of nicotine sulphate were experimented with in 1929. It was tried with corn sirup and glycerin. Nicotine oleate and nicotine tannate were also tested. Chemical determinations [14]

[14] Made by Bureau of Chemistry and Soils laboratory, Yakima, Wash.

(fig. 7) indicated that neither corn sirup nor glycerin retained the nicotine as effectively as oil.

Nicotine tannate showed promise, both alone and with fish oil, and further experiments will be made with these sprays. Nicotine oleate burned the fruit (pl. 2, E) and foliage severely.

In the orchard experiments were conducted with nicotine sulphate combined with glycerin and with oil emulsion. (Table 23.) The results from the nicotine-glycerin combination were very poor. The nicotine-oil combinations, however, gave very good results in terms of percentage of clean apples, and where this combination was used in four cover sprays (Nos. 2 and 3, 1929) the percentage of stung apples was materially reduced.

From all these experiments it may be concluded that nicotine sulphate alone, although it has some control value against the egg, and some immediate larvicidal value, can not be depended on for control of the codling moth; but that the combination of nicotine sulphate and oil is a very effective one for control because it destroys many of the eggs, and sufficient nicotine is retained to kill larvae for some time. This combination may be substituted for lead arsenate in one or more cover sprays, or it may be added to the lead arsenate.

PYRIDINE DERIVATIVES

Richardson and Smith (*6*) found that certain compounds related to nicotine, known as dipyridyls, were very toxic to aphids. A crude mixture of the sulphates of these compounds and a crude sample of benzyl pyridine furnished by the Bureau of Chemistry and Soils were tried on codling-moth larvae by the writers. (Table 24.) Neither of them were equal in toxicity to lead arsenate or nicotine sulphate, except the crude benzyl pyridine at 1 to 100. (Test 4.) At this strength, however, this material caused brown spots to appear on the sprayed fruit.

TABLE 24.—*Laboratory experiments with pyridine derivatives on the larvae of the codling moth, Yakima, Wash., 1928*

Test No.	Material used	Dilution	Worms entering fruit		Worms causing stings		Total blemishes	Ratio of stings to total blemishes
			Number	*Per cent*	*Number*	*Per cent*	*Per cent*	
1	Dipyridyl sulphate	1-100	27	54	2	4	58	0.07
2	do	1-200	25	50	7	14	64	.22
3	do	1-400	33	66	4	8	74	.11
4	Crude benzyl pyridine	1-100	15	30	4	8	38	.21
5	do	1-200	22	44	5	10	54	.19
6	do	1-400	22	44	9	18	62	.29
7	Lead arsenate	1-50	16	32	10	20	52	.38
8	Check		26	52	3	6	58	.10
9	Crude benzyl pyridine	1-100	18	18	13	13	31	.42
10	do	1-200	19	19	10	10	29	.34
11	do	1-400	21	21	14	14	35	.40
12	Nicotine sulphate (40 per cent)	1-800	4	4	5	5	9	.56
13	Lead arsenate	1-50	15	15	19	19	34	.56
14	Check		35	35	14	14	49	.29
15	Crude benzyl pyridine (1-100) emulsified with calcium caseinate 1 gram to 15 cubic centimeters		24	24	14	14	38	.37
16	Crude benzyl pyridine (1-200) emulsified with calcium caseinate 1 gram to 15 cubic centimeters		23	23	15	15	38	.40
17	Crude benzyl pyridine (1-400) emulsified with calcium caseinate 1 gram to 15 cubic centimeters		35	35	8	8	43	.19
18	Nicotine sulphate (40 per cent)	1-800	7	7	4	4	11	.36
19	Lead arsenate	1-50	15	15	18	18	33	.55
20	Check		45	45	10	10	55	.18

DERRIS AND PYRETHRUM

A commercial extract of Derris, labeled as containing 5 per cent active ingredients, was tested against the eggs at a concentration of 1 to 800. Of 251 eggs sprayed, 27.8 per cent failed to hatch, as compared with 23 per cent of 374 unsprayed eggs. The same extract, at concentrations of 1 to 400 and 1 to 800, was tested as a larvicide. Other materials tested in this manner included an alcoholic extract of Derris root,[15] a kerosene extract of pyrethrum, and a commercial pyrethrum extract, labeled as containing 92 per cent active ingredients. With the exception of the latter material, none of these extracts had any appreciable larvicidal value when tested within 48 hours after spraying.

Experiments were then made with the commercial Derris extract, and with three commercial pyrethrum extracts, used with and without a lubricating-oil emulsion, and sprayed on fruits to find out whether the oil would cause these materials to remain toxic longer. (Table 25.) All of the pyrethrum extracts were very toxic within 24 hours of spraying, but apparently had lost most of their toxicity a week later. The Derris was quite ineffective, even when freshly applied. The addition of oil emulsion had no beneficial effect.

TABLE 25.—*Laboratory experiments with Derris and pyrethrum on the larvae of the codling moth, Yakima, Wash., 1929*

Test No.	Material used	Percentage of worms entering fruit—	
		1 day after spraying	7 days after spraying
1	Commercial Derris extract 1–400	34	48
2	Commercial Derris extract 1–400, plus ¾ per cent lubricating oil (emulsified)	32	50
3	Commercial Derris extract 1–800, plus ¾ per cent lubricating oil (emulsified)	44	48
4	Pyrethrum extract No. 1, 1–200	8	48
5	Pyrethrum extract No. 1, 1–200, plus ¾ per cent lubricating oil (emulsified)	8	50
6	Pyrethrum extract No. 1, 1–400, plus ¾ per cent lubricating oil (emulsified)	8	44
7	Pyrethrum extract No. 2, 1–100	10	36
8	Pyrethrum extract No. 2, 1–100, plus ¾ per cent lubricating oil (emulsified)	0	36
9	Pyrethrum extract No. 3, 1–400	0	40
10	Pyrethrum extract No. 3, 1–800	10	40
11	Pyrethrum extract No. 3, 1–800, plus ¾ per cent lubricating oil (emulsified)	10	54
12	Lead arsenate 1–50	18	28
13	Check	34	64

The alcoholic extract of Derris and the kerosene extract of pyrethrum, in orchard experiments, were practically worthless, the fruit becoming extremely wormy. In an orchard experiment with the commercial pyrethrum extract No. 1, and lubricating-oil emulsion, 37.3 per cent of the fruit became wormy, as compared with 25.5 per cent in a plat sprayed with lead arsenate. Judging from the laboratory results, much of this control may be attributed to the effect of the oil on the eggs. An orchard experiment with the commercial Derris extract was discontinued because injury to the fruit (pl. 2, F) and foliage developed and much of the fruit was becoming wormy.

[15] This sample of Derris root was later found to be low in total extract and to contain not more than traces of rotenone, which explains the very poor results obtained with it.

COMPOSITION OF SPRAY MATERIALS

The characteristics of the oils used and the formula for the nicotine tannate are given below:

No. 1. Red engine oil:		
Volatility (4 hours at 110° C.)	per cent	0.4
Viscosity (Saybolt at 100° F.)	seconds	230
Specific gravity at 20° C.		0.921
Unsulphonated residue (38 N acid)	per cent	50
No. 2. Brown neutral oil:		
Volatility	per cent	2.7
Viscosity	seconds	116
Specific gravity		0.922
Unsulphonated residue	per cent	49
No. 3. Crystal oil:		
Volatility	per cent	0.84
Viscosity	seconds	122
Specific gravity		0.871
Unsulphonated residue	per cent	95.2
No. 4. Mineral seal oil:		
Viscosity	seconds	52
Unsulphonated residue	per cent	82
No. 5. Technical oil:		
Viscosity	seconds	129
Unsulphonated residue	per cent	89
No. 6. Summer oil:		
Viscosity	seconds	78
Unsulphonated residue	per cent	77
No. 7. Nicotine tannate:		
Tannic acid	pounds	3
Nicotine (50 per cent)	pound	1
Water	gallons	100

In No. 7 the tannic acid is sifted into 25 gallons of water while it is being agitated, the nicotine is added, and then the remainder of the water.

SUMMARY

The demand for more effective methods of controlling the codling moth that would not leave objectionable spray residues has been the chief reason for the studies described in this bulletin.

The use of lead arsenate at 2 pounds to 50 gallons, or of an increased number of applications at 1 pound to 50 gallons, improved the control, but also resulted in more arsenical residue.

Casein spreader, in small quantities, caused the lead arsenate to be somewhat more effective, but in larger quantities it did not have this result. Fish oil also increased the effectiveness of the lead arsenate, but made residue removal more difficult. Soap, glue, and flour paste reduced the value of the arsenical.

Thirteen nonlead arsenicals were tested, but none of them controlled the codling moth as well as lead arsenate, and several of them damaged the fruit or foliage severely. Barium arsenate, zinc arsenate, and manganese arsenate were the most effective.

Lubricating-oil sprays proved to be valuable against the eggs, and they also had some toxic effect on eggs deposited a few days after spraying, but did not repel ovipositing moths. There was little effect on the larvae. Heavy or relatively unrefined oils were often injurious to the fruit or foliage. Oil sprays alone were not so efficient as lead arsenate.

It was concluded that in order to use oil safely and effectively for codling-moth control a medium oil with a Saybolt viscosity of

65 to 75 seconds and a large proportion of unsulphonatable residue should be added in a proportion of slightly less than 1 per cent to not more than three or four lead arsenate cover sprays.

Nicotine sulphate was somewhat toxic to codling-moth eggs and larvae in warm weather, but by itself was of less value than lead arsenate. Of the materials tested to prevent too rapid volatilization of the nicotine, lubricating oil gave the best results, and very good control was obtained with a combination of nicotine sulphate, diluted to 1–800 or 1–1,600, and a 1 per cent lubricating-oil spray. This combination is of value when substituted for lead arsenate in one or more cover sprays.

Poor results were obtained with crude dipyridyl sulphate and crude benzyl pyridine. Derris, in the forms tested, was ineffective, and pyrethrum extracts were effective only for a short time after being applied.

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