THE TREATMENT OF LITTLE-LEAF OF DECIDUOUS FRUIT TREES.

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SUMMARY.

1. Following the identification of little-leaf of deciduous fruit trees in the Stanthorpe district as a disorder due to zinc deficiency, experiments were conducted to ascertain the best methods for the application of zinc as a corrective of the disease.

2. A winter spray consisting of a 5 per cent. or a 2½ per cent. solution of zinc sulphate in water gave satisfactory response within a few months; little control was obtained with a 1 per cent. solution.

3. Spring foliage sprays containing up to 2 per cent. of zinc sulphate had little or no immediate beneficial effect on affected trees.

4. Winter sprays not only produced an earlier response in affected trees than did spring sprays, but had more lasting effects. Thus, if a winter spraying was omitted there was only a slight reversion to the condition in the second year after treatment, whereas if foliage sprays were used and spraying was omitted one year the disorder reappeared completely in the following year.

5. Broadcasting and ploughing-in of 5 lb. zinc sulphate around an affected tree produced beneficial effects in the second and third year after treatment. Tree injections were unsatisfactory.

6. The application of the experimental results to orchard practice is discussed, and it is concluded that winter spraying is preferable to spring spraying, to the application of zinc compounds to the soil, and to tree injection. Probably, winter spraying and soil treatment in conjunction would be preferable to winter spraying alone in the early treatment of the disorder.

INTRODUCTION.

The presence of little-leaf in the Stanthorpe district was first referred to in 1928 and its increasing importance led to a considerable amount of field experimental work being undertaken by departmental officers. A report on such work carried out between 1934 and 1937 (Morwood, 1937) furnished considerable evidence of the response of affected trees to zinc treatment and appeared to establish the identity of the disorder as little-leaf. Nevertheless, even in 1937, additional information was still required as a basis for final recommendations on the method and frequency of treatment and on the quantity of material required under Stanthorpe conditions. A continuation of the little-leaf experimental work in a number of apple orchards was therefore decided on and it has supplied much of the required information. This paper accordingly has as its objective the presentation and discussion of the experimental data secured over the five-year period from 1937 to 1941. Certain of the data secured prior to 1939 were reported in an earlier paper (Ward, 1939).

That the importance of the problem fully justified the additional experimental work is supported by the fact that during the last few years little-leaf has become increasingly prevalent in a number of varieties of fruit trees in the Stanthorpe district until now it is present in trees growing on each of the local granitic soil types, and every succeeding year it appears in many previously healthy orchards. Apples have been more frequently affected than other deciduous fruits, but little-leaf has also become quite common in pears and stone fruits. However, although suspicious symptoms have been noted in grape vines, its presence therein has not been definitely established. A disturbing feature of the trouble is the frequency with which it has made its appearance in young, vigorous orchards during either the pre-bearing or early-bearing stage, as well as in mature, full-bearing orchards which had apparently been healthy in the past.

THE INFLUENCE OF ZINC ON PLANT NUTRITION.

The fact that zinc is one of the trace elements which is essential for the proper nutrition of a wide range of economic plants has been amply demonstrated by research in many countries, an insufficient supply of this element having been established as being responsible for serious functional disorders in several species of fruit trees, e.g., little-leaf of deciduous fruits and mottle-leaf of citrus.

Several workers, notably H. S. Reed and his associates in the United States (1935, 1936, 1938, 1939), have shown that in both these disorders there is a characteristic and profound disorganisation of a biochemical and a physical nature in the cytology of affected leaf tissues. Symptoms of interference with metabolic activity include the lack of chlorophyll, the necrosis of large areas of cells within leaf tissues, the disruption of carbohydrate synthesis, and changes in non-living substances within the cell, particularly tannins. Linked with these symptoms are others involving alterations in the structure of leaf tissues, the most notable of which are an abnormal elongation of the cells of the palisade parenchyma, and compacting of those of the spongy parenchyma, in which the necrotic areas mentioned above are usually present. A reduction in the number and size of plastids also occurs. The general effect of these derangements in leaf tissues is seen in the well-known outward symptoms of zinc deficiency, the most conspicuous of which are leaf mottling and dwarfing.

The application of zinc compounds to affected trees results in the accumulation of zinc in the tissues, and a considerable degree of restoration of metabolic processes follows. For example, the treatment of mottled citrus leaves with zinc sulphate is followed by a resumption of cellular activity, with a consequent return to the normal appearance and functioning of cell bodies such as the nucleus and chloroplasts (Reed and Defrenoy, 1935; Reed and

Parker, 1936). With the development of the latter bodies chlorophyll reappears in the leaves and mottling vanishes; but although zinc restores normal functions to affected tissues it does not change their abnormal structural characteristics. For instance, it does not alter their dwarfness, but without further treatment, and so long as the zinc supply remains unexhausted, new growth, whether of leaf or shoot, is normal in all respects.

METHODS OF SUPPLYING ZINC TO ZINC-DEFICIENT TREES.

Since the initial demonstration of the part played by zinc in the control of little-leaf, research, both overseas and in Australia, has been concerned largely with methods by which this element might be applied most effectively, and in the course of this work a wide range of zinc compounds and a diversity of methods of application have been studied. Foremost among the methods tested are those involving the application of various forms of zinc directly to the tree itself, for treatment through the soil appears to have met with only limited success under certain soil conditions. Attempts to supply zinc directly to trees have been made with zinc sulphate and zinc oxide, applied to the foliage or as dormant-period sprays, or introduced into holes bored in the tree trunk; metallic zinc pieces driven into the trunk and branches have also been experimented with (Chandler *et al.*, 1934; Chandler, undated); whilst dusts consisting of zinc oxide, zinc sulphide or metallic zinc have been tested on the foliage of citrus for the treatment of mottle-leaf (Parker, 1938).

EXPERIMENTAL METHODS EMPLOYED AT STANTHORPE.

The technique employed in the experiments discussed in this paper aimed at placing their results on a quantitative basis, and all were of the randomized block type in which each treatment was replicated eight times, the unit of treatment being a single tree showing definite symptoms of the "little-leaf" stage (Plate 1) of the disorder. On each treated tree affected leader branches were marked by label at the commencement of each experiment, and as a general rule results were based on the subsequent history of these branches. Since it is invariably the terminal portions of such branches that show the symptoms of the disorder most plainly, annual growth measurements were confined to the length of terminal shoots, but counts were also made of affected branches. In the latter case leaf mottling alone was not considered a conclusive symptom unless it was associated with the "little-leaf" condition.

These methods were not completely satisfactory from a statistical point of view because of considerable inconsistency of response within certain treatments, variation in degree of disease incidence, and the occurrence of cases of temporary apparent recovery in untreated plots; furthermore, in some experimental plots growth was generally erratic and adversely influenced by factors other than zinc deficiency. Thus uniformity between trees in each block was less than desirable and in consequence standard errors were high, but the data nevertheless served very well to express quantitatively what was evident from visual examination.

Plate 1.

Symptoms of little-leaf. Left, normal spring growth. Right, shoot showing "little-leaf" stage.

RESULTS OF METHOD-OF-APPLICATION EXPERIMENT.

Most of the Stanthorpe experiments provided data relative to the suitability of different methods of treating trees with zinc, but one in particular was designed to enable this aspect of the problem to be studied. This experiment was begun in 1937 on 56 eight-year-old Jonathan and Granny Smith apple trees all affected by little-leaf but otherwise apparently in normal health. Details of the treatments applied are shown in Table 1, whilst their effect on shoot growth and incidence of the disorder are presented in Tables 1, 2 and 3, which summarize the results of three seasons' observations. In this and in all other

Table 1.

Showing progressive growth responses by apple trees affected by little-leaf after different methods of treatment with zinc. Each figure is an average for eight trees.

Details of Treatments.	Date Applied.	Terminal Growth on Affected Leader Branches. (Inches per Tree.) 1937. (Before Treatment.)	1937–38.	1938–39.
1. Winter Spray— 50 lb. $ZnSO_4$/100 galls. water .. 25 lb. $ZnSO_4$/100 galls. water ..	30 July, 1937 28 July, 1938	16·0	65·1	96·0
2. Winter Spray*— 50 lb. $ZnSO_4$/100 galls. water .. 25 lb. $ZnSO_4$/100 galls. water ..	30 July, 1937 28 July, 1938	16·1	79·1	118·7
3. Injections—2 litres 0·125 per cent. $ZnSO_4$ solution	22 Oct., 1937	8·5	15·8	42·2
4. Spring foliage spray — 10 lb. $ZnSO_4$ and 5 lb. hydrated lime/100 galls. water	10 Nov., 1937 9 Nov., 1938	9·9	16·6	62·7
5. Soil application—5 lb. $ZnSO_4$ per tree	15 Sept., 1937	17·2	51·1	85·8
6. Soil application—$2\frac{1}{2}$ lb. ZnO per tree	15 Sept., 1937	14·6	29·3	49·5
7. Untreated	..	15·2	26·7	43·4
Significant differences (5 per cent. level)		.. ..	32·1	52·5

* Applied immediately after pruning.

Stanthorpe experiments discussed in this paper commercial quality chemicals were used in the preparation of the sprays.

Prior to treatment there was obviously little terminal growth on affected branches, the average length of these shoots being between 3 and 5 inches as compared with 30 inches on unaffected trees. Responses resulting in the restoration of normal shoot growth quickly followed some treatments, while others produced but little improvement.

Table 2.

Showing average increase in length of terminal shoot growth on affected leader branches.

Treatments. (As in Table 1.)	Average Increase in Length per Shoot. 1937–38.	1938–39.
	(Inches	per Shoot)
1	14·0	21·1
2	15·6	21·9
3	4·5	11·0
4	4·5	15·1
5	7·7	14·2
6	4·5	11·0
7	3·2	8·5
Significant differences (1 per cent. level)	7·7	8·6

Table 3.

SHOWING NUMBER OF LEADERS AFFECTED BY LITTLE-LEAF AT PROGRESSIVE STAGES OF THE EXPERIMENT.

Treatments. (As in Table 1.)	Number of Leader Branches Affected by Little-leaf.		
	1936–37. (Before Treatment.)	1937–38.	1938–39.
1	25	2	0
2	33	6	0
3	37	32	20
4	30	26	8
5	39	21	7
6	34	28	18
7	37	35	27

Untreated Plots.

The data indicate that during the three-year period there was on untreated trees an average improvement in shoot growth and some reduction in the number of affected branches (Treatment 7, Tables 1, 2, and 3). These figures are, however, rather misleading, for there was not by any means a general improvement in the trees; in some of them shoot growth increased a little, but more than half of them showed a steady and rapid decline until many branches had begun to die back from the top; some of these trees became affected in every branch (Plate 2). The transitory nature of the disorder in some of these trees was doubtless due to fluctuations in the availability of naturally-occurring zinc, arising perhaps from seasonal variations in soil moisture and other soil conditions. It is certain that similar changes in the incidence of little-leaf occurred on some of the treated trees irrespective of treatment, and this fact contributed partly to the high standard error appertaining to the experiment and must be borne in mind in assessing the effects of different treatments.

Winter Spray Treatment.

When a zinc sulphate spray at a strength of 50 lb. in 100 gallons of water was applied in July, 1937, there was a remarkable renewal of growth on all 16 sprayed trees in the following October. This new growth appearing on the previously affected branches was evidently normal in all respects, and the new shoots for the most part were comparable with those on unaffected branches. Throughout the growth period they were apparently devoid of "little-leaf" symptoms, but during the summer months signs of mottling appeared on eight out of the 58 labelled branches on the treated trees. At the close of the growing season the average length of terminal shoots on the marked branches was 21 inches as compared with 4 inches in the previous season. The new growth on affected leader branches sprayed during the winter was significantly greater than that on untreated branches (Tables 1 and 2).

With reference to treatment 2, which comprised a winter spray applied initially a few hours after pruning, it was thought that the zinc sulphate solution would readily enter the plant tissues through the pruning cuts. Trees so treated responded very well, as is indicated in Table 1, but when the trees were pruned a year later it was found that where the solution had contacted the cuts it had penetrated some distance—up to 15 inches—down the branch

Plate 2.

Showing condition representative of that of some of the untreated experimental apple trees. Note the die-back stage reached by some branches.

and had killed a thin strip of tissue therein (Plate 3). Though the injury was not severe it was undesirable, and in later work winter sprays were applied either before pruning or not less than two weeks afterwards.

After the initial treatment in 1937, winter sprays were again applied prior to pruning in July, 1938, but their strength was reduced to half that of the previous year. The following spring brought an even better response than that of the year before, a particularly satisfactory feature being its completeness, for all branches recovered and added terminal shoots up to 30 inches in length. Once again growth on plots receiving this treatment significantly exceeded that on control plots, and was more consistent than that on plots receiving any other treatment.

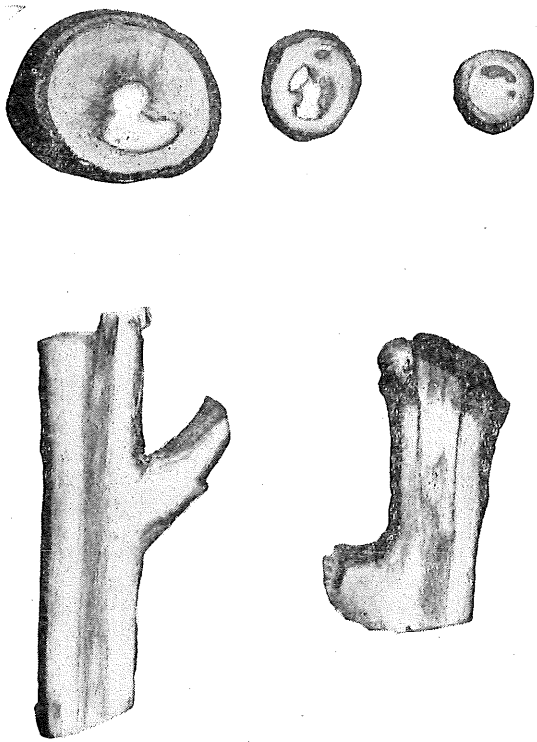

Plate 3.

Showing sections through branches in which wood tissue was killed by 5 per cent. zinc sulphate spray solution applied immediately after pruning.

Spring Foliage Sprays.

A foliage spray consisting of 10 lb. zinc sulphate, 5 lb. hydrated lime, and 100 gallons of water was applied in November, 1937, and the treatment was repeated one year later. The initial application was not followed during that season (1937-38) by any observable response; nearly all labelled branches bore the usual well-marked symptoms of little-leaf, including stunted leaves and shoots as well as mottling, and terminal shoots failed to add appreciably to their length (Treatment 4, Tables 1, 2, 3).

During the second season (1938-39), when the spray was again applied, there was an appreciable reduction in the number of branches showing "little-leaf"—from 26 to 8 (Table 3)—and shoot growth appeared much better than in the previous year. Some trees showed fair improvement, but several others failed to give anything but a short-lived response, and one severely affected tree did not improve at all. This inconsistency in behaviour indicated that the 10–5–100 foliage spray was decidedly inferior to the winter spray, even though rather less inconsistent results were obtained with foliage sprays in an experiment in which different concentrations of zinc were tested, and which is reported later in this paper.

Soil Treatment.

An examination of data from plots which received a single application of 5 lb. zinc sulphate or 2½ lb. zinc oxide broadcast and ploughed in around each tree in September, 1937 (Treatments 5 and 6; Tables 1, 2, and 3) suggests that the former treatment may have been responsible for an appreciable amount of recovery and some improvement in growth two years later, although the difference between this treatment and the control is not significant. Five of the eight treated trees showed a marked improvement by the second year, but the remaining three responded very slightly, if at all, in that time. In the third year after treatment (1940) the three unimproved trees were apparently responding to a slight degree, and the other five maintained their improvement. This result seems to indicate that zinc eventually became available from the soil application in sufficient quantity to produce beneficial effects. The possibility of still better responses with heavier or more frequent soil applications suggests itself, particularly as it has previously been noted that apple trees in acid soils generally respond far more readily to soil treatment than those on neutral or alkaline soils, in which zinc apparently rapidly becomes fixed and unavailable (Chandler *et al.*, 1934; Chandler, undated). Stanthorpe soils have a pH value of approximately 5. Soil application of commercial zinc oxide at the rate of 2½ lb. per tree was apparently ineffective in correcting little-leaf.

Tree Injections.

Two litres of 0.125 per cent. zinc sulphate (A.R.) solution were injected into the trunks of each of eight trees in October, 1937, by a technique based on that used by Roach (1936) for injecting nutrient solutions into fruit trees. This treatment eliminated some mottling and slightly stimulated growth on branches directly above the auger holes into which the injections were made, but some trees were wholly unresponsive to the treatment even two years after its application.

Further Observations.

The history of this experiment and others not discussed in detail, subsequent to 1939, serves to confirm the earlier observations made on the efficiency of the winter spray treatment. By 1939 a number of trees which had either been untreated or had failed to respond to treatment were very severely affected by little-leaf; some completely lacked terminal growth, and many leaders were dying back from the top. Eleven of these trees, having a total of 59 affected branches, on which the total terminal growth was 385 inches, were sprayed early in August, 1939, with 25 lb. zinc sulphate in 100 gallons of water. In the following November only three branches showed any little-leaf symptoms, and by the end of that growing season these 59 branches had 1,105 inches of top growth. Plates 2 and 4 show the condition reached by some of the control trees by the third year from the commencement of the experiment, whilst Plate 5 is a photograph of the same tree as that in Plate 4, taken one year later and after winter treatment with a 2.5 per cent. zinc sulphate spray. The restoration of this tree to full vigour was brought about by a second winter treatment, as is shown in Plate 6. It is noteworthy that even severely affected little-leaf shoots, when left unpruned, invariably added a considerable amount of new growth in the season following the winter spray treatment, and within one or two growing seasons their diameter had increased to normal proportions and they had developed fruiting spurs.

The conclusion to be drawn from the experiment described above is clear. Because of the consistency and completeness of its results the winter spray treatment stands out prominently from the other methods of applying zinc, and is indeed the only one that effected the recovery of all treated trees. It is therefore to be regarded as the most suitable of the methods tested for correcting little-leaf in commercial practice, particularly as the cost of the treatment is comparatively small. The use of a soil application of 5 lb. or more of zinc sulphate per tree in conjunction with winter spraying in the early treatment of little-leaf is a potential means of prolonging the beneficial effects of zinc applications and thus minimizing the frequency of spray treatment. Further information is required on this point.

RESULTS OF STRENGTH-OF-SPRAY-MIXTURES EXPERIMENTS.

Winter Sprays.

The effects of different strengths of winter sprays were observed in two experiments. In the first of these, sprays ranging in strength from 1 lb. to 50 lb. of zinc sulphate per 100 gallons of water, i.e., from 0.1 per cent. to 5 per cent., were applied to mature Jonathan and Delicious apple trees in August, 1938. Subsequent counts of affected branches, made in the following spring, showed the almost complete disappearance of the disorder from trees which had received the 5 per cent. and 2.5 per cent. sprays (Table 4), and the lack of

Table 4.

SHOWING THE EFFECT OF DIFFERENT CONCENTRATIONS OF $ZnSO_4$ WINTER SPRAY ON APPLE TREES. TREES SPRAYED AUG., 1938, UNSPRAYED IN 1939 WINTER.

Treatments.	Number of Affected Branches.		
	1937–38.	1938–39.	1939–40.
1. 5 per cent. $ZnSO_4$ ..	24	0	4
2. 2·5 per cent. $ZnSO_4$ ..	21	1	7
3. 1 per cent. $ZnSO_4$ ..	22	5	9
4. 0·1 per cent. $ZnSO_4$ ..	20	12	17
5. Control	24	16	24

satisfactory response from the two weaker sprays. When these trees were left unsprayed in the winter of 1939, evidence of reversion to little-leaf was seen in the case of all treatments, but this reversion strongly tended to increase as the strength of the sprays decreased.

Additional observations were made in another experiment in which winter zinc sulphate treatments were applied in July, 1939, on eight-year-old Jonathan and Delicious apple trees just commencing to fruit. Prior to treatment little-leaf was severe in the majority of the trees; they were affected to the extent that each of them carried an average of 3 to 4 "little-leaf" branches whose terminal growth was 2 inches in length (Table 5). The application of the sprays was followed in the ensuing spring by a very definite reduction in the number of affected branches and a marked improvement in shoot growth on those trees receiving the 5 per cent. and 2.5 per cent. sprays. The response from these two treatments was such that by the end of the growing season shoots on marked branches averaged 18.9 and 20.2 inches respectively in length, whilst the total amount of top growth on these branches had increased nine to ten times.

Table 5.

Showing the effect of different concentrations of $ZnSO_4$ winter spray on incidence of little-leaf and on shoot growth on affected branches. Trees sprayed July, 1939.

Treatment.	Number of Affected Branches.		Total Terminal Growth on Affected Branches (Inches).	
	1938–39.	1939–40.	1938–39.	1939–40.
1. 5 per cent. $ZnSO_4$	35	7	64·2	660·2
2. 2·5 per cent. $ZnSO_4$	40	6	88·2	806·7
3. 1 per cent. $ZnSO_4$	37	36	58·2	228·6

It was evident that the 1 per cent. spray produced little beneficial effect on the trees, for there was virtually no decrease in the number of affected branches. Though there seemed to be some stimulation of shoot growth, it was obvious that the 1 per cent. spray was far less effective in this respect than the two stronger ones, and indeed it gave no worthwhile degree of control of the disorder.

The two groups of observations made from these experiments generally support each other, and lead to the conclusion that the strength of winter sprays cannot be safely reduced much, if at all, below the 2.5 per cent. strength.

Spring Foliage Sprays.

The influence of zinc sulphate-lime and zinc oxide solutions when applied to foliage in spring at various strengths was studied in an experiment which began in 1937 and continued until 1940. The principal observations in this experiment consisted of annual counts of little-leaf affected branches, but yearly records were also made of the amount of top growth on them. The former records alone were of value as a means of indicating the true effects of the treatments, for, although at certain stages of the experiment no signs of little-leaf were discernable in many of the plots, no significant growth responses followed the application of any of the treatments. This primarily arose from the fact that growth in the trees in this experiment was limited by a number of factors of which little-leaf was only one; for example, the trees suffered from copper deficiency, which was subsequently rectified by a soil application of copper sulphate.

The various foliage sprays were first applied in November, 1937, and a second application was made in November, 1939; the results from the first spraying were observed in the spring of 1938, and of the second in the spring of 1940. For purposes of comparison, a winter treatment was included in the experiment, applications being made in 1938 and again in 1939. The varieties in the experiment were Jonathan, Granny Smith, Delicious, and Gravenstein apples.

The results of the series of observations made in this experiment are summarized in Table 6. Prior to the application of the various treatments the average number of "little-leaf" branches was about three per tree. In the growing season during which the foliage sprays were first applied, 1937-38, no noticeable decrease in little-leaf took place, but 12 months later there was a definite reduction in the incidence of the disorder on all sprayed trees. In that season, i.e., 1938-39, even unsprayed trees showed a slight improvement, and this would seem to indicate that the treatments were not necessarily responsible for the whole of the improvement on sprayed trees. The stronger zinc sulphate sprays showed a slight tendency to be more effective than the weaker solutions. Although the first winter spray had been applied more than eight months after the first foliage sprays, response to all sprays showed at the same time.

Table 6.

SHOWING THE EFFECT OF FOLIAGE SPRAYS ON THE INCIDENCE OF LITTLE-LEAF. FOLIAGE SPRAYS APPLIED 23RD NOV., 1937, AND 24TH NOV., 1939. WINTER SPRAYS APPLIED 3RD AUG., 1938, AND 29TH AUG., 1939.

Treatment.	Number of Affected Branches.			
	1937–38. (Before Treatment.)	1938–39.	1939–40.	1940–41.
Lb. per 100 gallons water—				
1. 2½ $ZnSO_4$: 1¼ lime	29	5	25	0*
2. 5 $ZnSO_4$: 2½ lime	20	3	20	2
3. 10 $ZnSO_4$: 5 lime	27	0	15	0
4. 20 $ZnSO_4$: 10 lime	30	1	27	0
5. 2½ Zinc Oxide	30	4	10	2
6. 5 Zinc Oxide	24	4	10	0
7. 25 $ZnSO_4$ (Winter Spray)	19	0	1	0
8. Untreated	25	16	25	25

* Treatment 1 was replaced by a 30-15-100 foliage spray in the spring of 1939.

In order that information on the duration of response might be obtained no foliage treatments were applied in the spring of 1938. That the omission of the sprays in that season was followed by a very considerable reversion to the little-leaf condition in 1939-40 is clearly shown in the table; in several instances groups of similarly treated trees almost completely reverted, and this occurred almost to the same degree on trees which received the strongest spray as on those which received the weakest. In view of the high variability of the experiment no significance can be attached to the apparently better results given by treatments 3 and 6. The winter spray which had been applied again in August, 1939, once more gave good results.

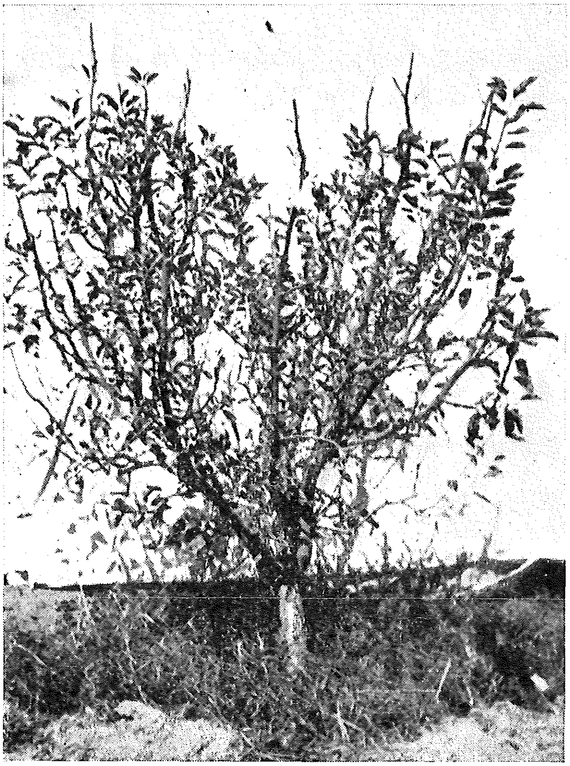

Plate 4.

Control tree B3, which is representative of a number of the untreated trees three years after the commencement of the experiment. Total terminal growth on the affected branches of this tree in 1939 was 5 inches.

The effects of a second application of the foliage sprays made in the spring of 1939 were observed a year later and these showed, firstly, that in the 1940-41 season there were very few symptoms of little-leaf to be seen on sprayed trees during the spring months although some mottling developed later; and, secondly, that there was no well-marked tendency for the stronger sprays to be more effective than the weaker. Thus the observations made in the 1938-39 season, indicating primarily that spring sprays were able to reduce the incidence of little-leaf 12 months after their application, were confirmed in 1940-41. Since the results given in 1938-39 did not indicate that the $2\frac{1}{2}$-$1\frac{1}{4}$-100 spray (Treatment 1, Table 6) would be effective it was replaced by a 30-15-100 foliage spray in the spring of 1939. This rather strong spray, which was applied purely for observational purposes, caused no foliage injury on any of the treated trees, and its application was followed by a definite response in the spring of 1940.

In assessing the value of spring spray applications, cognizance must be taken of the fact that the response from the 10-5-100 spray used in the experiment of which the results are summarized in Tables 1, 2, and 3 was inconsistent, and for this reason it is considered that this treatment is not satisfactory.

DURATION OF RESPONSE TO TREATMENT.

The practical value of any little-leaf treatment will depend to a considerable extent on the duration of the response obtained from that treatment, and therefore observations made on this aspect of the question of control are now summarized. In treatment by winter spraying the first point of note is that although rather spectacular improvement usually follows a single application there are occasionally a few branches that respond poorly or for a short time only. Sometimes such behaviour may have been attributable to incomplete spraying, but under experimental conditions it is unlikely that this explanation is always valid. In two experiments, symptoms of little-leaf were still discernible on one or more trees after a spraying in winter (see Tables 3 and 5) and it must therefore be assumed that a single application of even the 5 per cent. spray is not sufficient to cause complete recovery.

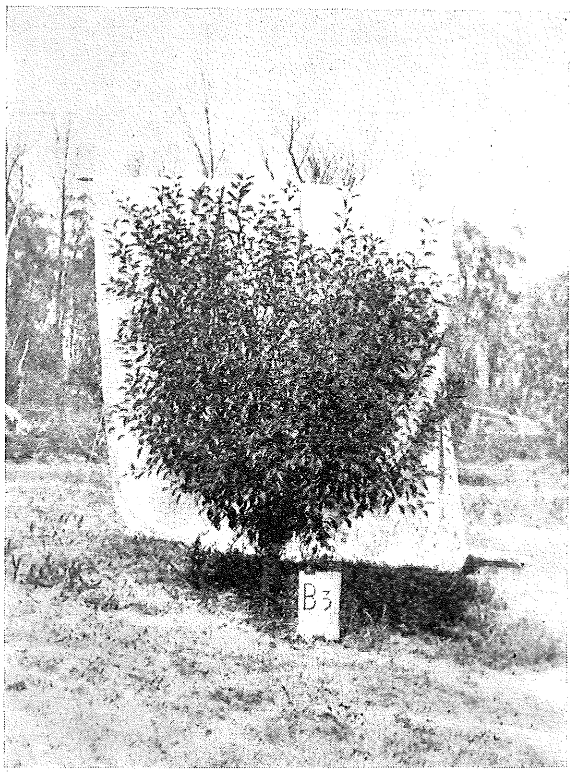

Plate 5.

Tree B3 photographed in 1940. Sprayed in August, 1939, with 2.5 per cent. zinc sulphate solution. Total terminal growth on affected branches in 1940 was 167 inches.

Whenever sprays not weaker than 2·5 per cent. have been applied in two or more successive winters complete disappearance of little-leaf has been effected for at least the following growing season. If the trees are left unsprayed in the third winter their improved condition is generally maintained, although signs of reversion can occasionally be seen. This indicates that the full effects of winter sprays are probably not maintained for more than two years, and that in order to ensure an adequate supply of zinc a spray application is required every alternate year after the initial applications in two successive years.

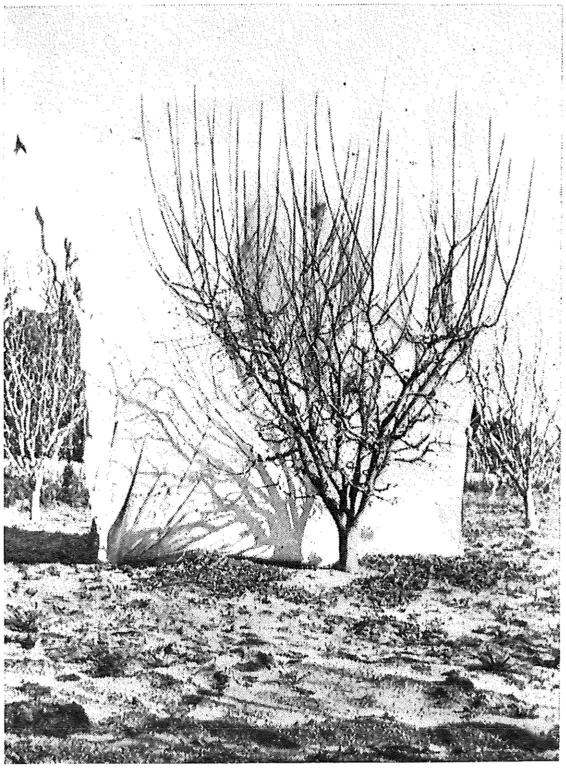

Plate 6.
Tree B3 photographed after restoration to full vigour by winter spray treatment.

The effects of spring foliage sprays on apples are but slowly felt, and that they quickly disappear is amply shown by the results of the experiment summarized in Table 6. It happened frequently that the response obtained 11 or 12 months after the spray application lasted only during the spring months and by summer mottling had appeared in the leaves. In several experiments in which foliage sprays were employed a few severely-affected trees showed scarcely any recovery. Perhaps the most important unsatisfactory feature of the treatment by spring spraying is the rapidity and extent of the reversion to little-leaf when a season is allowed to pass without a spray application being made. This reversion is often complete. It is concluded from these observations that spring foliage sprays are not sufficiently effective to warrant their recommendation for use in commercial practice.

GENERAL OBSERVATIONS.

The experiments reported in the preceding sections of this paper have been concerned with little-leaf in apples only, but experimental work with Williams' Bon Chretien pears and observations on stone fruits have provided additional information on the treatment of the disorder. The experiment on pears indicated that winter treatment and spring foliage sprays were both effective in reducing the trouble, but in each case the stronger spray tested, namely, a 5 per cent. winter spray and a 20–10–100 foliage spray, was apparently more effective than the weaker application. On pears, as on apples, the effects of foliage sprays tended to be less durable than those of winter sprays, and, in general, the response by pears to spray treatments has closely paralleled that given by apples.

Winter spray applications of zinc sulphate on affected stone fruit trees—including Japanese plums, peaches and apricots—have invariably been followed by a marked reduction of little-leaf, if not by a complete cure. Where a strong winter spray (5 per cent.) was combined with a winter-strength lime sulphur (1 in 10) and applied to affected plums satisfactory results were obtained. The mixture of the two ingredients, however, gave rise to a heavy precipitation in the spray vat, and the resultant mixture was at times inconvenient to use. A point of note is that as good results were obtained when the zinc was applied at least partly in precipitated form as when applied as a solution of zinc sulphate in water.

It has been thought that the greater efficacy of winter sprays as compared with foliage sprays was perhaps partly explained by the fact that in the former the trees received the zinc as zinc sulphate in solution, whilst in the zinc-lime foliage spray much of the zinc reaches the leaves in a precipitated state, probably as calcium zincate. Of course, as soon as the water evaporates from the solution of zinc sulphate applied as a winter spray fine crystals of that compound are left on the surface of the bark and buds of the trees, and in the process of repeated solution and recrystallization of the salt by the action of dew, rain and melting frost some of the dissolved zinc sulphate is absorbed into the dormant wood tissues, probably through the lenticels and dormant buds. A similar dissolving and absorbing action apparently takes place when the zinc is deposited on the trees in a precipitated form, as is suggested by the results obtained on plums after treatment with the zinc sulphate-lime sulphur spray referred to in the preceding paragraph.

Leaves receiving a zinc-lime spray must also slowly absorb zinc, as small quantities are dissolved by natural moisture, and there may be some further simultaneous absorption through the bark as well as the buds in the axils of the leaves. Apparently the quantity of zinc taken into the plant tissues in this way is less than that absorbed after a winter spray application, since foliage sprays on apples give markedly less response than winter sprays. Possibly this is because more zinc is applied in the winter spray, or because the zinc sulphate deposited by the latter has a higher solubility than the calcium zincate or other salt which is deposited by the zinc-lime foliage sprays. This explanation, however, seems scarcely satisfactory, since on citrus trees the zinc-lime spray quickly becomes effective, and, moreover, citrus responds to relatively insoluble materials such as zinc oxide and powdered metallic zinc applied either as sprays or dusts, and the duration of the response can apparently be as long as four years (Parker, 1938.) It seems a safe assumption that the intake of zinc from sprays applied to apple foliage differs considerably from absorption of the same element by citrus foliage. The explanation of this phenomenon can be found only by further investigation.

With respect to the nature of the response produced on apple trees by winter sprays, it seems that no matter how severely a branch may be affected by little-leaf it can be restored to a normal condition so long as shoots and buds remain alive. On an affected branch a terminal shoot possessing normal vigour one year may produce a dwarfed shoot the next, or it may fail to add any new wood growth whatever and exhibit only the typical leaf symptoms of severe little-leaf. If such a terminal is left untreated it may commence to die back in a short time, but spraying with zinc sulphate in winter almost invariably causes healthy renewed growth in the ensuing spring. A treated dwarfed shoot when left unpruned will make vigorous growth from its apical bud and, in the course of a season or two, the originally stunted portion of the branch will increase radially to a normal diameter and in due course will produce fruiting spurs. Severely affected trees which have been untreated for some years will often have died back from the tops of some, if not all, of their leader branches, and the fruit produced will be dwarfed. Subsequent treatment of such trees, involving the removal of dead wood and the application of appropriate zinc sprays, stimulates shoot growth, particularly on terminals, to such an extent that, after several growing seasons, previously dwarfed trees compare favourably with normal ones, and a proper balance can be restored to asymmetrical trees. This stimulation of growth is accompanied by the production of fruit of normal size.

It has been noted that mottling in apple leaves is sometimes of a transitory nature. Apparent response to the spraying of mottled foliage was seen in an experiment in which mottling was appreciably reduced after the application of various strengths of foliage sprays, but an equal amount of reduction occurred simultaneously on unsprayed trees in the same experimental block. Usually mottling becomes intensified in late spring and summer, but that the reverse can be true is also evident.

APPLICATION OF RESULTS TO ORCHARD PRACTICE.

From a consideration of the foregoing experimental data it is clear that spraying with zinc sulphate in winter has produced a faster, more complete, and more enduring response in apple and other deciduous fruit trees affected with little-leaf disease than any of the other treatments applied, and it follows, therefore, that it must form the basis of practical control recommendations. Such recommendations will necessarily include the application in winter of a zinc sulphate spray of no lower concentration than 2.5 per cent. in two successive years as an initial treatment to restore affected trees to a normal condition; thereafter, an application in alternate years would be required to prevent reversion to the little-leaf condition. Growth on severely affected trees would evidently be more readily stimulated if the strength of the spray used in the first year of treatment were 5 per cent.

The treatment outlined here is applicable to pears and plums, and probably to other stone fruits as well, and should, at a low cost in materials, effectively maintain an adequate supply of zinc to trees requiring this element.

In applying the winter spray it must be remembered that the spray solution will enter fresh pruning cuts and produce a toxic effect on the wood, and it is therefore preferable to apply the spray before pruning, or, if this is impracticable, the application should be delayed for at least two weeks after pruning.

The desirability of a treatment which would remain effective for a longer period than a winter spray is undoubted, but the possibilities in this direction are somewhat limited. The driving of triangular pieces of sheet zinc into the tree trunk appears to have a beneficial effect, but the pieces tend to fall out readily and the physical injury caused to the bark offers a means of entry for bark and wood diseases. A possible alternative method of securing a lasting response in local acid soils is to make an application of zinc sulphate to the soil around the trees, but, in view of the rather slow improvement shown by trees so treated, it would be necessary at the same time to apply a winter spray—which would probably have to be repeated in two successive years—in order to obtain an early response. Once the trees had been treated in this manner the supply of zinc in the soil might keep them free from little-leaf for some years.

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