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Norman H. Grubb

To cite this article: Norman H. Grubb (1920) Tests of Fungicides on Apple Trees, Journal of Pomology and Horticultural Science, 2:2, 93-114, DOI: [10.1080/03683621.1920.11513237](https://doi.org/10.1080/03683621.1920.11513237)

To link to this article: <https://doi.org/10.1080/03683621.1920.11513237>

Published online: 07 Nov 2015.

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TESTS OF FUNGICIDES ON APPLE TREES

CARRIED OUT AT EAST MALLING RESEARCH STATION

By NORMAN H. GRUBB, M.S.A.

IN the spring of 1919, when the staff of the East Malling Research Station was enlarged after the war, it was found possible to begin a series of experiments for the control of scab and other fungi on apple trees. The work was begun at the suggestion of Mr. E. S. Salmon, of the South Eastern Agricultural College, to whom I am very much indebted for advice and help in arranging and carrying on the experiments. I am indebted also to Mr. J. Amos for undertaking a large part of the actual mixing and application of the sprays, and for much help in making observations on their effects; and to Dr. R. C. Knight for his help in the method of working out the "probable errors."

The object originally proposed as the basis of the work was the testing of the comparative value of various fungicides, their fungicidal power, and the extent of the injury they cause to the foliage and fruit of certain varieties of apples. After two years work a number of interesting results—some quite unexpected—have begun to appear. It seems advisable to report the results so far obtained in the hope that they may be checked and extended by other investigators and applied to other varieties and conditions.

It must be said at once that the results described in this report can be taken at most as indications. The only trees available for the experiments were a number of bush trees constituting a pruning experiment which has been under way since 1916; some of the trees were planted in 1913-14, and others in 1914-15, and they have thus had only seven and six years growth in place respectively, and are only now beginning to bear moderate crops.

Of the varieties of apples included in the plot, six are rather subject to scab, and were chosen as subjects for spraying tests. Of four of these—Cox, Allington, Bismarck and Newton, there are 32 trees each, of the other two—Worcester and Grieve, there are 64 each. But in each case half the trees are "leader-tipped" annually; many of these, as well as some of those not leader-tipped, have as yet borne only light crops or none

at all, and the tipped trees have been found to behave quite differently, as regards fungi and fungicides, from those not tipped. The number of trees of any one variety available for deductions is therefore small, and a good deal of further investigation will be needed before some of these results can be regarded as established.

Although different varieties behave rather differently towards scab and other fungi—some are much more easily and completely protected by spraying than others—several of the results are more or less corroborated by each variety independently. These results may certainly be regarded as more reliable. Others, again, are obtained independently in the two seasons (1919 and 1920), and these also are more worth consideration.

It has not been considered worth while in this preliminary report to give more than a few **“probable errors.”* The small number of trees concerned, coupled with their extreme irregularity in cropping, makes the probable errors in most cases absurdly large. It has therefore seemed more satisfactory merely to state the number of trees concerned as some guide to the reliability of the result.

In each lot of trees used for the experiments some were left unsprayed for “control” purposes; and it was carefully arranged that those trees not sprayed in 1919 were in 1920 divided as equally as possible into groups for the various spray mixtures and for “controls.” There are thus in each lot some trees that have been sprayed both years; others sprayed in 1919 and not in 1920; others again sprayed in 1920 and not in 1919; and still others not sprayed at all.

Considerable care was taken to arrange that the trees treated in any particular way were not consecutive in the rows, but were scattered about among trees treated in other ways.

The dates when the various spray mixtures were applied were as follows:—

1919—1st spraying, June 6th and 7th; 2nd—June 27th.

1920—1st spraying, May 14th, 15th, 17th, 20th;

2nd—June 17th and 18th.

In 1919 the first spraying was done ten days or more after the blossom had dropped, and the second about three weeks later. In 1920 the first

* The “probable error” gives the limits within which there is an even chance of the true result occurring. Thus if the result is 10 and the probable error 2 (written 10 ± 2) there is an even chance that the true result is between 8 and 12.

spraying followed immediately after the dropping of the last blossoms (Newton Wonder), and the second, about a month later. (The blossoming season in 1920 was some weeks earlier than in 1919). No spraying has been done before blossoming; this point is of some importance in connection with the effect on crop.

A number of fungicides have been tested; lime-sulphur, alone and in mixture with other materials, "Bordeaux" of two different formulæ, and ammonium polysulphide with soft soap. Comparisons have been obtained of the value of lime-sulphur and Bordeaux; lime-sulphur alone and in mixture with lead arsenate* or saponin (or "saponex"), lime-sulphur and ammonium polysulphide; and the two Bordeaux formulæ.

The effect of the fungicides is seen in several directions. That of most value to the grower is, of course, the reduction of fungus attacks, particularly apple scab (*Venturia inæqualis*), but also apple mildew (*Podosphaera leucotricha*), brown rot of the fruit (*Sclerotinia fructigena*), and common apple canker (*Nectria ditissima*). But there are other effects of hardly less importance—on the size of the fruit, for instance. The injury caused by certain fungicides, especially to certain varieties, is a serious matter to the grower, particularly when it is shown in a marked reduction of the crop. I propose to discuss these points in the order mentioned.

1.—SCAB OR BLACK SPOT (*Venturia inæqualis*).

SPRAYING *v.* NOT SPRAYING.

The effect of a single summer's spraying on the development of the scab fungus varies from one season to another, and also from one variety to another, as well as with the particular fungicide used, and with the time of application. It is seen most plainly, of course, on examination of the fruit at the time of picking; but it is also very noticeable during the summer on examination of leaf infections, and during the winter in the case of the infections on the wood (with those varieties susceptible to this injury).

Table I shows, for the two years separately, the percentage of fruit by number which was entirely free from scab. All the sprayed trees are considered together, regardless of the mixture used, and compared with those not sprayed. The grading was not done at all as it would be done

* The brand used was Swift's paste, and the strength 4 lbs. per 100 gallons.

for market; the fruit marked "clean" was in every case so far as could be seen quite free from scab, and all the rest was lumped together as "scabby." In 1919 especially, much of the "scabby" fruit could have been sold as first grade. In 1920 an attempt was made to separate the scabby fruit of Allington into two grades, "slight" and "bad," but the result does not seem to add much to the value of the figures, and is not shown in the tables.

TABLE I.—PERCENTAGE OF FRUIT CLEAN BY NUMBER.

	1919				1920			
	No. of Trees.	Sprayed.	No. of Trees.	Not sprayed.	No. of Trees.	Sprayed.	No. of Trees.	Not sprayed.
Untipped Trees.								
Grieve	16	76.6 ± 6.4	16	40.4 ± 10.7	24	77.2 ± 7.2	8	18.5 ± 9.9
Worcester ...	16	82.7 ± 7.8	16	20.9 ± 7.1	23	65.2 ± 5.8	9	21.9 ± 7.6
Cox	12	88.2	4	38.9	12	66.2	4	0
Allington ...	12	82.9	4	64.9	12	24.8	4	4.8
Bismarck ...	8	52.9	6	24.2	10	83.3	4	25.0
Newton	8	74.3	8	26.0	12	76.8	4	26.8
Tipped Trees.								
Grieve	20	95.1	12	100.0	24	96.2	8	36.0
Worcester ...	20	90.0	12	58.2	23	92.2	9	59.4
Cox	11	100.0	5	83.3	12	(71.4 little fruit).	4	(62.5 little fruit).
Allington ...	10	96.8	6	76.7	11	63.7	3	23.3
Bismarck ...	10	No crop.	6	No crop.	12	(100.0 little fruit)	4	(42.9 little fruit).
Newton	10	96.1	6	92.8	12	88.2	4	36.5

It will be seen that in every case but one (tipped trees of Grieve in 1919) there was a larger percentage of clean fruit on the sprayed trees than on those not sprayed. In most cases, especially on the untipped trees, and the tipped trees in 1920, the difference is very marked, much greater than could be accounted for by any experimental error, as is shown by the few probable errors given. This result, of course, merely confirms the results of previous experiments in many places, and is no more striking than has often been obtained by other investigators.

It is difficult to say anything definite as to the comparative susceptibility of the fruit of different varieties to scab. In 1920, of the varieties that cropped well (Cox and Bismarck had a very light crop) Allington was by far the most scabby, as will be seen from the table. But in 1919, Allington was one of the least scabby; which seems to suggest that the incidence of the disease on different varieties

may differ from season to season. Much more work will be needed before definite data on this point can be gathered.

The table does not well show a point that was noticed in each year—that James Grieve seems to be more easily and completely protected from scab by spraying than any of the other varieties. This is more noticeable when one considers the cumulative effect of spraying, and will be referred to again below.

In studying the scab on the leaves and wood it was naturally found difficult to obtain any definite figures to show the severity of the attack. After close observation it was found possible to estimate the amount of scab on each tree, and assign to each a figure from 0 to 5, 0 being quite free from scab, and 5 the severest attack of all.

It is obvious that this method will give no more than an indication; and the more so, as it is very difficult to maintain the same standard in observations made at intervals of some weeks or months, and nearly impossible for two observers to agree as to a standard. But the effect of the spraying on both leaf and wood infections, as compared with the unsprayed trees, was too obvious to be missed even by a casual observer. Observations on these infections were made, as far as the leaves were concerned, only in 1919; on the wood infections in both years. Table II shows the results obtained.

TABLE II.

	Leaf Infections, 1919.				Wood Infections, 1919.				Wood Infections, 1920.			
	No. of Trees.	Sprayed.	No. of Trees.	Not sprayed.	No. of Trees.	Sprayed.	No. of Trees.	Not sprayed.	No. of Trees.	Sprayed.	No. of Trees.	Not sprayed.
Untipped Trees.												
Grieve	16	1'06	16	3'00	16	0'43	16	2'43	24	1'21	8	3'5
Worcester	16	1'37	16	4'44	—	—	—	—	23	0'65	9	2'44
Cox	12	0'83	4	2'50	12	1'58	4	4'00	12	2'58	4	3'75
Allington	12	1'92	4	3'00	12	0'33	4	0'50	12	0'08	4	1'00
Bismarck	8	2'37	6	4'83	—	—	—	—	12	—	4	Trace on 1 or 2 trees.
Newton	8	2'37	8	4'37	—	—	—	—	12	—	4	ditto
Tipped Trees.												
Grieve	20	0'45	11	0'73	—	—	—	—	23	1'09	8	3'25
Worcester	20	0'50	12	3'25	—	—	—	—	23	0'65	9	1'89
Cox	11	0'10	5	1'20	—	—	—	—	12	1'67	4	3'25
Allington	10	0'30	6	1'83	—	—	—	—	11	0'27	5	1'20
Bismarck	10	0'30	6	0'67	—	—	—	—	—	—	—	—
Newton	10	0'60	6	1'33	—	—	—	—	—	—	—	—

COMPARISON OF FUNGICIDES.

The comparative value of different fungicides for the control of Apple scab has been frequently investigated. Our results to a large extent confirm those obtained by previous investigators, and, as a whole, are fairly consistent. A few of our results, as far as I know, are new, such as those obtained by the use of ammonium polysulphide.

Two different formulæ were used in making Bordeaux mixtures; the ordinary or "equal lime" Bordeaux, 8-lbs. copper sulphate, 8-lbs. lime, 100 gallons water, called "8-8-100"; and the "excess lime" Bordeaux, with about three times this proportion of lime. In 1919 this was used at $7\frac{1}{2}$ -25-100, in comparison with 8-8-100; and in 1920 only the excess lime formula was used, at 8-25-100. Their chief interest in comparison is in the amount of "Bordeaux injury" they cause; as fungicides they appear to have practically identical effects, the average percentage of clean fruit of four varieties differing in the case of the untipped trees by 0.3 per cent., and only by 0.2 per cent. in the case of the tipped trees. The average is so nearly the same that for purposes of comparison with other fungicides the two formulæ may be taken together. It may be remarked here that the average crop per tree was also practically identical whichever formula was used.

A comparison of Bordeaux and lime-sulphur for the control of scab was obtained on four varieties in 1919 and three varieties in 1920. Lime-sulphur (a commercial brand) was used on Worcester and Bismarck at 1:30 in 1919 and 1:29 in 1920; on Grieve and Newton at 1:60 in 1919 and 1:59 in 1920. Table III shows the results.

TABLE III.—PERCENTAGE OF FRUIT CLEAN BY NUMBER.

	1919				1920			
	No. of Trees.	Lime Sulphur.	No. of Trees.	Bordeaux.	No. of Trees.	Lime Sulphur.	No. of Trees.	Bordeaux.
Untipped Trees.								
Grieve	4	83.3	12	74.4	12	67.4 ± 11.9	12	82.1 ± 6.13
Worcester ...	4	75.0	12	84.0	12	66.2	0	—
Bismarck ...	2	50.0	6	58.3	5	No fruit	5	83.3
Newton	2	66.7	6	76.9	6	67.9 ± 5.8	6	83.4 ± 6.4
Tipped Trees.								
Grieve	6	100	14	93.0	11	100	12	94.9
Worcester ...	6	72.2	14	95.1	11	86.9	0	—
Bismarck ...	3	No fruit	7	No fruit	6	No fruit	6	100
Newton	3	100	7	96.8	6	80.2	6	92.2

In spite of irregularities, there can be little doubt that Bordeaux has kept the scab more completely in check than lime-sulphur. Against this one has to reckon the frequent reduction in value of the fruit by Bordeaux injury, "russetting"; but this is much more than balanced by the heavier crop of the trees sprayed with Bordeaux. Both these subjects will be dealt with presently.

Ammonium polysulphide was used in comparison with lime-sulphur on the untipped trees of Allington and Cox in 1919. The result is shown in Table IV.

TABLE IV.—PERCENTAGE OF FRUIT CLEAN BY NUMBER.

Untipped Trees. 1919	No. of Trees.	Lime Sulphur 1:60.	No. of Trees.	Ammonium Polysulphide 1:100 + soap 1%
Cox	4	91.7	4	86.4
Allington	4	89.8	4	78.0
Both	8	90.7 ± 2.8	8	82.0 ± 3.4

In each case the ammonium polysulphide was slightly less effective than the lime-sulphur. But this appears to have been much more than balanced by the far heavier crop of the trees sprayed with A.P.S. (see Table X below).

VALUE OF SPREADERS.

The value of "spreaders" and other substances used in mixture with lime-sulphur has not yet been tested fully enough to give definite results. Saponin was used with lime-sulphur in 1919 on the untipped trees of Allington and Cox; while "Saponex" was tested on Worcester and Allington in 1920. Lead arsenate was used with lime-sulphur on Cox in 1920; but the crop was so small that the results are of doubtful value and are not given. The results obtained with spreaders as regards scab on the fruit are shown in table V (the tipped trees are omitted as they give substantially the same result).

TABLE V.—PERCENTAGE OF FRUIT CLEAN BY NUMBER.

Untipped Trees 1919	No. of Trees.	Lime-Sulphur 1:60.	No. of Trees.	Lime-Sulphur and Saponin 1%
Cox	4	91.7	4	88.9
Allington	4	89.8	4	88.3
Both	8	90.7 ± 2.8	8	88.6 ± 5.1

TABLE V.—Continued.

Untipped Trees. 1920	No. of Trees.	Lime-Sulphur.	No. of Trees.	Lime-Sulphur and "Saponex."
Worcester	12	66.2 ± 7.4	11	64.1 ± 6.4
Allington	5	24.6	7	24.9

It seems clear at least that the spreader (saponin and "saponex") did not greatly increase the value of lime-sulphur as a preventive of scab, and it may even have slightly reduced it. As will be seen later, the spreader does seem to have increased lime-sulphur's effectiveness against mildew; and the crop, especially on the tipped trees, was heavier where it was used.

The effect of particular fungicides on wood infections of scab was observed at the time when the figures in table II were obtained. In general it may be said that the results go to confirm the comparative value of the fungicides as shown by the scab on the fruit; Bordeaux is considerably more effective than lime-sulphur; and while saponin and "saponex" failed to make lime-sulphur more effective, lead arsenate considerably increased its action as a "scabicide." Ammonium polysulphide was considerably less effective than lime-sulphur.

2.—APPLE MILDEW. (*Podosphaera leucotricha*).

The effect of the fungicides on Apple mildew was observed by counting the number of *wood* infections. The counting was done at the time when the infections were cut out; those from the summer of 1919 were not removed until after growth started in 1920; while the 1920 infections were removed soon after leaf fall. The results for the two years are thus not strictly comparable. No attempt was made when removing the 1919 infections to count leaf infections; or in the following winter to count infections of terminal buds. It was quite clear that these (terminal bud infections) were very numerous; but such a large proportion of them are doubtful that the only way to arrive at their number even approximately is to allow them to grow out in the spring before counting them.

The figures given in table VI, then, refer only to wood infections. These vary (in winter) from a very slight infection just behind the

terminal bud to a complete infection of a whole shoot, which usually dies before growth starts in the spring. Table VI shows the effect of all the fungicides used in both years; the effect of the two Bordeaux formulæ, however, was so nearly the same that they are not shown separately. The tipped trees had so few infections in 1919 that they are omitted; Worcester Pearmain, also, is so little susceptible to the disease that it is not worth while to include it.

TABLE VI.—AVERAGE NUMBER OF WOOD INFECTIONS OF MILDEW.

Untipped Trees. 1919		No. of Trees.	Lime- Sulphur.	No. of Trees.	Bordeaux.	No. of Trees.	Not Sprayed.	
Grieve		4	3.7	12	7.4	16	9.6	
Bismarck		2	37.0	6	76.8	6	75.8	
Newton		2	8.0	6	24.5	8	26.5	
Average (one tree each var.)		8	15.2	24	36.2	30	37.3	
Untipped Trees. 1920		No. of Trees.	Lime- Sulphur.	No. of Trees.	Bordeaux.	No. of Trees.	Not Sprayed.	
Grieve.....		12	6.8 ± 2.5	12	11.2 ± 2.7	8	17.9 ± 6.1	
Bismarck		5	45.6	5	57.0	4	75.5	
Newton		6	9.8	6	14.7	4	17.5	
Average (one tree each var.)		23	20.7	23	27.6	16	36.7	
Tipped Trees. 1920		No. of Trees.	Lime- Sulphur.	No. of Trees.	Bordeaux.	No. of Trees.	Not Sprayed.	
Grieve.....		11	1.5	12	2.7	8	3.7	
Bismarck		6	9.5	6	17.3	4	14.7	
Newton		6	2.3	6	4.7	4	6.5	
Average		23	4.3	24	6.6	16	8.3	
Untipped Trees. 1919	No. of Trees	Lime- Sulphur.	No. of Trees	Lime-Sulphur and Saponin.	No. of Trees	A.P.S.	No. of Trees	Not Sprayed.
Cox	4	27.5	4	21.0	4	12.2	4	55.5
Allington.....	4	38.5	4	33.2	4	23.2	4	40.0
Average	8	33.0 ± 6.4	8	27.1 ± 9.1	8	17.7 ± 4.5	8	47.7 ± 14.5
1920		No. of Trees	Lime- Sulphur.	No. of Trees.	Lime-Sulphur and Saponex	No. of Trees.	Not Sprayed	
Allington, <i>untipped</i>		5	36.8	7	24.9	4	48.0	
,, <i>tipped</i>		6	11.0	5	10.2	5	23.8	
1920		No. of Trees.	Lime- Sulphur.	No. of Trees.	Lime-Sulphur and Lead Arsenate.	No. of Trees.	Not Sprayed.	
Cox, <i>untipped</i>		6	14.3	6	24.3	4	38.0	
,, <i>tipped</i>		6	5.2	6	7.0	4	15.7	

The table seems to indicate :—

- (1) That Bordeaux has at best only a slight influence on the mildew.
- (2) That while lime-sulphur alone appreciably reduces the disease, its effect is increased by the use of a spreader.
- (3) That lead arsenate may reduce the value of lime-sulphur in the control of mildew, and
- (4) That ammonium polysulphide with soap is probably the most effective fungicide against mildew of all those tested.

3.—OTHER DISEASES.

The effect of fungicides on diseases other than scab and mildew (except canker) has not yet been carefully observed. In the autumn of 1920 it was quite evident that the fruit from the sprayed trees was keeping better than that from the trees not sprayed. This was particularly noticeable in the case of Allington; practically all the fruit found rotten at the time of picking was on the unsprayed trees. But the number was not great enough to be at once evident, and no records were made. Some of the fruit from the sprayed trees of Newton and some from the unsprayed trees was stored for a few weeks separately, and there was obviously much less rot in the sprayed fruit. But here again no records were kept, owing to the small quantity stored.

In studying canker it was found that only two varieties, Worcester and Grieve, were enough affected to give any definite results; and even of Grieve many trees were entirely free from canker, and the results, though definite, are thus not very reliable. No attempt was made in 1919 to discover whether the spraying had affected the canker; but as many of the 1919 infections persisted for more than a year (those few that died out were easily seen), a rough classification in 1920 into "old" and "new" infections gave results applicable to both years.

In studying the new infections in December, 1920, it was found that those trees which had no "old" infections were in practically every case free also from "new" infections. It should be said that the infections classified as "new" were mainly bud infections, sometimes through axillary buds on the new shoots, more often through fruit buds, either terminal or on spurs. A large number of new infections were found also

at the base or "collar" of the 1920 shoots, especially where these had borne fruit on the terminal bud formed in 1919, the infection in that case being apparently through the fruit scar. Wherever any considerable number of new infections was found one could be practically certain of finding an old infection close by, generally just above the new ones. And on the unsprayed trees, wherever an old infection was found, one could always find a considerable number of new infections just below it.

This relative position on the trees of the old and new infections appears to be seasonal. Hardly any new infections were found in the upper parts of the trees, yet the old infections which could be said with any certainty to be 1919 bud infections were nearly all towards the tops of the trees.

One other observation not connected with the effect of spraying must be mentioned. Of several hundred infections of canker cut out and counted, not a single one could be recognised as a wound infection. It is possible that one or two of the old infections on the larger branches of James Grieve may have started from wounds; but the proportion was in any case very small, and it is practically certain that there was not a single wound infection on any of the Worcesters.

This gives an interesting confirmation of the observations made by Mr. S. P. Wiltshire (recorded in the Annual Report for 1919, of the Agricultural and Horticultural Research Station at Long Ashton). This complete absence of wound infections may, of course, be exceptional, but it seems fairly certain that in our conditions (or perhaps in seasons like that of 1920) young trees of Grieve and Worcester are very little, if at all, subject to canker infection through wounds.

Table VII shows the relation between the spraying and the number of canker infections found, the "old" infections being, of course, related to the 1919 spraying and the "new" to the 1920, and also the proportion between the "old" and "new" infections in relation to the 1920 spraying.

TABLE VII.—AVERAGE NUMBER OF CANKER INFECTIONS.

Treatment in 1919.

	No. of Tree.	Lime-Sulphur.	No. of Trees.	Bordeaux.	No. of Trees.	Not sprayed.
Grieve	4	0.5	12	1.2	16	2.1
Worcester	4	7.5	12	0.8	16	7.4

TABLE VII.—Continued.

Treatment in 1920.						
	No. of Trees.	Lime-Sulphur.	No. of Trees.	Bordeaux.	No. of Trees	Not sprayed.
Grieve	12	2·7	12	3·1	8	8·6
		Lime Sulphur.		Lime-Sulphur & Saponex.		Not sprayed.
Worcester	12	4·5	11	2·7	9	36·4

Proportion "Old" to "New" Infections, 1920.

	No. of Trees.	Lime-Sulphur.	No. of Trees.	Bordeaux.	No. of Trees.	Not sprayed.
Grieve	12	1 : 6·20	12	1 : 1·23	8	1 : 4·31
				Lime-Sulphur & Saponex.		
Worcester	12	1 : 0·95	11	1 : 0·83	9	1 : 4·97

Worcester shows the effect of spraying in 1920 much more plainly than Grieve; of the latter so few trees were affected at all and the infections were so irregular, that it was a surprise to find any indications of an effect of spraying.

The large average number of "new" infections on the trees of Worcester not sprayed in 1920 is partly due to a single tree, which had almost 200; but even if this is omitted the average is still 16·5, between four and five times the average of the sprayed trees. The proportion between "old" and "new" infections (in the case of Worcester) gives perhaps the best indication of the effect of spraying. It shows that where the trees were sprayed, the presence of an old spore-producing infection has led to less than one-fifth as many new bud infections as where they were not sprayed.¹

Nothing of any value can be deduced regarding the effects of the different spray mixtures. It may be that the "saponex" has slightly increased the effectiveness of the lime-sulphur in 1920, but a much longer series of experiments would be needed to confirm this.

It is somewhat difficult to understand how this effect of the spraying on the bud infections of canker is brought about; and the same difficulty occurs in connection with the scab infections on the wood, most of which are towards the tips of long shoots, on wood formed at least as late as

¹ It is not intended, of course, to suggest that spraying may make it unnecessary to cut out the canker from diseased trees; the knife will still be the most effective cure.

August. The slightly greater vigour of the sprayed trees would, no doubt, have some influence; but it is hard to believe that there is not some much more direct action of the fungicide than this.

SIZE OF FRUIT.

An effect often observed in fungicide spraying experiments is an increase in the size of the sprayed fruit. It has long been known that scabby fruit tends to be smaller than clean fruit, owing no doubt to the check caused by the fungus to the swelling of the fruit. But we now find that the clean fruit on the sprayed trees is usually larger than the clean fruit on the trees not sprayed, and similarly with the scabby fruit. This effect is presumably closely connected with the increased vigour and later leaf fall of the sprayed trees.

Table VIII shows the average weight of the clean and scabby fruit separately from the sprayed and unsprayed trees; only the figures from the untipped trees are given, for although similar figures were obtained from the tipped trees, the spraying had so frequently reduced their total crop that this alone would account for the greater size of the sprayed fruit.

TABLE VIII.—AVERAGE WEIGHT OF FRUIT IN OUNCES.

Untipped Trees.	1919				1920			
	Clean.		Scabby.		Clean.		Scabby.	
	Sprayed.	Not sprayed.	Sprayed.	Not sprayed.	Sprayed.	Not sprayed.	Sprayed.	Not sprayed.
Grieve	3·70	3·47	3·74	3·23	3·77	3·30	3·60	3·50
Worcester ..	2·48	2·42	2·00	2·40	1·80	1·96	2·25	2·01
Cox	2·80	2·29	2·58	2·13	2·76	None	2·89	2·57
Allington ...	2·53	1·83	2·39	1·86	3·67	2·76	3·00	2·63
Bismarck ...	4·78	3·80	4·29	3·08	6·36	4·50	None	4·33
Newton.....	4·25	3·37	4·75	3·26	3·92	3·54	3·54	3·45

The average increase in 1919 was almost $\frac{3}{5}$ -oz. and in 1920 nearly $\frac{2}{5}$ -oz., too considerable an amount to be ignored. And it occurs in every case with both clean and scabby fruit in each year, except with Worcester Pearmain. It is worth noting that the clean fruit of Worcester averages no bigger than the scabby fruit; Worcester, in fact, seems to be an exception to the rule. The same thing will be seen in Table XIV, where the cumulative effect of spraying on the size of the fruit is shown; it can hardly be merely accidental.

A curious observation may be mentioned here, since it is rather in line with the increase in size of fruit due to spraying. It was found that the new shoots of Bismarck and Allington, and possibly other varieties, are stouter on the sprayed trees. With the varieties named the difference is very striking and unmistakable to any trained eye. No attempt has yet been made to obtain figures showing this difference; it is possible that the weight of prunings may give some indication of it.

SPRAY INJURY.

Many varieties of apples have long been known to be subject to injury by various copper sulphate sprays, "Bordeaux" and "Burgundy" mixtures, where copper sulphate is used either with lime or with washing soda.* Some of the same varieties, and others, are equally subject to injury by lime-sulphur, and possibly other sulphide sprays. "Bordeaux injury" is seen partly in leaf fall, which usually follows within a few days or weeks after the spraying; and partly in a marking or "russetting" of the fruit, very noticeable at picking time, which greatly reduces the value of the crop. Lime-sulphur injury is also seen partly in leaf fall, but still more in a marked reduction of the crop. It seems likely that most varieties are more or less subject to this reduction when sprayed with lime-sulphur, some very much more than others; it appears to take place in June and July, the "June-drop" on trees sprayed with lime-sulphur being heavier than on those sprayed with Bordeaux, and in some cases than on those not sprayed at all.

1.—BORDEAUX INJURY.

It has been found in Canada and the United States that a large excess of lime in Bordeaux greatly reduces the injury. As explained above, two formulæ were used in comparison in 1919, "equal lime," 8-lbs. copper sulphate, 8-lbs. lime to 100 gallons water (8-8-100) and "excess lime" 7½-25-100. In 1920 only the "excess lime" formula was used, altered to 8-25-100. These mixtures were used on 4 varieties in 1919 and on 3 varieties in 1920.

* So far as I know, Burgundy mixture has never been used on apples in this country. It was extensively used in the United States and Canada in 1904 and 1905, but was soon abandoned on account of the serious injury it caused.

Since the 8-25-100 formula used in 1920 led to considerable injury, it is proposed in future experiments to reduce the strength to 6-20-100, in the hope that the great fungicidal effect may be obtained without risk of either Bordeaux injury or the reduction of crop due to lime-sulphur.

In 1919, though no careful estimate of the amount of injury was made, it was quite plain that both leaf fall and marking of the fruit were much greater where the old formula 8-8-100 was used. This was certainly the case with Grieve and Worcester, and also with Allington as far as leaf fall was concerned (there was hardly any fruit on the tipped Allingtons, the only ones sprayed with Bordeaux). It was scarcely noticeable with Bismarck, and only slightly so with Newton, and consisted mainly of a slight discolouration of the fruit caused by the "equal lime" mixture. The "excess lime" formula caused in 1919 comparatively little leaf fall, and not enough injury to the fruit, even of James Grieve, to reduce its value appreciably.

In 1920 the formula 8-25-100 was tested in comparison with lime-sulphur on Grieve, Bismarck and Newton. Scarcely any leaf fall was noticed on any of the three varieties, and of Bismarck there was not enough fruit to allow of any observations. The fruit of Grieve, however, was badly marked, scarcely a single fruit on the Bordeaux sprayed trees being quite free from russetting; and it was clear that the market value of the fruit was considerably reduced. (As will be seen later, on the untipped trees this was much more than counterbalanced by the heavier crop of the Bordeaux sprayed trees). Even Newton Wonder was by no means free from russetting of the fruit, which was more noticeable on the untipped than the tipped trees. Even those fruits which were not much russeted appeared to have rather an unnatural bluish-green colour, which might considerably reduce their value on the market. No facilities for the proper storing of the fruit were available, and it was thus impossible to watch the change of colouring during ripening.

2.—EFFECT ON CROP.

Table IX shows the average crop per tree sprayed with lime-sulphur, as compared with those sprayed with Bordeaux and those not sprayed. The "tipped" and "untipped" trees are shown separately, and the results, as will be seen, are clearly affected by the tipping.

TABLE IX.

	Average Crop per Tree. Effect of Lime-Sulphur and Bordeaux.								
	Lime-Sulphur.			Bordeaux.			Not sprayed.		
	No. of Trees.	No. of Fruits.	Weight.	No. of Trees.	No. of Fruits.	Weight.	No. of Trees.	No. of Fruits.	Weight.
Untipped, 1919.			lbs. ozs.			lbs. ozs.			lbs. ozs.
Grieve	4	13½	3 4½	12	13½	3 0½	16	11½	2 6
Worcester	4	5	0 11½	12	9½	1 7	16	9	1 6
Cox	4	30	5 7½	—	—	—	4	28	3 14
Allington	4	36½	6 3½	—	—	—	4	60½	7 0
Bismarck	2	2	0 8	6	2	0 9½	6	10	2 1½
Newton	2	1½	0 5	6	11	2 15½	8	9	1 14
Av. 4 varieties (Grieve, Worc., Bism., Newton).	12	5½	1 3	36	9	2 0	46	10	1 15
Untipped, 1920.									
Grieve	12	11½	2 13½	12	23½	5 8½	8	6½	1 7½
Worcester	12	55	6 9	—	—	—	9	58	7 4½
Cox	6	5½	0 15½	—	—	—	4	1½	0 4½
Allington	5	81	16 5½	—	—	—	4	91½	15 0
Bismarck	5	None	None	5	4½	1 3	4	2	0 8½
Newton	6	71	16 7	6	95	22 12	14	96½	20 8
Av. 3 varieties (Grieve, Bism., Newton).	23	27½	6 7	23	41	9 13	16	35	7 8
Tipped, 1919.									
Grieve	6	1	0 4	14	4	1 3½	11	5½	1 8½
Worcester	6	3	0 7½	14	4½	0 10	12	5½	0 14½
Cox	10	2	0 9½	—	—	—	5	7	1 7
Allington	—	—	—	10	6	1 7	6	7	1 6
Newton	3	4½	1 12	7	18	6 5½	6	14	4 14
Av. 3 varieties (Grieve, Worc., Newton).	15	3	0 13	35	8½	2 12	29	8½	2 7
Tipped, 1920.									
Grieve	11	½	0 3	12	3	0 13½	8	3	0 10½
Worcester	11	2	0 5½	—	—	—	9	7	1 5
Cox	6	½	0 0½	—	—	—	4	2	0 7½
Allington	6	8½	2 2½	—	—	—	5	23	5 8
Bismarck	6	½	0 1	6	2	0 14	4	3½	1 6½
Newton	6	20	6 6	6	41	14 11	4	63	15 10
Av. 3 varieties (Grieve, Bism., Newton).	23	7	2 3	24	15½	5 7½	16	23	5 14½

On the untipped trees the only case where lime-sulphur gave a higher average crop than Bordeaux (by weight though not by number), was James Grieve in 1919. In every other case where the two fungicides were compared the Bordeaux sprayed trees had more fruit, in one case (Bismarck, 1919) by weight only, in every other case by number as well as weight.

As compared with the trees not sprayed, those sprayed with lime-sulphur had in some cases more fruit, in others less. It is, I think, clear that this is mainly a matter of variety; with some varieties, such as Grieve and Cox, the scab on the unsprayed trees has reduced the crop more than the lime-sulphur. This is borne out, as will be seen, by the tipped trees, which are found to be much more resistant to scab, and in *every* case have borne more fruit where not sprayed than where sprayed with lime-sulphur. Some of the yields are, of course, absurdly small—*e.g.*, one fruit from six trees of Cox and Bismarck; but they are worth giving as showing the uniformity of the effect.

This greater resistance of the tipped trees to scab is no doubt due to two causes. In the first place the pruning removes a large number of sources of infection (from those varieties whose wood is infected by scab); while in the second place, the greater vigour of the tipped trees might be expected to produce a thicker and more resistant cuticle on the leaves and fruit. Since varieties like Newton and Bismarck, which show barely a trace of scab on the wood, behave in the same way as the others, it seems likely that the second cause is the more important of the two.

The Bordeaux, as would be expected, seems generally to have increased the crop of the untipped trees as compared with those not sprayed. But when one comes to the tipped trees the effect, if any, is reversed. It seems possible that in the case of the tipped Newtons in 1920 the Bordeaux may actually have reduced the crop slightly; but the result needs confirmation before any reliance can be placed on it.

Table X shows the average crop as affected by lime-sulphur, lime-sulphur with spreader, and Ammonium polysulphide.

TABLE X.—AVERAGE CROP PER TREE, EFFECT OF SPREADERS, ETC.,
AND A.P.S.

	Lime-Sulphur.			Amm. Polysulphide.			Not sprayed.		
	No. of Trees.	No. of Fruits.	Weight.	No. of Trees.	No. of Fruits.	Weight.	No. of Trees.	No. of Fruits.	Weight.
			lbs. ozs.			lbs. ozs.			lbs. ozs.
Untipped, 1919.									
Cox	4	30.0	5 7½	4	73.5	12 5½	4	28.0	3 14
Allington	4	36.5	6 3½	4	81.5	11 11½	4	60½	7 0
Both	8	33.5	5 13½	8	77.5	12 0½	8	44.0	5 7

TABLE X.—Continued.

	Lime-Sulphur.			Lime-Sul. & "Saponex."			Not sprayed.		
	No. of Trees.	No. of Fruits.	Weight.	No. of Trees.	No. of Fruits.	Weight.	No. of Trees.	No. of Fruits.	Weight.
			lbs. ozs.			lbs. ozs.			lbs. ozs.
Untipped, 1920.									
Worcester	12	55.5	6 9	11	64.0	7 2½	9	58.0	7 4½
Allington	5	81.0	16 5½	7	88.5	17 1	4	91.5	15 0
Both	17	68.0	11 7½	18	76.0	12 1½	13	75.0	11 2½
(1 tree each).									
Tipped, 1920.									
Worcester	11	2.0	0 5½	12	4.5	0 12½	9	7.0	1 .5
Allington	6	8.5	2 2½	5	20.0	5 6	5	23.0	5 8
Both	17	5.0	1 4	17	12.0	3 1	14	15.0	3 6½
(1 tree each).									

The most interesting point is the very heavy crop of the trees sprayed with Ammonium polysulphide in 1919. Their number is, of course, too small to allow of a reliable result; and since no tipped trees were included and none sprayed with Bordeaux for comparison, it is difficult to judge whether Ammonium polysulphide has actually increased the crop or not; but it seems fairly certain that it has less injurious effect than lime-sulphur.

The saponin used with lime-sulphur in 1919 did not appear to reduce this injury, though here again no tipped trees were treated. In 1920, however, the "saponex" does seem to have reduced the injury, especially on the tipped trees. As we saw above, the saponex did not appreciably increase the "scabicide" effect of the lime-sulphur; thus the reduction of injury following its use can hardly have been due to the greater freedom of the trees from scab. The use of lead arsenate with lime-sulphur must be further tested before any definite statement about it can be made.

CUMULATIVE EFFECT.

It seems natural to expect that trees sprayed with fungicides year after year will be freer from fungus diseases than trees sprayed in the current year, but previously left unsprayed; yet little, if any, definite evidence on this point seems to have been hitherto published. As a matter of fact, the evidence here given was obtained incidentally, as a result of portioning out the "control" trees of 1919 among the various treatments in 1920.

The cumulative effect is plainly seen on the untipped trees of all varieties in the proportion of clean and scabby fruit, and is more or less visible in the average crop per tree, especially of the tipped trees. There are indications, as will be seen, that it extends even to a difference in 1920 between the trees sprayed with lime-sulphur and those sprayed with Bordeaux in 1919.

In the tables showing "cumulative effect" (Tables XI—XIII), column 1 should be compared with column 2, and 3 with 4. The treatment of the trees represented in columns 1 and 2 on the one hand, and 3 and 4 on the other, was the same in 1920, and differed only in 1919.

Table XI shows the percentage by number of fruits free from scab in the various groups.

TABLE XI.—PERCENTAGE CLEAN BY NUMBER.

	No. of Trees.	Sprayed, 1919. Sprayed, 1920.	No. of Trees	Not spray- ed, 1919. Sprayed, 1920.	No. of Trees	Sprayed, 1919. Not spray- ed, 1920.	No. of Trees.	Not spray- ed, 1919. Not spray- ed, 1920.
Untipped Trees.								
Grieve	12	81.1	12	66.1	4	20.0	4	0.0
Worcester.....	11	73.8	12	53.9	5	30.6	4	13.2
Allington.....	9	27.7	3	17.6	3	5.2	1	4.4
Newton	6	79.6	6	73.4	2	24.6	2	28.2
Av. (1 tree of each)	38	65.5	33	52.7	14	20.1	11	12.4
Tipped Trees.								
Allington.....	7	69.1	4	53.1	3	24.0	2	20.7
Newton	8	90.2	4	86.2	2	40.6	2	34.9

Newton Wonder and Allington alone among the six varieties bore any considerable crop on the tipped trees (as will be seen in Table XIII), and these bear out the result; of the others many trees had no crop at all; and Cox and Bismarck are omitted throughout because they had so little fruit.

It is noticeable that the untipped trees of James Grieve show the cumulative effect much more plainly than any other variety. Grieve, in fact, seems to be more easily and completely protected from scab by spraying than any of the other varieties.

Table XII shows the average crop (number and weight of fruit) in 1920 as influenced by the spraying in 1919.

TABLE XII.—AVERAGE CROP PER TREE—CUMULATIVE EFFECT.

	Sprayed, 1919. Sprayed, 1920.			Not sprayed, 1919. Sprayed, 1920.			Sprayed, 1919. Not sprayed, 1920.			Not sprayed, 1919. Not sprayed, 1920.		
	No. of Trees.	No. of Fruits	Weight.	No. of Trees.	No. of Fruits.	Weight.	No. of Trees.	No. of Fruits.	Weight.	No. of Trees.	No. of Fruits.	Weight.
Untipped Trees.			lbs. ozs.			lbs. ozs.			lbs. ozs.			lbs. ozs.
Grieve.....	12	26'4	6 4½	12	9'1	2 2½	4	12'5	2 11½	4	1'0	0 3½
Worcester	11	70'0	7 14	12	49'0	5 13	5	53'0	6 15	4	64'5	7 10½
Allington	9	82'7	16 10	3	93'3	17 3	3	61'3	11 4	*(1	182'0	26 4)
Newton	6	92'3	22 0	6	73'8	17 2	2	77'5	18 12½	2	115'5	22 4
Av.(1 tree of each)	38	67'8	13 3	33	56'3	10 9	14	51'1	9 14½	*(11	90'7	14 1½)
Tipped Trees.												
Grieve.....	16	2'4	0 10½	7	2'1	0 8½	4	3'2	0 10	4	3'0	0 11
Worcester	15	3'1	0 9	8	3'7	0 9½	5	6'4	1 2½	4	7'7	1 6½
Allington	7	14'1	3 12½	4	12'7	3 5½	3	18'0	4 11	2	31'0	6 11½
Newton	8	23'1	8 7½	4	47'0	14 14	2	58'0	16 3½	2	80'5	16 9½
Av.(1 tree of each)	46	10'7	3 6	23	16'6	4 13½	14	21'4	5 11	12	30'3	6 5½

* The heavy crop of the single untipped tree of Allington not sprayed in either year is probably accidental; and it of course affects the average of the four varieties. The table is at best somewhat unsatisfactory, since both lime-sulphur and Bordeaux are concerned in the result, and we have already seen that they probably have very different effects on the crop. The fact that the tipped trees show the heaviest average crop on the trees not sprayed at all, and the least on the trees sprayed both years, may simply indicate that the effect of the lime-sulphur in reducing the crop outweighs the effect of the Bordeaux and other mixtures.

Owing to the variety of treatments employed, the number of trees is not really great enough to allow of comparing any possible cumulative effect of lime-sulphur as against Bordeaux individually—*i.e.*, a possible effect on the fruit of 1920 of the lime-sulphur and Bordeaux used in 1919. However, by taking three varieties together an indication of some slight effect in this direction may be seen. Of those trees sprayed in 1920 with lime-sulphur, 5 which were sprayed in 1919 with lime-sulphur bore (in 1920) an average of 9-lbs. of fruit, 67 per cent. clean by number; while 15 of them sprayed in 1919 with Bordeaux bore an average of 12-lbs. 11-oz. of fruit, 75·3 per cent. clean by number. The trees sprayed in 1920 with Bordeaux confirm this result; 4 of them sprayed in 1919 with lime-sulphur bore an average of 10-lbs. 2-oz. of fruit, 82·3 per cent. clean; and 8 of them sprayed in 1919 with Bordeaux bore an average of 11-lbs. 1-oz. of fruit, 88·9 per cent. clean.

The average weight of the fruit, as influenced in 1920 by the treatment in 1919, is shown in Table XIII.

TABLE XIII.—AVERAGE WEIGHT OF FRUIT, OUNCES.

	Sprayed, 1919. Sprayed, 1920.	Not sprayed, 1919. Sprayed, 1920.	Sprayed, 1919. Not sprayed, 1920.	Not sprayed, 1919. Not sprayed, 1920.
	Clean Fruit.		Scabby Fruit.	
Untipped Trees.				
Grieve	3·82	3·61	3·46	3·50
Worcester	1·75	1·74	2·09	1·94
Allington	3·70	3·54	2·96	2·32
Newton	3·99	3·84	4·06	3·03
Average	3·31	3·18	3·39	2·70
Tipped Trees.				
Grieve	4·44	3·93	3·00	3·17
Worcester	2·79	2·46	2·95	3·29
Allington	4·69	4·15	4·18	3·48
Newton	5·91	5·28	4·57	3·43
Average	4·46	3·95	3·67	3·34

There seem to be at least some indications that the spraying has progressively increased the size of the fruit. This could only partially be accounted for by the difference in the crop; for, as we have already seen (Table VIII) even where the spraying increases the crop, it usually at the same time increases the size of the fruit except in the case of Worcester.

The effect on Worcester is not well shown in the Table. The effect was reversed in the case of the scabby fruit from the trees sprayed in 1920 (columns 1 and 2), and the clean fruit from the unsprayed trees (columns 3 and 4), while all the other varieties showed the same tendency in these cases as in those shown in the Table.

SUMMARY OF RESULTS.

Tests of fungicides on apple trees have shown :—

1. That apple scab (*Venturia inæqualis*) on fruit and leaves has been reduced by every fungicide tested, generally to a considerable extent. This bears out results obtained by other investigators.

2. That scab infection of the wood is also greatly reduced by summer spraying. This will obviously reduce the sources of re-infection in the following summer.

3. That the effectiveness of the fungicides tested in the control of scab varies considerably.

(a) *Bordeaux mixture* is found generally to be the most effective. The two formulæ used "equal lime" (8—8—100) and "excess lime" ($7\frac{1}{2}$ —25—100) gave practically identical results as "scabicides." Bordeaux injury was considerably reduced by the "excess lime" formula, but was still very evident in 1920 with the formula 8—25—100.

(b) *Lime-sulphur* is less effective than Bordeaux against scab, and its effectiveness is not increased by the use of spreaders (saponin, etc.). Lime-sulphur appears to reduce the crop, which was in almost every case lighter than where Bordeaux was used and frequently than where no spraying was done. This injury may probably be reduced by the use of spreaders or lead arsenate in mixture with lime-sulphur.

(c) *Ammonium polysulphide* with soap is the least effective against scab of all the fungicides tested. The trees sprayed with it, however, bore more than double the crop of similar trees sprayed with lime-sulphur.

4. That Ammonium polysulphide with soap is more effective in the control of apple mildew (*Podosphaera leucotricha*) than any other fungicide tested. Bordeaux was here found to be the least effective; the value of lime-sulphur was increased by spreaders, and may have been reduced by lead arsenate.

5. That summer spraying with fungicides may improve the keeping quality of the fruit by reducing attacks of brown-rot (*Sclerotinia fructigena*). This is probably due to the greater liability of cracked and scabby fruit to infection.

6. That bud infections of canker (*Nectria ditissima*) may be considerably reduced by summer spraying.

7. That the size of the fruit is usually increased by fungicide sprays. Worcester Pearmain is probably an exception.

8. That several of these effects of spraying are cumulative, the spraying done in 1919 having affected the trees and fruit in 1920, regardless of the treatment in 1920.