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CONCENTRATION OF MATERIALS AND RATE OF APPLICATION IN THE CONTROL OF APPLE SCAB

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The control of apple scab* has received and probably will continue to receive a major share of the attention given to spraying problems by Michigan apple growers. Detailed knowledge of the life history of the fungus causing the disease, coupled with information gained from recent investigations on its responses to environment permit the recommendation of a general treatment which will control scab. Certain spray materials, such as lime-sulphur and bordeaux, have become standard in the control of this disease. However, scab control cannot be considered a settled matter. The rather frequent offerings of new spray materials involve continued testing of their efficacy and even with the older materials such points as methods of application and amounts and strengths of materials to be used have received comparatively little attention until very recent times. A similar condition exists with regard to the control of many troubles.

Of the various considerations which should govern the choice of the material to be employed, three are of outstanding importance. The first requisite of any spraying material is that it shall be effective in the control of the diseases or insects for which it is used. The second consideration is the production of fruit of good "finish," i. e., free from russeting, which detracts from the appearance and may affect the size and form of the fruit and possibly its keeping. The third consideration is foliage injury. This is undesirable because a leaf which has been injured by spraying materials is impaired in its functioning and severe injury may lead to defoliation. The immediate effects of foliage injury, especially when followed by premature defoliation are evident. The residual effects are not so apparent but are none the less serious. These factors are all important because they have a direct influence on the grade or quality of the fruit or upon the productiveness of the tree.

In recent years there has been a tendency to reduce the strength of some of the standard spraying materials used for the control of scab. There have been two reasons for this:—(1) the desire to reduce the cost and (2) to eliminate, as much as possible, russeting of fruit and injury to foliage.

Even with an acceptable material, there is an unsettled point as to the amount of diluted material necessary to insure satisfactory control. This may be termed "dosage." The general tendency has been to increase the dosage but with such increases there immediately arise

*Caused by Venturia inaequalis.

certain economic considerations. Heavier applications not only entail increased costs for material and labor but reduce the acreage that it is possible to cover with a certain equipment.

The Relation of Strength of Materials and Dosage.—When the strength of materials and dosage are considered together a number of very interesting questions arise. Will spraying materials used at strengths weaker than generally recommended give satisfactory scab control? Will increased strength insure better results? Is there danger of overspraying? Which is best; a light application of strong material, a heavy application of weak material, or a moderate application of medium strength material? These questions also apply to the problems of foliage injury and finish of the fruit. To obtain answers to these questions a series of tests was carried out in 1924. This report considers in detail only the results obtained in scab control. General statements are made on the effect of the different applications on foliage injury and the finish of the fruit.

THE EXPERIMENT

The Orchard.—The work was done in an orchard at Morrice, Shiawassee county, belonging to George Winegar and Son. The trees were twelve years old and the varieties are Hubbardston and Jonathan with Wagener fillers. It had been in alfalfa sod for two or three years, the general practice having been to leave most of the alfalfa on the ground. The trees were in good vigor and had been making a satisfactory growth.

The Schedule of Applications and Periods of Rainfall.—Though certain other factors have some influence, rainfall is the chief of those influencing the development and spread of scab. Heavy precipitation, however, does not necessarily mean that conditions will be favorable for the development and spread of scab; the duration of rain periods and to some extent the time of day when the when the rain falls are more important. A rain early in the day is much less likely to produce conditions favorable for the spread of scab than rain which falls late in the afternoon or early evening because the trees are very likely to remain wet throughout the night.

The season of 1924 was marked by conditions very favorable for the development of scab. Table 1 contains, besides the schedule and dates of application, a statement of the more important rain periods during the early part of the season. The total precipitation was not great but the rains occurred at such times that they were very effective in promoting the spread of scab. All the early summer applications were made just previous to periods of rain. This combination of seasonal conditions and timely application resulted in a very critical test for any material or method of application.

The Materials and the Strengths at Which They were Used.—Two materials—bordeaux and lime-sulphur—were used. Lead arsenate

Table 1.—Dates of applications and periods of rainfall.

Application*	Date	Periods of rain and scab infection
"Dormant"	None	
"Prepink"	May 2–3	May 3—Rain began falling just after spraying was completed, about 5 P. M. and continued into night. Spore discharge was relatively light at this time because of the unusually late maturity of the ascospores in the old leaves.
"Pink"	May 15–16	May 17—Rainfall began at 5 P. M. and continued all night. Spore discharge was very heavy. May 23—Rainfall began at about 3 P. M.; continued intermittently all night and until about 8. A. M. on 24th.
"Petal-fall"	June 6–7	June 7—Rain began falling as spraying was finished in the evening. Showers continued through the night and forenoon of the 8th. June 13—Light rain in the evening and during the night. June 17—Showers from 7 P. M. until middle of the night. Trees wet all night.
"Two-weeks"	June 19–20	June 23—Showers in the evening. June 24—Showery from 4 P. M. till 8 A. M. of June 25.
"Second Brood"	Aug. 12–13	Conditions were not favorable for scab development during the late summer.

*The applications here listed were made at the stages indicated for each in the spraying calendar, Sp. Bul. 140, Mich. Agric. Exp. Sta., 1925.

powder was added in all applications except the prepink and nicotine sulphate was included in the petal-fall application. These materials were used at different strengths which have, for this experiment, been arbitrarily termed **weak, medium** and **strong.** The amounts or formulae used were as follows:

Bordeaux.—Weak:—2-4-100, plus 1 pound lead arsenate powder.
Strong:—6-12-100 plus 3 pounds lead arsenate powder.

Lime-sulphur.—Weak:—1½ gallons in 100, plus 1½ pounds lead arsenate powder.
Medium:—2½ gallons in 100, plus 2 pounds lead arsenate powder.
Strong:—3 gallons in 100, plus 3 pounds lead arsenate powder.

The formulae for the bordeaux indicate: (1) the pounds of copper sulphate; (2) the pounds of lump or quick lime, and (3) the gallons of water. The lime-sulphur was a standard commercial product testing 32 to 33 degrees Beaumé. The lead arsenate was also a standard brand of acid lead arsenate without spreader.

Dosage and Methods of Application.—The medium strength lime-sulphur was applied in the usual way and the trees received what may

be termed a moderate application (see Table 2). The weak and strong lime-sulphur and the weak and strong bordeaux were applied each at three different dosages. These have been termed **light, moderate** and **heavy** applications. The spraying was done in such a way that the moderately sprayed trees received approximately twice, and the heavily sprayed trees approximately three times, as many gallons as those lightly sprayed. The relative amounts per tree, then, were as 1, 2 and 3. This was accomplished in the following way: The plots sprayed with each strength of each material were made up of three rows of trees: one row received a light application; one a moderate; and the third a heavy application. The spraying for each plot was always begun on the "heavy" row and all three rows were given a uniform, **light** application. The "light" row was sprayed no more. By the time the three rows were covered the material on the first and second rows had dried. They were again sprayed exactly as before so that the dosage was double that on the lightly sprayed row. As soon as the material had dried from the second covering, the "heavy" row was again sprayed. The final result was that one row received one, another row two, and the third, three light applications.

All spraying was done from the ground. The rows, as sprayed, ran north and south and the usual procedure was to drive on the windward side of the row and to complete each tree before beginning the next. On a few occasions, when the wind was blowing directly from the north or south, or approximately that, the work was accomplished by spraying one-half of each tree from one side, then returning on the other side of the row and completing each tree.

The sprayer used was an outfit equipped with a four h. p. engine and pump with a delivery of 10 gallons per minute. The operating pressure was maintained at 300 to 310 pounds for all applications. A spray gun was used at all times. Most of the spraying was done with a disc opening of 9/64 inch but a disc with 1/8 inch opening was used for part of the work.

Comparative Amounts of Active Ingredients.—It has been stated that the comparative amounts of dilute materials applied to the trees receiving light, moderate and heavy applications varied as 1, 2 and 3. The strong lime-sulphur was twice as strong as the weak and the strong bordeaux was three times as strong as the weak. By considering together the dosage and the strength of the materials, it is possible to determine the comparative amount of active ingredients received by the trees under different treatments. For instance, the rows sprayed with light applications of weak and strong lime-sulphur received equal quantities of dilute material but the row sprayed with the strong lime-sulphur received twice as much actual lime-sulphur as the other since the dilute material was twice as strong. For another example may be taken the light application of weak bordeaux and the heavy application of strong bordeaux. The trees sprayed with the heavy application received three times as many gallons of diluted material and since the strong bordeaux was three times stronger than the weak, they received approximately nine times as much copper as those sprayed with a light application of weak bordeaux.

Actual Dosage of Dilute Materials.—These comparative values are, of course, theoretical and were not maintained exactly in the orchard because of the impossibility of spraying all trees exactly alike. The dosage might be affected by wind direction and velocity, by the size of the trees and possibly by certain other factors. The statement of the actual number of gallons applied per tree which is presented in a following table shows that, although there was some variation, the calculated dosages were given in a fairly satisfactory way. The greatest variation was between the plots sprayed with weak and with strong lime-sulphur.

In Table 2 is presented a complete record of the materials used, the formulae or rates of dilution, the rate of application, the actual number of gallons applied per tree, the comparative amounts of dilute materials, the comparative amounts of active ingredients and the percentage of apples affected with scab. The actual dosage records are presented in two groups, one for the pre-blossom applications which include the "prepink" and "pink" and one for the after-blossom applications. In the statement of comparative amounts of dilute materials per tree the value 1 is given to the smallest dosage of each material (of both strengths), which is the light application. In a like manner with the comparative amounts of active ingredients the value 1 is assigned to the plot of each material which received the smallest amount of actual fungicide. This would be, with both bordeaux and

Table 2.—The control of scab as affected by the strength of material and the rate of application.

Materials and dilutions	Rate of application	Actual number gallons applied per tree		Comparative amounts of		Percentage of apples affected by scab
		Pre-blossom applications	After-blossom applications	Diluted material	Active ingredients	
Weak lime-sulphur, 1½ gals. in 100	Light	1.4	3.3	1	1	23.0
	Moderate	2.8	6.6	2	2	8.9
	Heavy	4.2	9.9	3	3	5.1
Medium lime-sulphur, 2½ gals. in 100	Moderate	2.3	4.5	1.5	2.5	2.2
Strong lime-sulphur, 3 gals. in 100	Light	1.6	2.7	1	2	7.7
	Moderate	3.2	5.4	2	4	2.9
	Heavy	4.8	8.1	3	6	2.0
Weak bordeaux, 2-4-100	Light	1.6	2.4	1	1	19.9
	Moderate	3.2	4.8	2	2	5.6
	Heavy	4.8	7.2	3	3	1.0
Strong bordeaux, 6-12-100	Light	1.3	2.4	1	3	2.4
	Moderate	2.7	4.8	2	6	0.3
	Heavy	4.0	7.2	3	9	0.6
Checks	No treatment	.....	.....	.....	.....	100.0

lime-sulphur, the plot receiving the light application of weak material.

RESULTS

Control of Scab.—The plots all contained, as previously stated, trees of three varieties, but scab control records were obtained from one variety—Hubbardston. This is not always a highly susceptible variety but under the conditions prevailing in 1924, scab developed very freely where unchecked. General observations were made throughout the season as to the prevalence of scab on both fruit and foliage and detailed records were obtained at harvest to determine the exact percentage of apples that were affected with scab. In obtaining these records only one degree of scabbiness was recorded. If any scab could be seen on an apple it was classed as scabby. The control of scab on the foliage was practically parallel to the control on the fruit. On trees where scab was not controlled on the fruit there was considerable foliage infection; on trees with a low percentage of scabby apples there were practically no scabby leaves. The records for the fruit are presented in Table 2. That conditions were very favorable for the development of scab is shown by the fact that all the fruit on the check trees was scabby and most of it badly scabbed.

DISCUSSION

In the following paragraphs the results are considered with the idea of comparing the results from the use of one strength and dosage of one material with other strengths and dosages of the same material and not to compare lime-sulphur with bordeaux. However, the comparative value of lime-sulphur and bordeaux for the control of apple scab is clearly shown.

Strength of Material.—Weak lime-sulphur and weak bordeaux were both less effective than equal dosages of higher concentrations. For example: with lime-sulphur, a light application of weak was less effective than a light application of strong; a moderate application of weak was less effective than a similar dosage of strong material and a heavy application of weak lime-sulphur was also less effective than a heavy dosage of strong lime-sulphur. The difference in results, however, between moderate applications of weak and strong lime-sulphur was much less than between light applications of weak and strong materials and the difference between heavy dosages of the two strengths was still less than with moderate dosage. The differences between weak and strong bordeaux were essentially the same as just stated for lime-sulphur.

The statements made in the preceding paragraph refer to the so-called weak and strong materials applied in the special way previous-

ly described. The results from those applications are strictly comparable but the results from the moderate application of medium strength lime-sulphur are not strictly comparable with those from the materials applied in the special way because of the difference in the method of application. However, the excellent results indicate definitely that the medium strength lime-sulphur when applied in a thorough and careful manner is very effective in the control of apple scab.

Rates of Application.—The effectiveness of the materials, both weak and strong, increased with increases in dosage. For instance, with weak lime-sulphur, the moderate application was more effective than the light and the heavy was more effective than the moderate. This is true also of the strong lime-sulphur and weak and strong bordeaux but there are significant differences between the results from the different dosages of the weak lime-sulphur and weak bordeaux on one hand and strong lime-sulphur and strong bordeaux on the other. The percentage of scabby apples on trees receiving a light application of weak lime-sulphur and weak bordeaux was much higher than on trees receiving similar applications of strong materials. Likewise, moderate and heavy applications of weak materials did not control scab as well as moderate and heavy applications of strong materials. The differences in results between moderate and heavy applications of weak materials were rather significant but for the strong materials the differences were insignificant. The light applications of strong lime-sulphur and strong bordeaux were both slightly less effective than heavy applications of weak lime-sulphur and weak bordeaux. There is one exception to the statements made in this paragraph—the percentage of scab on trees receiving a heavy application of strong bordeaux was very slightly higher than with the moderate application but the amount in both instances was so very small that the irregularity may be considered as insignificant.

Comparative Amounts of Active Ingredients.—The amount of scab decreased as the amount of active ingredients increased. The reduction per unit increase of fungicidal material was greater between small numbers of units than with large numbers. These points may be brought out by a rearrangement of part of Table 2 and with the addition of some other material. This is presented in Table 3.

For convenience in discussion the comparative amounts of active ingredients as shown in Tables 2 and 3 may be termed "units." The data in Table 3 show that a unit, as for instance, of lime-sulphur, when applied as a light application and at a weak dilution is worth relatively less than if it were combined with more units of the same material by increasing the dosage, or by increasing the strength, or both. However, after a certain moderate concentration was attained, the increase in scab control was not in proportion to the increase in the number of units of active ingredients.

The data, as rearranged in Table 3 are consistent in showing that an increase in the number of units of fungicidal material, regardless of concentration or dosage, resulted in a reduction in the amount of scab.

Coverage and Concentration.—A number of factors are involved in scab control, such as a proper spraying schedule and correct timing of

Table 3.—Ranking of treatments according to scab control.

Material and strength	Rate of application	Comparative amounts of active ingredients	Percentage of apples affected with scab	Decrease in scab per unit increase of fungicide
Weak lime-sulphur	Light	1	23.0	.....
Weak lime-sulphur	Moderate	2	8.9	14.1
Strong lime-sulphur	Light	2	7.7	15.3
Weak lime-sulphur	Heavy	3	5.1	*3.3
Strong lime-sulphur	Moderate	4	3.0	2.1
Strong lime-sulphur	Heavy	6	2.0	0.5
Weak bordeaux	Light	1	19.9	.....
Weak bordeaux	Moderate	2	4.6	14.3
Strong bordeaux	Light	3	2.4	3.2
Weak bordeaux	Heavy	3	1.0	4.6
Strong bordeaux	Moderate	6	0.3	**0.46
Strong bordeaux	Heavy	9	0.6	**0.16

*This amount was obtained by subtracting 5.1 from the average of the two preceding items since they received equal amounts of active ingredients.

**These amounts were obtained by subtracting 0.3 and 0.6 respectively from the average of 2.4 and 1.0 as the treatments under which those amounts of scab had developed received equal amounts of active ingredients.

the applications. Assuming that these and possibly other conditions have been met, it is evident that there are two other factors which have a direct bearing on the degree of control. They are what may be termed **coverage** and **concentration.** By coverage is meant the covering of the surface of the foliage and fruit with a film of the diluted fungicide, and concentration may be defined as the actual amount of the fungicidal material in this covering film.

With a light application of weak lime-sulphur 23 per cent of the fruit was scabby, but trees sprayed with a light application of strong lime-sulphur produced fruit which was only 7.7 per cent scabby (see Table 2). In both instances the coverage was the same (as indicated by one unit of diluted material in each) but the concentration on trees sprayed with the strong lime-sulphur with two units of active ingredients was double that on trees receiving a light application of weak lime-sulphur with one unit of active ingredients. With the light application of strong lime-sulphur, the concentration probably approached the optimum but the failure to control scab satisfactorily was due largely to incomplete coverage. The nature of the occurrence of scab on these trees, supports this statement. The scab was present mostly as large lesions and confined to small groups of apples here and there over the trees. This condition indicated that these groups of apples had not been covered at some application. With the light application of weak lime-sulphur the nature of scab occurrence indicated clearly that the coverage was incomplete and also that the concentration was too low, as scab was severe and generally distributed over the trees. A similar comparison might be made with the light applications of weak and strong bordeaux.

A study of the results obtained from heavy applications of weak lime-sulphur and strong lime-sulphur yields further evidence. Both

received the same coverage with three units each of diluted material. The use of the weak lime-sulphur with three units of fungicidal material, however, resulted in 5.1 per cent of scabby fruit while the strong lime-sulphur with six units of active ingredients reduced scab to 2 per cent and that in a very mild form. Other similar comparisons could be made between the moderate application of weak and strong lime-sulphur or of weak and strong bordeaux.

Foliage Injury and Russeting of the Fruit.—A detailed statement of the relation between strength of materials and dosage on one hand and foliage injury and russeting of the fruit on the other is not presented in this report; however, it may be stated that lime-sulphur and lead arsenate cause relatively little russeting as compared with bordeaux but the amount is, in general, proportional to the amount of active ingredients applied. Bordeaux, even on the most lightly sprayed plots, caused heavy russeting and it was greater with increases in the amount of active ingredients applied. Foliage injury on bordeaux-sprayed trees was relatively light and there was no indication that the degree of injury was determined by the amount of active ingredients used. Lime-sulphur and lead arsenate, on the other hand, caused much injury. This varied from practically nothing on trees receiving the smallest amounts of active ingredients to almost complete defoliation on trees to which large amounts of active ingredients were applied.

Control of Scab and Cost of Spraying.—Increases in dosage, as stated in an introductory paragraph, are of direct economic importance because they entail increased costs for material and labor and reduce the acreage that can be covered with a certain equipment, or make it necessary to increase the equipment in order to complete the operation in an equal length of time. The costs of materials, labor, and sprayer have been determined for these experiments and together with results, are presented in Table 4. The treatments are arranged according to the amount of scab. The cost of materials includes the lead arsenate as well as the fungicide. Lime-sulphur was figured at 16 cents per gallon, copper sulphate at 7 cents, quick lime at 1¾ cents, and lead arsenate powder at 16 cents per pound. The dosage used in these calculations is an average of those for the weak and strong concentrations of each material. The labor item includes two men and team at $1.00 per hour. The amount applied was 200 gallons per hour including the time for refilling and driving to and from the orchard. The labor cost per gallon, then, was ½ cent.

The cost of the sprayer includes gasoline, oil, grease, repairs and a deterioration charge for the outfit. The cost of the sprayer was $600.00. Seven years is assumed as the length of time it will be used, operating a total of about 2,000 hours (a little more than 30 nine-hour days per year) and delivering 200 gallons per hour. Repairs are figured at $20.00 per year. These items give a total of $4.61 per day or ¼ cent per gallon as the cost of the sprayer, including maintenance and operation. Such costs will vary from year to year, and according to the size of the trees, the method of application and proximity to water supply but the figures used here are reasonable for this particular work, but are undoubtedly much lower than for average conditions.

Table 4.—Scab control and the cost of treatment.

Material	Rate of application	Comparative amounts of		Scabby fruit (per cent)	Spraying cost per tree for the season (cents)				Reduction of scab* (per cent)	Increase in cost of treatment (cents)
		Diluted material	Active ingredients		Material	Labor	Sprayer	Total		
Weak lime-sulphur	Light	1	1	23.0	5.4	6.0	3.0	14.4	.....	.....
Weak lime-sulphur	Moderate	2	2	8.9	10.8	12.0	6.0	28.8	14.1	14.4
Strong lime-sulphur	Light	1	2	7.7	10.8	6.0	3.0	19.8	1.2	-9.0
Weak lime-sulphur	Heavy	3	3	5.1	16.2	18.0	9.0	43.2	2.6	23.4
Strong lime-sulphur	Moderate	2	4	3.0	21.6	12.0	6.0	39.6	2.1	-3.6
Strong lime-sulphur	Heavy	3	6	2.0	32.4	18.0	9.0	59.4	1.0	19.8
Medium lime-sulphur	Regular	1.5	2.5	2.2	12.2	9.0	4.5	25.7	.....	.....
Weak bordeaux	Light	1	1	19.9	3.4	5.0	2.5	10.9	.....	.....
Weak bordeaux	Moderate	2	2	4.6	6.9	10.1	5.0	21.0	14.3	10.1
Strong bordeaux	Light	1	3	2.4	10.4	5.0	2.5	17.9	2.2	-3.1
Weak bordeaux	Heavy	3	3	1.0	10.4	15.1	7.5	33.0	1.4	15.1
Strong bordeaux	Moderate	2	6	0.3	20.9	10.1	5.0	36.0	0.7	3.0
Strong bordeaux	Heavy	3	9	0.6	31.4	15.1	7.5	54.0	**0.4	**21.0

*The treatment under which the greatest amount of scab developed is taken as a base for figuring the reductions. The treatments are arranged in the order of the amount of scab found, beginning with the greatest and the reduction is determined for each item by subtracting its per cent of scab from the next greatest amount.

**This amount is the difference between the figures for the heavy application of weak and the heavy application of strong bordeaux, rather than between the moderate and heavy applications of the strong. This was necessary because of the insignificantly greater amount of scab with the heavy application than with the moderate.

The data presented in Table 4 show some significant details as for example those presented by the different dosages of weak and strong lime-sulphur. An increase in the amount of actual fungicidal material always resulted in a decrease in the amount of scab, but an increase in the cost of treatment was not always necessary to obtain the better control. The moderate application of weak lime-sulphur gave 14.1 per cent less scab than the light application of the same strength and at an increase in cost of 14.4 cents per tree for the season. The light application of strong resulted in a further reduction of 1.2 per cent below the moderate application of weak but instead of an increase in cost, this better control was actually obtained for 9 cents per tree less than the previous treatment. The next step, a heavy dosage of weak material, shows another reduction in scab of 2.6 per cent but at an increased cost of 23.4 cents per tree. The succeeding treatment reduced scab by 2.1 per cent and at a cost lower by 3.6 cents per tree. Why were some increases in control obtained at an increase in cost and others at actually lower cost? From the light application to the moderate of the weak material there was a doubling in cost of all items because the strength was constant but the rate of application was doubled. Similarly with a moderate application of weak to a light application of strong, the cost of material was the same for both but the labor and sprayer costs for the latter were just one-half because of the difference in dosage. Between the light application of strong and the heavy of weak there is a moderate increase in the cost of material but the labor and sprayer costs are tripled because one is a light and the other a heavy application. The fourth step, from a heavy application of weak to a moderate of strong, shows an increase in cost of material, but a total cost actually less because of lower labor and sprayer charges. The same statements may be applied, with small exceptions, to the bordeaux treatments.

It is evident, then, that the cost of spraying for the control of scab cannot be lowered by decreasing concentrations as this would involve increases in labor and sprayer costs because of the necessarily heavier application. On the other hand, increased concentration and smaller dosage would usually be unsafe because of the danger of incomplete coverage and the consequent poor control. In what way, then, are spraying costs to be lowered? The development and use of cheaper materials is a possible but rather improbable step. The only obvious way of accomplishing this end is through more efficient spraying and improvement in spray management in general. This would involve many factors but probably the most important are, the use of sprayers of a capacity that will require the least outlay for men and teams consistent with satisfactory results, the maintenance of the spraying equipment in a highly efficient condition, a plentiful and convenient water supply so that the sprayer can be used in actual spraying operations for the maximum proportion of the time, and a rapid method of measuring and mixing concentrated materials when refilling the sprayer.

CONCLUSIONS

The evidence plainly indicates that both bordeaux and lime-sulphur may be depended upon to give satisfactory control of scab if properly used. Bordeaux, however, is likely to cause so much russeting of the fruit under Michigan conditions that its use on apples is not advised. The results indicate also that a greater dilution of lime-sulphur than is generally recommended for scab control in Michigan is likely to be followed by unsatisfactory results unless the rate of application is heavy. Increases in concentration with light application may result in poor control, or if concentration and dosage are both increased more injury to foliage and fruit will be likely to follow and the cost will be unnecessarily greater.

A thorough application of moderate strength lime-sulphur (2½-100) is best for average conditions but even when used in this way, lime-sulphur is not an ideal material, because of the injury to foliage that frequently follows its use. However, it is evident that no great improvement may be expected by changes in concentration or dosage but rather in the development of other materials to use for all or part of the applications or by some modification of lime-sulphur itself.

The total cost of summer applications of spraying materials cannot be significantly reduced by simply changing the concentration of the ordinary materials. Economies must, therefore, come through increased efficiency in application and improvements in spray management in general.

Another factor of importance is the proper timing of the applications. The concentration of materials, the rate of application, and the schedule of treatments may all be correct and results still be unsatisfactory unless the applications are properly timed. Delays or improper timing of one or more applications in a schedule have been responsible for many failures in the control of scab and other troubles.

Residues of Spraying Materials on Leaves.—To secure information on the amount of the various materials remaining on the leaves under the different treatments and at various intervals after application, leaves were collected and measured and the residues determined.

Samples were taken from all the treated plots indicated in Table 2, and from another plot sprayed with lime-sulphur and lead arsenate with casein-lime spreader added. This was applied in the usual way and was comparable in every respect with the plot sprayed with the so-called medium strength lime-sulphur. The samples were taken at three periods, as follows:

1. July 31 and August 1.
2. August 15 and 16.
3. September 7 and 8.

Sample 1 was taken just before the second brood application and shows the accumulation of spraying materials from the early summer applications less any removed by weathering. Sample 2 was taken

immediately after the second brood application and before rainfall occurred. This shows the accumulation from the early applications plus all the materials that adhered from the last spray. Sample 3 was collected after the first rain of consequence following the second brood application.

The leaves were collected at random but always from non-fruiting spurs and from the lower portion of the tree. The number of leaves per sample for each plot varied, with a few exceptions, from 300 to 400 and they were taken from two to four trees, but usually three. They were air dried, measured with a planimeter to determine area, ground and residues determined.* The results are given in Table 5 for leaves sprayed with lime-sulphur and lead arsenate and in Table 6 for those sprayed with bordeaux and lead arsenate. They are expressed in two ways: as percentage of the total dry weight of the sample and as milligrams per 100 square centimeters of leaf surface (upper and lower).

These determinations show that with the strength of material constant the residues increase with the dosage, and with dosage constant the residues are greater with increases in strength of material. The addition of casein-lime to lime-sulphur and lead arsenate made the sulphur more persistent but had no significant effect on the lead arsenate.

The amounts of residues were affected very appreciably by weathering. The lowest amounts were found after a prolonged period without application. The greatest amounts were, of course, found immediately after the last application and the subsequent period of weathering reduced the residues, in most instances, to a point intermediate between the first two determinations.

*The analyses were made by the Division of Chemistry of the Agricultural Experiment Station. The methods of analysis were as follows:—

Sulphur.—Magnesium nitrate method. A. O. A. C., 2nd. ed. (1925), p. 45, paragraph 18.

Arsenic.—Oxidation of material. A. O. A. C., 2nd. ed. (1925), p. 48, paragraph 5. (Smaller samples were used for this than is indicated by the directions.)

Determination. Cuprous chloride distillation method. A. O. A. C., 2nd. ed. (1925), p. 48, paragraph 5.

Copper.—Oxidation of material. Same as for arsenic. Determination: Thiosulphate titration method. A. O. A. C., 2nd. ed. (1925), p. 52, paragraph 17.

Table 5.—Residues of sulphur and arsenic on apple leaves.

Sample	Rate of application	Sulphur*						Arsenious oxide					
		1		2		3		1		2		3	
Material		Per cent**	Mgm. per 100 sq. cm.	Per cent**	Mgm. per 100 sq. cm.	Per cent**	Mgm. per 100 sq. cm.	Per cent**	Mgm. per 100 sq. cm.	Per cent**	Mgm. per 100 sq. cm.	Per cent**	Mgm. per 100 sq. cm.
Lime-sulphur, 1½—100	Light	0.36	0.15	0.77	1.80	0.44	0.67	0.05	0.06	0.08	0.27	0.07	0.24
Lead arsenate, 1½—100	Moderate	0.48	0.59	1.24	3.21	0.63	1.35	0.06	0.15	0.16	0.53	0.13	0.47
	Heavy	0.59	0.89	1.64	5.80	0.70	1.77	0.08	0.19	0.19	0.75	0.13	0.51
Lime-sulphur, 3—100	Light	0.58	0.93	1.56	4.61	0.68	1.61	0.08	0.22	0.19	0.69	0.15	0.58
Lead arsenate, 3—100	Moderate	0.94	2.00	2.22	7.22	0.87	2.42	0.13	0.38	0.29	1.06	0.15	0.60
	Heavy	1.12	2.77	2.71	11.39	1.25	4.50	0.10	0.33	0.42	1.94	0.18	0.83
Lime-sulphur, 2½—100	Moderate	0.51	0.73	1.10	2.51	0.54	1.11	0.07	0.20	0.17	0.51	0.10	0.37
Lead arsenate, 2—100													
Lime-sulphur, 2½—100													
Lead arsenate, 2—100	Moderate	0.67	1.30	1.26	3.87	0.69	1.84	0.09	0.29	0.13	0.49	0.08	0.36
Casein-lime, 1—100													

*The amount of sulphur shown is the difference between the total amount found with sprayed leaves and that found in unsprayed leaves.

**This percentage is calculated from the total dry weight of the sample.

Table 6.—Residues of copper and arsenic on apple leaves.

Sample	Rate of application	Copper (Metallic)						Arsenious oxide					
		1		2		3		1		2		3	
Material		Per cent*	Mgm. per 100 sq. cm.	Per cent*	Mgm. per 100 sq. cm.	Per cent*	Mgm. per 100 sq. cm.	Per cent*	Mgm. per 100 sq. cm.	Per cent*	Mgm. per 100 sq. cm.	Per cent*	Mgm. per 100 sq. cm.
Bordeaux, 2-4—100	Light	0 04	0 11	0 17	0 73	0 12	0 52	0 04	0 12	0 08	0 33	0 07	0 31
Lead arsenate, 1—100	Moderate	0 07	0 23	0 12	0 48	0 08	0 36	0 07	0 22	0 09	0 34	0 07	0 32
	Heavy	0 23	0 76	0 30	1 26	0 14	0 63	0 10	0 35	0 15	0 63	0 08	0 40
Bordeaux, 6-12—100	Light	0 16	0 65	0 22	0 86	0 15	0 65	0 08	0 35	0 12	0 46	0 08	0 36
Lead arsenate, 3—100	Moderate	0 21	0 75	0 32	1 32	0 21	0 85	0 13	0 45	0 17	0 72	0 14	0 55
	Heavy	0 33	1 28	0 41	1 77	0 26	1 22	0 14	0 56	0 23	1 00	0 20	0 92

*This percentage is calculated from the total dry weight of the sample.

SUMMARY

An experiment with apples was conducted to determine the relation of the strength of the spraying material and the rate of application to the control of scab, foliage injury and russeting of the fruit. This report considers in detail only the results concerning scab control. These results are summarized in the following paragraphs:

A weak material is less effective than a strong for the control of scab, if the trees receive equal amounts of the diluted spray. Heavy applications are better than light when the concentration is uniform. A heavy application of weak material gives slightly better control than a light application of strong material but a moderate application of medium strength material is, all things considered, the best combination for average conditions.

There is a definite relation between the amounts of active ingredients applied and the control of scab attained. An increase in the amount, regardless of concentration or dosage, results in a smaller proportion of scabby apples, but increases beyond the optimum result in relatively small reductions in the amount of scab.

Labor and sprayer charges are the principal determining factors in the cost of spraying. Variations in the strength of the materials are relatively unimportant. It is obvious, then, that it is poor economy to make heavy applications of weak materials when equal or better results may be obtained with lighter applications of stronger materials.

Though many factors are involved in the control of apple scab, two stand out clearly as the result of these studies. Susceptible portions of the plant must be well covered with a film of spraying material and the concentration of the actual fungicidal material in this film must be optimum or greater. Incomplete coverage, regardless of concentration, or too low concentration with any degree of coverage, may result in unsatisfactory control. Poor coverage and low concentration together may be expected to give very unsatisfactory results.

Lime-sulphur and bordeaux are both effective in the control of scab, assuming a proper schedule and correct timing of applications, but, all things considered, lime-sulphur is preferable for average Michigan conditions. However, neither of these materials can be considered as ideal and any important advances in spraying must come through new materials or through the improvement of those now in use.

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