SESSION IV

CONTROL OF APPLE MILDEW

Chairman: R. W. Marsh
Long Ashton Research Station

THE CONTROL OF APPLE MILDEW

by R. T. Burchill
East Malling Research Station

Podosphaera leucotricha (Ell. and Ev.) Salm. has been known as the cause of apple and pear mildew for approximately 85 years. This fungus, which is now found in all the apple growing districts of the world, attacks young shoots, leaves, fruits and blossom trusses of most commercial varieties. A severe infection on shoots can lead to defoliation, curtailment of growth, and a reduction in the number of fruiting buds formed on the two-year old wood below. Infections of the blossom trusses result in the non-production of fruit; and successive attacks on the same trees will lead to a cumulative loss of crop. Direct attacks on the fruit can cause a form of russeting which reduces its market value.

For many years the disease was adequately controlled, but during the last decade it has become more prevalent. Various reasons for this have been suggested, including changes in climatic conditions; however as the increase has been world-wide, this seems unlikely. Other observers have called attention to changes in spray materials and pruning practices as contributory factors. The increasing importance of apple mildew and the confusion concerning the reason encouraged us to investigate the life history and control of the disease more closely.

Apple mildew is a member of the Erysiphales (the powdery mildews) and, in common with most members in this group, forms two stages in its life history, the imperfect stage, (sometimes called the oidia stage) producing the conidiophores and conidia, and the perfect stage or perithecium. The latter is frequently found but no function has yet been ascribed to it, although in other members it functions as the over-wintering body. Successful perennation depends on the ability of the fungus to invade buds during the summer; once within the bud, the hyphae remain dormant until the following spring when, with renewed host activity, the fungus spreads to cover the emerging leaves, forming the PRIMARY INFECTION. Conidia from these infections are then carried by the wind to healthy tissues giving rise to the SECONDARY or SUMMER INFECTIONS.

Much of the work at Long Ashton was devoted to a study of the perennation of the disease and as most of this has been reported earlier, only a brief summary will be given here. It was confirmed that the sole means of perennation was by mycelium present within diseased fruit and vegetative buds. Most buds were infected by mycelium spreading from an infected leaf lamina, down the petiole and into the bud. Direct infection of buds by conidia was less common. Infection of terminal buds could occur at any time during the growing season and continued until just after growth had ceased.

Infection of axillary buds was successional, the earlier formed ones being attacked at the beginning of the summer and the later ones at the middle and end of the season. Each bud remained susceptible for approximately one month after emergence, i.e. until bud closure and suberisation of the outer scales prevented infection. For similar reasons fruit buds on dwarf shoots were also susceptible to infection for approximately one month after formation, i.e. during May and June. The fruit buds were the first to open in the spring, and if mildewed, were a source of conidial infection during April and May. The terminal buds opened about three weeks later and, if infected, usually produced extension shoots on which mildewed leaves arose in succession throughout the season. Diseased axillary buds were not an impotant source of infection because they rarely opened or produced only a few mildewed leaves which were soon shed.

Surveying all the sources of infection it is clear that conidia are available as soon as the first leaves unfold and these give rise to secondary infections which in turn provide the inoculum for further spread of the disease. There is thus a continuing supply of conidial inoculum available from bud-burst until autumn defoliation. For most of this period, i.e. mid-May until September, the tree is producing a succession of vulnerable buds, together with a much smaller number of fruit buds which are normally susceptible only in May and June. In favourable weather, therefore, new mildew infections may continue to arise throughout the season.

Control

In controlling mildew, the ultimate objective is to eliminate overwintering stages of the fungus by protecting the buds from infection. Apart from the costly process of cutting-out mildewed organs, there is no established method of preventing conidial formation and control is therefore based mainly on the use of protective fungicidal sprays. It is unlikely that these directly prevent infection of buds for the buds when young are almost entirely enclosed between the stem and the concave face of the petiole which subtends them, and are thus shielded from spray deposition. Terminal buds and fruit buds are in addition densely invested with hairs which adds to the difficulty of providing a protectant covering.

The major effect of the fungicide, therefore, is probably to check the establishment and spread of the secondary leaf infection. As these are the source of the mycelium that invades the bud, via the petiole, control of secondary infection indirectly safeguards the bud. At the same time, it restricts the build-up of conidia which would otherwise be available for spreading the disease to leaves and, occasionally, directly to the buds.

Because of the continuing production of new foliage, and the long period of susceptibility of the terminal buds, it is apparent that spray applications in general do no more than interrupt the flow of infection.

Protection of the fruit buds, which have only a limited period of susceptibility, is more easily timed. This point was demonstrated in 1956/57 and 1957/58 in trials carried out at Long Ashton on Cox's Orange Pippin trees. Eight lime sulphur (at 1%) spray programmes were compared, namely at the stages 1*, 1+2, 2+3, 1+2+3, 2+3+4, 1+2+3+4, 3+4 and 4. Six trees were used for each comparison and there were also six unsprayed trees and six sprayed with dinocap (1 lb per 100 galls) at times 2+3. In 1957 the treatments were the same except that trees sprayed with lime sulphur at stage 1 only received instead dinocap (1 lb per 100 galls) at times 2+3+4.

Results were assessed from the percentage of mildewed trusses in May of the year following treatment. In both years pre-blossom sprays had little effect on the over-wintering potential, whereas the post-blossom sprays reduced infection to less than a quarter of that in the controls. Dinocap at 2+3+4 gave control equal to that obtained with lime sulphur applied at the same times.

The results of this trial indicated the importance of post-blossom applications in reducing fruit bud infections, pre-blossom having little effect. In the 1957-58 trial the effect of the sprays on terminal bu in-fection was also assessed but there was little correlation between the times of application and the degree of control obtained. It is suggested that this difference is related to the periods of susceptibility of the two types of bud. As noted previously, fruit buds are only susceptible to infection during May and early June, so that sprays at the petal fall and fruitlet stages (applied on the 18th May and 7th June 1956 and the 6th May and 11th June 1957) might be expected to reduce the infection of these buds. Terminal buds, on the other hand, continue development and remain susceptible throughout the growing season; in fact, those infected from July to September constitute one of the main sources of overwintering mildew infection. Obviously no direct protection can be expected at this period from sprays applied in May and June although some indirect control may result from the suppression of secondary infection in the orchard.

The necessity for controlling secondary infections cannot be too strongly emphasised; experiments at Long Ashton showed that almost 90% of the primary infections in the spring of 1957 resulted from secondary leaf infections of the previous year which had subsequently spread to the buds.

Absolute control of these infections is difficult, because of the long infection period. Investigations at the East Malling Research Station have shown that new infections continue to arise throughout the summer, and this year they have occurred as late as mid-September. Late infections of terminal leaves are particularly important as they are responsible for many of the terminal bud infections. (The majority of buds infected at this time appear normal and cannot be distinguished externally from healthy ones.)

---

* 1 = green cluster 2 = pink bud 3 = petal fall 4 = fruitlet

If the aim is to control all these infections, then spraying must be continued until the end of the growing season, when closure of the buds affords complete protection. In the Netherlands secondary infections have been effectively controlled and the number of bud infections reduced by approximately weekly applications of half-strength dinocap, extended well into August.

Changes in pruning practices have contributed much to the increase in mildew during recent years. Under the renewal and regulated systems very few extension shoots are pruned, and many apparently healthy terminal buds carrying late season infection escape detection.

In a pruning trial at Long Ashton in January 1958, 24 trees of equal girth and size from two selected plots, were renewal pruned and in addition one inch of each extension growth over six inches long was removed on half of these trees. On all trees, however, obviously mildewed buds and shoots were removed during the pruning. In June 1958 the numbers of mildew infections were recorded. On trees receiving normal pruning the percentage infection of terminal buds ranged from 16-19% whereas on those trees receiving normal pruning plus tipping, the percentage infection was 1.8 - 2.8%.

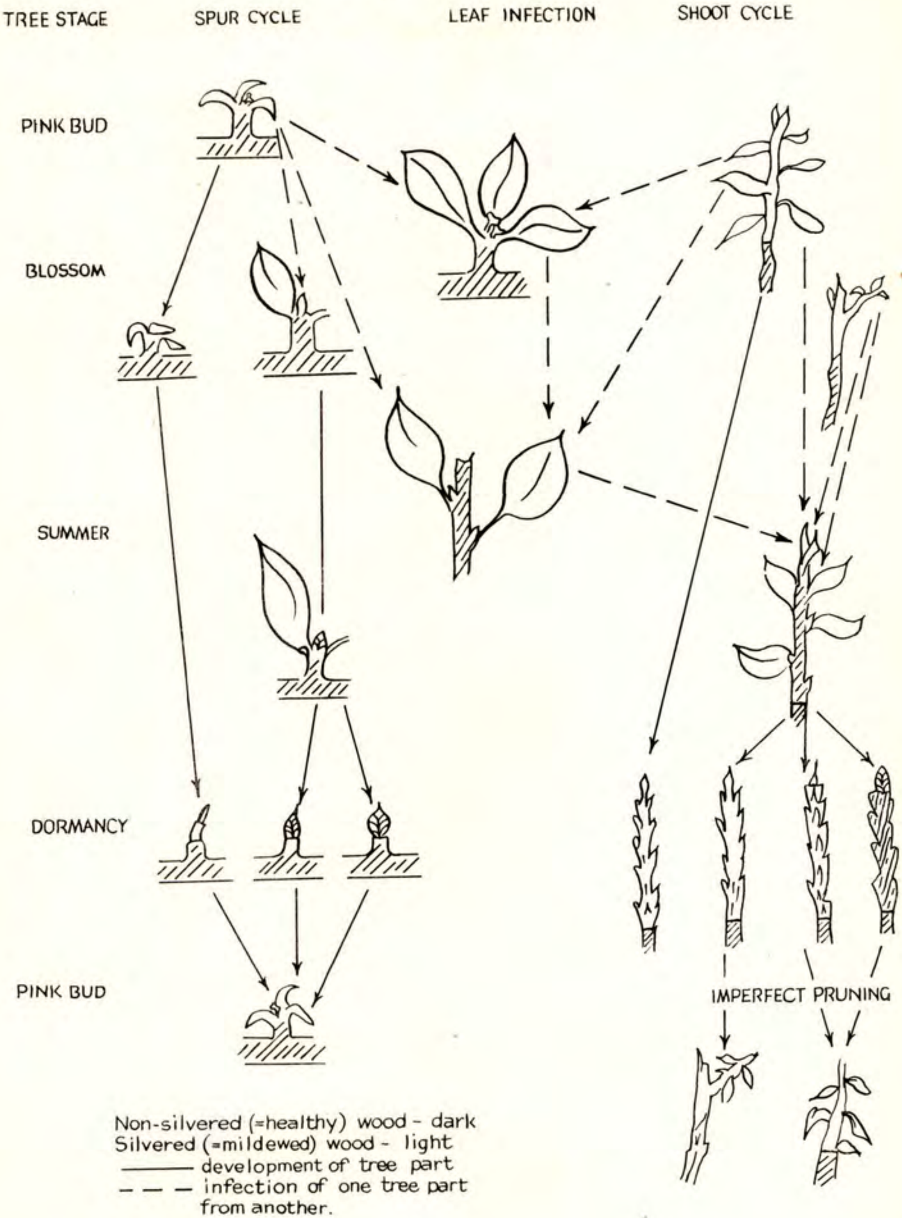
Although effective in reducing primary infections the regular use of this method of pruning would militate against proper tree management and might jeopardise tree shaping and crop production. However, a limited application of the method, or even spur-pruning, might be justified in areas of high mildew intensity.

An alternative control measure is the use of DNC/petroleum sprays applied in March (just before bud burst). M.H. Moore and Miss Bennett (at The East Malling Research Station) during the course of five years' experiments have shown the value of such applications in reducing the number of primary infections in the spring but, as with tip-pruning, this is a control measure to be recommended only in areas of high mildew infection.

A systemic fungicide capable of destroying the perennating mycelium within the buds, would no doubt be the ideal solution to the mildew problem, but until such a fungicide is developed, control must be based on the use of fungicides applied during the growing season.

The need to remove all visible mildewed shoots in winter and diseased blossom trusses and extension shoots in the spring, coupled with an intensive spray programme in the early summer, cannot be too strongly stressed. Not only will this reduce fruit bud infections, but it will also prevent a rapid build-up of the disease at a time when there are so many young susceptible leaves available for infection. A continuation of spraying until the end of the growing season although affording further protection to leaves and terminal buds may not be practical on economic grounds. Finally where control during the summer has not been satisfactory then a tipping of all extension shoots will reduce the mildew to a low level in the following year.

GENERALISED REPRESENTATION OF THE LIFE HISTORY OF APPLE MILDEW



THE LIFE HISTORY OF APPLE MILDEW AND THE FIELD ASSESSMENT OF THE DISEASE

by June V. Baker
National Agricultural Advisory Service, Cambridge

Summary

The life history of the disease is briefly described and the results of two growers trials are given to illustrate the value of recording mildew on different tree parts for different purposes.

Introduction

Apple Mildew is a complex disease for the fungus can attack all young parts of the tree during the growing season and overwinters in buds. Successful control depends on the wise use of anti-mildew fungicides and pruning methods. Both are essential, and in laying down trials using one, the other needs to be considered.

In trial work the problem of assessing the disease arises, and with apple mildew a choice appears to be available as to which tree part to observe. In spray trials, some workers have assessed secondary leaf mildew only (e.g. Sprague, 1955) while others have favoured primary mildew on the flower trusses the following spring (Hey, 1957). In survey and trial work the author has made six or seven records in the course of three visits per season to each orchard or plot, assessments being made according to the method already described (Baker, 1961). While all were of value in understanding the disease itself, the relative merits of each for different purposes also became evident.

Life history of the disease

The diagram (Fig. 1) shows the development of apple mildew through the season. There appear to be two 'cycles' of infection, the spur and the shoot cycle. One could almost exist independently of the other, but on most varieties of apple, both occur.

The spur cycle

By early pink bud, flower trusses are visible which are abnormal due to the complete coating of mildew spores on all surfaces and consequent malformation of flower parts. The number of such primarily mildewed trusses increases through the blossom period, and infected leafy trusses appear. All these are producing spores which after a few weeks begin to infect young spur leaves, so that some time in the first two weeks of May the first secondary mildew lesions can be seen on the lower surfaces of the leaves. Concurrently, infections occur in the very young buds in the axils of the leaves and also (Roosje, 1959) on the young fruitlets on flower trusses.

As the young spur buds develop, the outer scales harden and the fungus within them is cut off from external influences (among them, fungicides) and can grow freely. The bud continues to develop but if much fungus is present it becomes distorted. By autumn, when the buds are clearly visible, distorted ones are readily distinguishable from normal ones. Records made in many orchards showed (Baker, in preparation) that in the years 1956, 1957 and 1958, there was a direct relationship between the number of mildewed flower trusses in an orchard in spring and the number of distorted buds seen in autumn. In addition, however, the spurs which carried primary mildew, the soft parts of which dropped from the trees by the end of June, remain with silvered wood and small, distorted buds, and some of the normal looking buds on healthy spur wood may also harbour the fungus.

Any of these three types of bud may give primarily mildewed growth next year but most of the primarily infected buds will die, and most of the normal looking ones will be healthy, the greatest proportion of primary mildew coming from secondarily infected, distorted spur buds. Over the winters 1956-7 and 1957-8, there was a direct relation between the number of distorted buds seen in autumn and mildewed flower trusses seen the following spring.

In this cycle of infection, control is achieved by cutting out the primarily mildewed trusses at pink bud, and spraying during the blossom period to protect the young leaves, spur buds and fruitlets.

The shoot cycle

During blossom, buds on shoots produced last year, and those previously dormant on older wood, begin to grow. Some may have contained the fungus, and so produce completely mildewed tissues in the form of young shoots, spurs, a few leaves only, or, occasionally, flower trusses. These represent an additional, abundant source of spores. Whereas the 'infectors' in the spur cycle have generally died by midsummer, these may continue to develop for a longer period and, in the case of young shoots, often until growth ceases in autumn.

Spores from all primary and secondary mildew sources infect young spur and shoot leaves to give lesions on the lower surfaces, young buds on otherwise healthy shoots, and growing points of shoots (when all subsequent growth is completely mildewed). If a shoot is infected as its seasonal growth is finishing it may have only terminal bud infection.

In the shoot cycle of infection, control is achieved by spraying from blossom time onwards to prevent secondary infection of leaves, shoots and buds and pruning in winter to remove mildewed areas of shoots and terminal buds. Some primary infection may be evident at the time of spring pruning and can be removed then.

With the life cycle in mind, the effects of various treatments can be studied.

Effect of previous year's spraying, tipping in winter and late spring pruning

In 1956 in a large Essex orchard of Cox's Orange Pippin trees on type II rootstock, assessments were made on four sections which had been treated similarly except for three factors. In 1955 the grower had applied a programme of three mercury and three captan sprays to one section, whereas the rest of the orchard received two pre-blossom and two post-blossom sulphur sprays. In the sulphur area, tipping of leader shoots was carried out in winter 1955-6 in one section, late spring pruning when young shoots were developing in another, and no such treatment in the third. The results are shown in Table 1.

Table 1 Mean percentage mildew on four occasions in an Essex orchard with four different treatments

Date of observation	Part of tree mildewed	1955 No sulphur	1955 Sulphur		
			Tipped	Not tipped	
			No spring pruning	Late spring pruning	No spring pruning
25.5.56 (full blossom)	Flower trusses	16.2	-	3.6	4.4
	1955 shoots	97.0	-	30.0	46.0
11.7.56	Leaves on spurs	0.6	0.1	0.3	0.6
	" on shoots	15.4	7.9	2.3	7.3
8.10.56	1956 shoots	92.0	45.0	14.0	41.0
	Distorted spur buds	11.2	6.8	3.4	3.4
2.5.57 (full blossom)	Flower trusses	*4.0	-	-	3.4

* spring pruned before recording

The trial was not replicated and the results not analysed statistically, but it serves to illustrate the following points:-

1. For the effect of previous years' spraying, records at blossom time of mildew on both flower trusses and 1955 shoots were of value. By mid-summer, the 1956 spray programme was having an influence, but differences between non sulphur and sulphur sprayed sections were maintained throughout the 1956 season.

2. For the effects of tipping in winter, a spring count was not available: mildew on the 1955 shoots in the tipped section could not be recorded since cut shoots were not susceptible of examination. Tipping mainly affects the shoot cycle, and the percentage 1956 shoots affected in autumn was of greatest interest. In this instance, no difference was apparent between tipped and non tipped control sections. This was probably due to the marked necrogenous effect of mildew in this orchard - a good deal of bud death and shoot dieback occurred in all sections, and in the sulphur area only 3-5% completely mildewed shoots developed in 1956 even in the non tipped sections - infector shoots which might have been responsible for increased secondary leaf and young shoot infection. There were 10%

completely mildewed shoots in the no sulphur section.

3. For the effects of late spring pruning, the results of most value were those on shoot leaves in midsummer and 1956 shoots in the autumn. The operation was done too late to influence the infection of young spur buds, and affected the shoot cycle most of all.

Effects of current season's spraying and early spring pruning

In 1957 in a Suffolk orchard of Cox's Orange Pippin trees on type II rootstock, assessments were made on eight sections. The grower applied four different anti-mildew spray programmes, with one replication of each. All sprays were applied at normal commercial rates on the same dates, but materials used at pink bud and blossom or from mouse ear to early fruitlet varied: before and after this they were either lime sulphur or wettable sulphur. Within each of one set of four sections, no anti-mildew spring pruning (4 trees only) and very thorough pruning (4 trees only) were compared with commercial pruning at pink bud (rest of section). The results are shown in Table 2.

Table 2 Mean percentage mildew on four occasions in a Suffolk orchard with seven different treatments

Date of observation	Part of tree mildewed	Spray treatments (Commercial pruning)				Spring pruning (all spray treatments)		
		Sulphur throughout	Dinocap pink bud and blossom	Dinocap mouse ear to fruitlet	Dinocap plus sulphur pink bud and blossom	None	Commercial	Thorough
7.5.57 (full blossom)	Flower trusses	2.3	2.1	2.4	2.7	12.3	2.4	0
	Leafy trusses	15.5	-	-	21.8	18.0	18.7	0
18.6.57	*Leaves on shoots	26.5	18.3	14.3	7.2	19.0	15.8	16.7
	1957 shoots	11.9	10.0	10.0	4.4	16.3	11.3	6.3
11.10.57	Distorted spur buds	3.9	2.0	1.4	3.0	8.0	1.9	1.3
1.5.58 (early blossom)	Flower trusses	1.9	0.8	0.3	0.8	2.0	1.0	0.7

* Topmost 14 leaves on eight leading shoots per treatment examined for secondary lesions.

1. For the effects of current season's spraying, affecting both the spur and the shoot cycle, the shoot leaf, shoot, bud and flower counts were all of value. It is worth noting, however, that whereas for shoot leaf and shoot records, the two dinocap treatments had similar effects, with dinocap plus wettable sulphur being rather better, all the treatments containing dinocap were similar for bud and flower infections, and somewhat better than the all-sulphur programme.

2. For the effects of spring pruning here, the shoot, bud and flower figures were of more value than the leaf counts, the shoot and bud counts showing clear differences.

In this orchard, a commercial preparation containing DNC was used just before bud burst in 1958, and whether or not this influenced the proportion of flower trusses appearing which were mildewed could not be determined: but in fact rather less than one half of the amount of flower trusses were mildewed in spring than spur buds distorted in the autumn, and the bud records gave more recognisable differences.

Discussion

A case can be made out for using each one of the six different records for mildew, and others, such as leafy trusses in spring or even fruit russetting at harvest, can be added. No generalisation can be made as to which are the best to use, as requirements for trials differ. In a single trial, leaf assessments may well be of value. Where several orchards are to be compared with each other in any one season, leaf assessments are less reliable as they cannot always be done on the same day or even within the same week. For this type of work the more 'static' counts of distorted buds (which can be done any time from late summer to just before bud burst) or shoots (from the cessation of growth until winter pruning time) or flower trusses (pink bud to spring pruning time - a rather shorter period) are probably more reliable.

In conclusion, experience in survey and trial work has shown that the complexity of the apple mildew disease is such that the most valuable information is gained when assessments are made on more than one occasion and on more than one tree part.

Acknowledgements

Grateful thanks are expressed to members of the Plant Pathology Department at Cambridge, and to N.A.A.S. Horticultural Officers Mr. A.D. Todhunter and Mr. R.W. Rennison, who all assisted with the assessments; and to the owners of Spring Grove Orchards Ltd., West Bergholt, Colchester, and Mr. C.R. Thompson, of Risby Fruit Farms Ltd., Risby, St. Edmunds. The author also wishes to thank Mr. W C. Moore, Director of the Plant Pathology Laboratory, Harpenden, for providing accommodation and facilities for preparing the apple mildew work for publication.

References

BAKER, J. V. (1961). Plant Path. 10, 32.
HEY, G. L. (1957). Grower, 47, 800.
ROOSJE, G. S. (1959). Jversl. Proefst. Fruit in de volle grond. Wilhelminadorp 1959, 42.
SPRAGUE, R. (1955). Bull. Wash. St. Coll. agric. Exp. Sta. 560

WINTER AND SPRING PRUNING AGAINST APPLE MILDEW

by June V. Baker
National Agricultural Advisory Service, Cambridge

Summary

Trials and shoot observations have shown that particular attention is needed to the position of the cut when pruning shoots in the winter, and that timing is important when removing mildewed flower and leaf trusses in spring.

Introduction

The fungus causing Apple Mildew, Podosphaera leucotricha, is a very successful parasite. Once it becomes established within developing buds it is locked away from potential destruction. Thus once a neglected apple tree has been attacked, infection is likely to remain on it indefinitely, unless all the infected buds are destroyed in a severe winter, which seems to be a rare occurrence in this country.

The two main means of controlling the disease at present are: (a), the application of suitable fungicides to prevent infection or to arrest it in the early stages of development and (b), the excision of invaded buds either when dormant (i.e. those on shoots) or a few weeks after bursting (i.e. those on spurs). This paper is concerned with the latter.

Winter pruning of the one year old shoots is an accepted practice in commercial orchards of certain varieties of apple and mildew infection can be cut out at this time. Pruning of the spurs at blossom time is rarely done for any other purpose than to remove mildew infection. It is important to know, for winter pruning, which parts of attacked shoots need to be removed, and for spring pruning, at what time the operation can best be done. Observations made in various orchards in East Anglia, all on the variety Cox's Orange Pippin, are described to illustrate these points.

Winter Pruning

Invaded buds on shoots formed in the previous season may occur either on silvered wood, that is, wood which developed from mildew infected growing points during the growing period, or on non-silvered, healthy wood. When on silvered wood, distorted buds occur consecutively along the shoot, whereas on 'non-silvered' wood they tend to be scattered, since each invaded bud represents a separate infection whether by mycelium or by spores. However, observations on one hundred marked shoots in each of four orchards in 1958 indicated that the first three buds immediately behind a silvered area were more likely to break in a mildewed condition than those more widely separated from the silvered area: also that on a healthy looking, non-silvered shoot, the first five buds (including the terminal bud) were more likely to break mildewed than any others. This result is detailed in Table 1. Dead and dormant buds were not included in the calculations.

Table 1 Percentage of growths showing primary mildew developing from buds on 1957 shoots in May 1958

Orchard (Parish and County)	Date of examination and tree stage	Non silvered shoots		Silvered shoots		
		Up to 5 buds from tip	6th bud to base of shoot	Within silvered area	Up to 3 buds below silvered area	From 4th bud below silvering to base of shoot
Burlingham (Norfolk)	May 15th Late blossom	5.8	0	19.8	4.9	0
Orwell (Cambs.)	May 6th Early blossom	8.9	1.7	16.7	11.7	0
Wisbech St. Mary (Cambs.)	May 15th Late blossom	14.9	3.0	17.9	18.8	4.6
Bradfield St. Clare (Suffolk)	May 9th Full blossom	16.5	0	26.8	11.3	4.2

Midsummer and post harvest recordings indicated that a good deal more primary mildew showed up after the blossom time observations. Some of the mildewed growths dropped from the trees however, so that by the end of the season much the same amount of primary mildew was visible as in May. A primarily mildewed growth took the form of a shoot, a dard, a spur, or perhaps only one or two leaves and a bud on the 1957 shoot. Of the mildewed shoots which developed, all came within the range of five buds from the tip of a non silvered 1957 shoot or up to three buds beyond the silvered area of a mildewed 1957 shoot.

These findings were used in two ways in 1959 and 1960. In a three year replicated pruning trial begun in 1958, the shoots of treated trees were pruned in such a way that when tipping, the topmost five buds were removed and when cutting silvered shoots, the cut was made between the third and fourth bud below the silvered area.

In shoot development observations on 330 shoots in one orchard in 1959, pruning by this method was compared with pruning away only obviously distorted terminal buds and silvered parts of shoots, and with unpruned shoots. It is worth noting that in the pruning trial, a rather better control was effected in 1959 and 1960 using this method, than by the less precise pruning done in 1958, and that in the shoot observations, this method was preferable to that where only obviously mildewed growth was removed.

The pruning trials, in addition, showed that there was no carry-over of any effect of winter pruning from one year to another. This is shown in Table 2, where the figures for primary shoot mildew on one year shoots have been converted to square roots and analysed statistically.

Table 2 Mildewed shoot production on one year shoots on trees with silvering plus tips removed compared with untreated trees.

Orchard (Parish and County)	Experimental pruning was -			
	for the first time	for the second time	residual from 1958	
			in 1959	in 1960
Orwell (Cambs.)	-1.40* ± .37	-1.38* ± .34	.00 ±.62	-.71 ±.47
Wisbech St. Mary (Cambs.)	-1.50* ± .38	-1.46* ± .62	-.75 ±.58	-1.23 ±.81

In practice it appeared that although mildew carried in shoot buds from infections the previous summer could rarely be eliminated, it could be substantially reduced by careful winter pruning, but that this operation needed carrying out every year, as the benefit in summer from doing it the previous winter was probably not carried over to the summer after next. It is worth adding that with the more precise methods employed, no more time seemed to be taken than with more haphazard methods of riddling the trees of mildew. However, the recognition of silvering, on which the method depends, is easier when the shoots are dry rather than when soaked by rain, dew or mist.

Spring Pruning

In a survey of Cox's Orange Pippin orchards in East Anglia from 1956-8, it was found that about half of the growers whose orchards were recorded for mildew had removed mildewed trusses during the blossom period. The cost per acre of this operation varied, but for three growers who supplied estimates it ranged from £10 to £20 on established trees, and a fourth grower, having reduced mildew by other means in addition, recorded a drop from £18. per annum in 1957 to £3 in 1958 in one of his orchards.

Observations made on 10 occasions from bud burst onwards in 1957 on 55 marked spurs on Cox's Orange Pippin trees in an orchard at Coton, Cambridgeshire, showed that primary mildew was apparent from green cluster onwards, reaching a maximum by blossom time in the floral buds and petal fall in the vegetative buds. Spur tissues could appear healthy after bursting for up to four weeks before showing characteristic symptoms of primary mildew. By early pink bud approximately 50 per cent of the total primarily mildewed trusses had shown up.

Such information as this might indicate that removal of primarily mildewed trusses could best be done at blossom time. However, in some seasons, secondary mildew has appeared by this time. This trend is illustrated by details for four seasons in Table 3.

Table 3 Flowering periods on Cox's Orange Pippin trees in East Anglia from 1956-9 and dates of first observation of secondary mildew on leaves

	Pink bud	Petal fall	Secondary mildew
1956	April 23rd - May 16th	May 23rd - June 1st	May 11th
1957	April 10th - 25th	May 4th - 22nd	May 15th
1958	April 30th - May 5th	May 12th - 27th	May 13th
1959	April 18th - 26th	May 11th - 19th	May 11th

Thus in many orchards secondary mildew first appears after pink bud, and before petal fall.

Observations on the effects of spring pruning in survey orchards and in growers trials have led to the conclusion that the most advantageous time to carry out spring pruning is before full blossom. Primary mildew will appear after this in the form of flower and leaf truss mildew, and a few growers are able to go over the orchards a second time: but even where mildew is serious, one attempt at removing the primary sources of infection may well be of great benefit. Reference to Table 2 in the previous paper (p.176) shows, in the spring pruning section, that commercial pruning, done in mid-April (pink bud), gave satisfactory reduction of distorted spur buds, while thorough pruning, also done in mid-April, but again May 1st to 8th (late blossom) gave little or no better reduction of distorted spur buds, yet appeared to be associated with a reduction of secondary mildew in the young shoots.

Discussion

Evidence given by various workers (Kosswig, 1958, Burchill, 1958) emphasises the importance of tipping to remove overwintering shoot infection. The author's observations support this, and in addition suggest that when cutting silvered shoots from the trees, a short piece of non-silvered wood behind the silvered area should also be removed. Neither tipping nor silvered shoot removal is, however, practicable on large trees of culinery varieties such as Bramley's Seedling. If shoot mildew becomes a problem on them, the most suitable control measure would probably be to spray towards the end of the growing season with a fungicide such as dinocap to prevent infection of the shoot tips.

Removal of mildewed flower trusses is often advocated, and practised, but it is not known at present above what level of infection this is advisable. It may be, for instance, that at levels below 2 per cent, the operation becomes unnecessary, because other sources of mildew are later available and may even be more potent than this. Certainly, at 5 per cent, flower truss mildew begins to look quite serious on a tree, and many growers who normally consider spring pruning, would do so. Again 2 per cent in an isolated orchard may be worth removing to keep the disease in check, whereas 2 per cent in an orchard in an intensive apple growing area may not be. This matter needs further examination.

Finally, while this paper refers only to removal of existing infection, mention should be made of the infection process itself. Research workers in the past have studied the infection conditions required for leaf infection. If a study could be made of the requirements for young bud infection, and infection of the very susceptible tips of growing shoots, progress might be made towards recommendations for spraying when infection conditions obtain, so that pruning away established infection becomes less necessary. It may well be that there are only a few days in the whole of the growing season when conditions are suitable for widespread bud and growing point infection.

Acknowledgements

The author is most grateful to members of the N.A.A.S. Plant Pathology Department at Cambridge who assisted in so many ways, and particularly to Mr. G H. Brenchley for his encouragement in this work. Thanks are also due to the many growers who co-operated with us in trial and survey work, to Mr. B.M. Church at Rothamstead Experimental Station who arranged for statistical analyses on some of the results, and to Mr. W.C. Moore who provided accommodation and facilities for writing up the work.

References

BURCHILL, R.T (1957). Ann. Rep. Long Ashton Res. Sta. 1958, 114.
KOSSWIG, W. (1958). Höfchen-Briefe, 1958, 11, 14.

THE IMPORTANCE OF SHORT TIME INTERVALS BETWEEN SPRAYS AGAINST APPLE POWDERY MILDEW

by G. S. Roosje
Institute of Phytopathological Research, Wageningen.
- attached to Fruit Research Station, Wilhelminadorp.
The Netherlands

Introduction

Apple powdery mildew is nowadays considered to be the predominant fungus disease in apple culture in the Netherlands. The disease has been known for many decades, but did not cause excessive damage before about 1950.

A factor that could be responsible for the increased importance of the disease since about 1950 is the strong expansion of the very susceptible variety Jonathan after 1945 on which mildew overwinters more readily than on most varieties. Another factor, which is certainly also responsible for the increased incidence of mildew after 1950 is the change from inorganic sulphur compounds for scab control to the organic fungicides, such as organic mercury compounds, ziram, thiram, 2,4-dinitro-thiocyanobenzene and captan, which meant a change from fungicides active against apple mildew to fungicides not or only slightly active in this respect.

It is possible that more virulent strains of the causal fungus have arisen in the last decade, but there is no evidence to support this possibility.

Since apple mildew became a major problem on susceptible varieties investigations on this disease have been intensified in many countries including the Netherlands.

The purpose of the investigations carried out in the Netherlands was to gain more information regarding the conditions favourable for mildew infection and also to improve mildew control by spraying according to critical phases in the development of the fungus.

Damage by apple mildew

On shoots and leaves

In 1959 mildew damage was assessed on Jonathan trees on which no mildew control had been practised in that year. It was found that the leaves formed between May and the middle of July had 55% of the undersurface covered with mildew; by 23rd July 36% of the long shoots were overgrown by the fungus and at the end of the season 98% of the terminal buds of the long shoots were infected. It was also found, that the length of long shoots on trees heavily infested with mildew was 18% less than on trees with only a light attack.

On quantity of fruits

Our own experiments and those of other Dutch investigators show, that the loss of crop in the year in which a severe mildew attack occurs for the first time varies from 0 - 20%. Müller (1957) also reported no influence of severe mildew attack of the leaves on the yield in the first year. But in years following a serious attack, more severe losses have been reported.

In a particular experiment the average yield per tree in 1959 of Jonathan on M IX, which had not been sprayed against mildew in 1958 and were therefore seriously attacked, amounted to 5,4 kg, whereas comparable trees which received 12 sprays (4 times o,5% of a proprietary mixture of wettable sulphur and captan followed by 8 times 0,12% Karathane WP*) against mildew, yielded 18,7 kg per tree. All the trees were treated uniformly in the season 1959. So this experiment showed a reduction in yield of about 70% as a result of a severe mildew attack in the previous season.

Uitterlinden (1960) also reported 45% reduction in yield in 1959 of Jonathan on M IV not sprayed against mildew in 1958 in comparison with trees treated 8 times with 0,12% Karathane WP.

A third experiment reported by Immikhuizen and van der Waal (1961), showed 75% reduction in yield on Jonathan trees, where removal of the overwintered infection and spraying against mildew had been omitted in the previous season. In a fourth experiment reported on by the same authors, a reduction in yield of about 30% resulted on unsprayed trees in comparison with trees, which were sprayed 15 times with 0,06% Karathane WP in the previous season.

These Dutch data agree very well with data published by Müller (1957) for the variety Krügers Dickstiel. He reported that trees not treated against mildew in 1952 had about twice as much mildew attack as trees treated in that year, which resulted in 1953 in 63% reduction of the yield. Trees which were not sprayed in 1952 and 1953 showed an 84% reduction of yield in 1954. In Hungary Czorba (1956) found in three experiments on Jonathan, that a severe mildew attack in 1954 reduced the yield in the next year experiments respectively by 43%, 51% and 57%.

On quality of fruits

Mildew attack of the fruits of some pear varieties, especially Doyenne du Comice, is well-known, but is not often serious. The mycelium and later in the season also the perfect stage of the fungus can easily be detected on the skin of pears, even when the fruits approach maturity. Cunningham (1923) reported that apple mildew caused a brown or yellowish russeting on the fruits of some apple varieties in New Zealand. A weblike russeting on Jonathan fruits has also been recognised as due to mildew by Sprague (1955) reporting from the western fruit growing area in the U.S.A.

---

* Karathane WP is a formulation of dinocap and contains 22,5% 2-(1-methylheptyl)-4,6-dinitrophenyl crotonate and 2,5% dinitrocapryl phenol.

The mildew fungus does not persist on the Jonathan apple fruits until maturity as it does on pear fruits. Sprague (1955) stated that infection of the ovary at pre-bloom period resulted in a fine expanded webbing of the mature fruit; he could reduce the percentage of fruits with weblike russeting by early sprays against mildew from 41% in unsprayed trees to less than 10% and in one case even to less than 1% in unsprayed trees.

Our trials, summarised in Table 1, demonstrate also, that the occurrence of weblike russeting of Jonathan fruits can to some extent be prevented by early sprays against apple mildew. The 1959 trial proved that in this year only the sprays applied before 11 May, i.e. before petal-fall, were effective in preventing russeting. The results of the 1960 trial indicated, that the period between 29th April and 9th May, i.e. the blossom period, must have been highly conducive for the occurrence of this type of russeting.

Table 1 Russeting of Jonathan apples by apple mildew

Trial in year	Sprays against apple mildew	Period of sprays	Percentage of fruits with weblike russeting	
			on M IX	on M XVI
1958	4 x 0,5% Compound A* and 8 x 0,12% Karathane WP	1 May - 13 August	5,7	9,3
	None	-	18,0	27,2
1959	14 x 0,06% Karathane WP	20 April - 21 July	25,4	19,0
	4 x 0,06% Karathane WP	20 April - 11 May	18,6	13,4
	4 x 0,06% Karathane WP	11 May - 2 June	36,8	44,5
	None	-	46,3	39,8
1960	6 x 0,5% wettable sulphur and 10 x 0,12% Karathane WP	23 March - 16 August	11,8	
	2 x 0,5% wettable sulphur and 10 x 0,12% Karathane WP	29 April - 16 August	13,9	
	1 x 0,5% wettable sulphur and 10 x 0,12% Karathane WP	9 May - 16 August	25,0	
	None	-	24,1	

* Compound A is a proprietary mixture of wettable sulphur and captan.

The results of several experiments carried out in the Netherlands agree very well with those obtained by Sprague, although the reduction of russeting obtained was generally less.

The damage of mildew to quantity and quality of the production as shown above will justify even expensive control measures, though the growers are often unaware of the damage that mildew can cause.

The next paragraphs will deal with observations made and the experiments undertaken for the purpose of improving knowledge of the biology of fungus.

Observations on the weather conditions favourable for infection by apple mildew conidia

Hammarlund (1925) considered dry conditions to be favourable for the production and spread of the conidia. Yarwood (1957) expressed the opinion that mildew conidia do not require humid conditions for germination and infection, though Fisher (1956), Berwith (1936) and Stoll (1941) held the opposite point of view on apple mildew.

Nover (1957) working on powdery mildew of wheat and barley found that low atmospheric humidity did not stop germination, - possibly because of the high water content of mildew conidia - , but he ascertained a much better germination and rate of infection at a high relative humidity (RH).

In March 1956 some Jonathan trees on M IX, about six-year old, severely infested with mildew, were planted in an open place at about 1 km from the nearest apple trees. 128 two-year old heavily pruned Jonathan trees were then planted in five concentric circles around the source of infection. The 128 trees were planted in such a way that the field could be divided in 16 sectors with 8 trees each. The diameter of the field was about 20 metres (66 feet). Around the field a poplar windscreen was planted, which was not allowed to grow higher than 3 metres (10 feet). Temperature-, humidity-, and wind direction recorders were placed in or near the observation field.

During the growing seasons of 1956 up to 1959 the numbers of newly infected leaves per tree in the different sectors were counted almost daily. At the same time the infected leaves were removed from the field. The results of the counts are summarised in Table 2.

Table 2 Mildew counts in circular experimental field in 1956 up to 1959

Year	Period of mildew counts	Number of days in the check period	Number of counts	Number of days on which mildew was found	Peaks of attack on the dates
1956	24 May - 31 August	100	83	82	29/6, 12-15/7, 27/7, 17-18/8
1957	17 May - 5 September	112	93	92	18-19/6, 23-26/7
1958	19 May - 22 August	96	79	79	29-31/5, 7/6, 17/6-21/6, 26/6
1959	12 May - 18 August	99	83	80	24-28/5, 2/6, 9-10/6, 24/6, 16/7

It is evident from Table 2, that newly attacked leaves were found almost every day after the first lesions appeared. The first new mildew spots on Jonathan on untreated trees in a commercial orchard were found in 1956, 1957, 1958, 1959 and 1960 on 24 May, 4 May, 14 May, 4 May, and 25 April respectively.

The total numbers of infected leaves of all the peaks of attack in a given year and the total numbers of infected leaves on all other days are assembled in Table 3.

Table 3 Data obtained from the circular mildew experimental field from 1956 till 1959 inclusive

Year	Period of count	Number of peaks of attack	Total number of leaves found attacked in peaks of attack A	Total number of leaves found attacked on other days B	Ratio B : A
1956	24 May - 31 August	4	346	1025	3,0
1957	17 May - 5 September	2	593	1943	3,3
1958	19 May - 22 August	4	991	1770	1,8
1959	10 May - 18 August	5	1324	3127	2,4

The data of Table 3 indicate, that the sum total of all leaves attacked during peaks of attack has been less than the attack on all the other days together. This does not seem very promising for the development of a control programme based on spraying according to meteorologically defined infection periods. (See paragraph 3).

The correlation* of peaks of attack and meteorological data recorded 7 - 10 days previously suggests that a period of rather warm and dry weather followed by a period of high RH favours the occurrence of infection by apple mildew conidia.

Accordingly we set up the working hypothesis, that favourable conditions for apple mildew development prevailed when at least one day with high RH (above 80% at 10.00 a.m., 1.00 p.m. and 4.00 p.m.) followed one or more days with low RH (less than 70% at 10.00 a.m., 1.00 p.m. and 4.00 p.m.).

Attempts to control apple mildew by spraying according to specific weather conditions

Aerts and Soenen (1955) concluded from their observations in the field and from the results of artificial inoculations, that infection can only take place at temperatures higher than 20°C. They considered a temperature exceeding 20°C to be the main factor for mildew infection to succeed.

* I am indebted to Dr. J.J. Post, formerly attached to K.N.M.I. for his help in interpreting the observations.

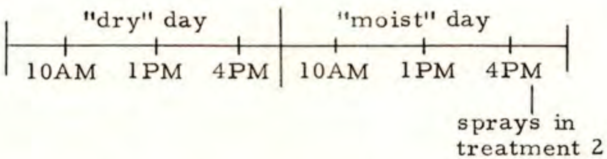
Berwith (1936) observed infection by conidia at temperatures between $13^{\circ}C$ and $25^{\circ}C$. Müller (1957) also proved that infection can occur at temperatures below $20^{\circ}C$. Our own observations made in the circular experimental field described above showed for instance, that new mildew spots appeared almost every day between 7 June and 29 June in 1956, although the daily maximum temperatures, measured in a meteorological screen, remained between $13^{\circ}C$ and $17^{\circ}C$, and only on three occasions exceeded $15^{\circ}C$. In 1961 the first new mildew spots were found on Jonathan on 25 April though only on 6 April did the maximum temperature rise above $20^{\circ}C$, a temperature was not reached again until 5 June; but on 5 June unsprayed trees in commercial orchards had already developed a severe attack of mildew. We must conclude that in our country mildew infections can occur at temperatures below $20^{\circ}C$.

In 1958 three field experiments on Jonathan were designed to test the validity of the working hypothesis mentioned above, in co-operation with the Plant Protection Service, Division Utrecht and the Horticultural Advisory Service at Barendrecht, who carried out two of the three experiments. The Royal Netherlands Meteorological Institute provided the requisite weather data.

The different treatments and the results of one of these experiments, carried out at Wilhelminadorp, are given in Table 4.

The sprays in treatment 2 were carried out in the afternoon of the moist day as indicated by the scheme:

1958 scheme



No sprays were applied in treatment 2 when critical conditions occurred within 8 days after the previous spray.

Table 4 Mildew control experiment at Wilhelminadorp, 1958

Treatment *	Number of sprays	Percentage of leaves attacked **
Spraying at regular intervals of 8 - 10 days	12	14
Spraying at the end of a "moist" day after a "dry" day ***	5	50
No mildew spray	0	80

* 0,5% of a mixture of captan and wettable sulphur was used in sprays up to 30 May, after this date 0,12% Karathane WP.
** Average of 5 counts on different levels of the long shoots.
*** Applications were made on 30 May, 20 June, 2 and 16 July, and 4 August.

It appears from Table 4 that the 5 directed sprays in treatment 2 were less effective than the 12 sprays applied irrespective of the weather conditions. The results of the other two experiments carried out in 1958 agree fully with the results of the experiment at Wilhelminadorp. A possible explanation for the insufficient control by treatment 2 could be found in lack of curative action because the fungicides were applied at the end of the moist day, i.e. the supposed infection day. Accordingly a different scheme was followed in two trials, carried out in 1959. The treatments and the results are given in Table 5, whereas the scheme below shows when the sprays in treatment 2 and 3 were applied.

1959 scheme

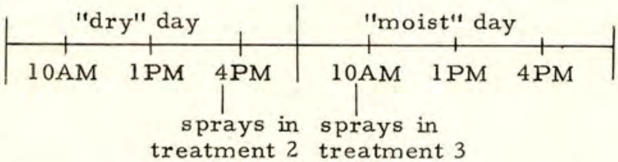


Table 5 Mildew control experiment at Wilhelminadorp in 1959

Treatment (with 0,06% Karathane WP)	Number of sprays	Percentage of leaves attacked *
At regular intervals of 7 days	14	20
On afternoon of a "dry" day	12	22
On morning of a "moist" day after a "dry" day **	3	55
No mildew spray	0	65

* Average of 3 counts on different levels of the long shoots.
** Applications were made on 16 May, 26 May and 26 June.

It appears from Table 5 that the third treatment was totally inadequate though sprays were applied earlier on the supposed infection day than in 1958. Treatment 2 was as good as regular spraying, doubtless because the season of 1959 was exceptionally dry. Indeed the number of sprays applied in treatment 2 approached that of treatment 1.

The results of the second experiment carried out in 1959 by the Plant Protection Service, Division Utrecht, agreed with those of the trial at Wilhelminadorp.

The probable explanation of the inadequate results of the few directed sprays has to be sought in the ratio B : A of Table 3, indicating that the combined effect of many little infection periods is more important than that of 2 to 5 infection peaks.

The idea of a schedule of sprays directed to favourable weather conditions for infection was accordingly abandoned.

Further study of the temperature and humidity requirements for germination of apple mildew conidia

In 1957 and 1958 J. J. Post (formerly attached to K. N. M. I.) carried out many experiments on the temperature and humidity requirements for germination of and resulting infection by mildew conidia. He used saturated solutions of different salts to maintain specific humidities of the air of desiccators provided with circulating fans. Shoot ends (2 to 3 leaves) of Golden Delicious were placed in tubes with water in the desiccators immediately after inoculation of the shoot ends.

It appeared from experiments carried out by this method that infection can occur at all the tested humidities, i.e. 90%, 84%, 69%, 48%, and 40% RH.

In 1958 and 1960 inoculation experiments were carried out at Wilhelminadorp with potted M II and MM 111 rootstocks reared in a greenhouse, to investigate further the range of temperature and humidity conditions under which infection by mildew conidia can occur. Inoculation was effected in 1958 by shaking mildewed shoots above the plants. In 1960 the plants were inoculated in a way similar to that described by Kirby and Frick (1960). The plants were brought into a conditioned room one hour after inoculation. In the experiments from 1958 infection resulted at:-

15,5° C and 55% RH	20° C and 54% RH
16° C and 79% RH	20,5° C and 71% RH
18,5° C and 54% RH	21° C and 82% RH

In the experiments during 1960 infection was successful at:-

11° C and 80% RH	20° C and 42% RH
15° C and 40% RH	20° C and 80% RH
15° C and 80% RH	20° C and 98% RH

These experiments show, that infection can occur under widely varying conditions of temperature and relative humidity, though it should be borne in mind that these are greenhouse experiments (see section 6). The most striking feature, which indicates the difference in behaviour of apple mildew on greenhouse grown and on outdoor apple leaves is the fact that on outdoor leaves the attack is limited to the under surface, whereas the attack on greenhouse leaves is mainly confined to the upper surface.

These laboratory studies, like those of the circular field give no hope for effective control by spraying according to specific weather conditions.

It may be concluded from sections 2 and 4 that the young leaves have to be covered permanently with a protective layer of a suitable fungicide if mildew infection is to be prevented. Now the question remains how long the intervals between sprays should have to be to meet this requirement.

Determination of the maximum effective intervals between sprays against apple mildew

Redistribution of fungicide from older leaves to younger leaves occurs mainly through rainfall. Constant coverage of the younger leaves of growing shoots can in a rainless period only be attained by frequent spraying, because the growing shoots develop new leaves every few days.

From their field trials Groves, Wampler and Lyon (6) drew the conclusion, that the most efficient way to utilise a mildew fungicide (Karathane WP) is to apply small amounts at frequent intervals. According to one of their trials spraying once a week with 0, 03% Karathane WP was equal in effectiveness to spraying once in two weeks with a concentration between 0, 09% and 0, 12% Karathane WP. In a second experiment 0, 03% Karathane WP once a week had about the same effect as 0, 09% Karathane WP once in two weeks, whereas 0, 03% Karathane WP once a week in their third experiment resulted in better control than even 0, 12% Karathane WP once in two weeks.

Sprays against apple mildew were in the Netherlands originally applied with 10 - 14 days or even longer intervals. Many mildew control experiments were carried out in the Netherlands by official institutions in which 0, 1 - 0, 12% Karathane WP was applied at 10 - 14 day intervals, whereas also many experiments were undertaken in which 0, 06% Karathane WP was applied at 7 day intervals. Although a direct comparison of the schedules was not made in official experiments, the indications were that a better control was obtained, with sprays with 0, 06% Karathane WP at one week intervals than with 0, 12% Karathane WP at two week intervals.

Although spraying every week with 0, 06% Karathane WP or a low concentration of sulphur compounds can reduce mildew attack to a level probably economically unimportant, the results are in fact unsatisfactory, for it appeared from many experiments, that 10% to 30% of the leaves of Jonathan are infected even when the trees were sprayed every week with a suitable fungicide. In 1959 two field trials were conducted to investigate whether the degree of control reached with weekly sprays could be lowered by spraying two to three times per week. The results of one of these trials are summarised in Table 6.

Table 6 Control of apple mildew with 0,06% Karathane WP at different intervals

Total number of sprays between 20 April and 21 July (13 weeks)	Count* 13 May % infected leaves	Count* 10-15 June		Count* 16-17 July	
		% infected leaves	Rating**	% infected leaves	Rating**
14	5,9	32,3	28,1	23,1	21,0
34	1,7	0,7	0,4	0,9	0,5
0	40,4	75,1	243,3	78,7	139,3

* In each count leaves of different levels of the shoots were examined.
** Rating means: % infected leaves x % coverage of under-leaf surface of infected leaves, divided by 10.

It appears from Table 6 that near perfect mildew control was attained by spraying two to three times per week. Apparently constant coverage of newly expanded leaves had been reached. But of course such a tight schedule of sprays presents insuperable practical difficulties. Fortunately it is probably unnecessary from an economical point of view to get a better control than the level which is reached by weekly sprays. But the trial shows again the importance of short time intervals. The second field trial with short intervals, carried out by the Plant Protection Service, Division Utrecht gave similar results Immikhuizen and Waal, (1961).

Since many fruitgrowers operate automatic mist blowers or speed sprayers, spraying is no longer considered an arduous task. Hence, spraying every week between pink bud stage and the end of extension growth with a suitable fungicide in low concentration could be recommended officially in the Netherlands as a practical system to control apple mildew.

The curative action of mildew fungicides

It appeared, in 1960, from inoculation experiments on potted seedlings reared in a greenhouse at Winchester Fruit Research Laboratory, U.S.A.*, that 0,06% Karathane WP exerted an effective curative action, even when applied 86 hours after inoculation. Further experiments on potted apple rootstocks at Wilhelminadorp in 1961 showed complete curative control of mildew by 0,03% Karathane WP applied 48 hours after inoculation. The experiments also suggest a curative action of 0,25% and 0,04% wettable sulphur if applied 24 hours after inoculation.

---

* The author stayed at Winchester Fruit Research Laboratory, Winchester, (Virginia), U.S.A., from April - July 1960, mainly to carry out research on apple powdery mildew. He is indebted to Dr. A.B. Groves, plant pathologist at forementioned laboratory, for his useful suggestions.

In the orchard, the practical importance of the curative action of Karathane WP and wettable sulphur does not appear to be great for complete control can only be obtained by spraying every two to three days. Apparently the composition of apple leaves, grown in a greenhouse, differs importantly from outdoor leaves. Though, preliminary comparisons of the activity of different fungicides against apple mildew can be made with uccess in greenhouse tests.

Summary

Since 1956 studies have been made in the Netherlands on the weather conditions favourable for infection by apple mildew conidia. These observations led to the hypothesis that the most favourable weather conditions for infection by the conidia were at least one day of high relative humidity followed by one or more days of low RH.

The hypothesis has been tested by field experiments in 1958 and 1959. The control achieved by spraying according to this hypothesis was less than by spraying at regular intervals. A probable explanation for this failure is given. The conclusion was reached that mildew infection can take place during periods when the maximum temperature (measured in a meteorological screen) remains considerably below 20° C.

In 1959 and 1960 inoculation experiments on potted M and MM apple rootstocks, reared in a greenhouse, were carried out to verify the data derived from the field observations. Infection occurred over widely varying conditions of temperature and relative humidity.

The level of mildew attack in orchards after spraying every seven days is still rather high. In 1959 two field experiments were conducted to show that complete control of mildew can only be reached by more frequent spraying but spraying so frequently is impractical.

Infection and spraying experiments on greenhouse plants showed a remarkably strong curative action of both dinocap and wettable sulphur. The practical significance of this curative action could not be assessed under outdoor conditions, because the exact date of infection periods are unknown, but the poor results of sprays against apple mildew do not indicate that it is of importance.

References

AERTS, R. et SOENEN, A. (1955). Comptes Rendus de Recherches, I.R.S.I.A. 15, 57.

BERWITH, C.E. (1936). Phytopathology, 26, 1071.

CSORBA, Z. ès FEHÉRVÁRI, G. (1956). A Kiserletügyi Közlemények, 169.

CUNNINGHAM, G.H. (1923). N. Zeal. J. Agric. 26, 344.

FISCHER, R. (1956). Tätigkeitsbericht 1951-1955 Bundesanstalt fur Pflanzenschutz, Wien, 212.

GROVES, A.B., WAMPLER, E.L. and LYON, C.B. (1958). Plant Dis. Reporter, 42, 252.

HAMMARLUND, C. (1925). Hereditas, 6, 1.

IMMIKHUIZEN, E. en WAAL, M.A. van der, (1961). De Fruitteelt, 51, 206.

KIRBY, A.H.M. and FRICK, E.L. (1960). Meded. Landbouwh. en Opzoekingsstat. v.d. Staat Gent, 25, 1215.

MÜLLER, R. (1957). "Untersuchungen über die Biologie und Bekämpfung des Apfelmehltaues Podosphaera leucotricha (Ell. et Ev.) Salm." Diss. Landwirtschaftl. Hochschule Hohenheim.

NOVER, I. (1957). Phytopath. Z. 31, 85.

SPRAGUE, R. (1955). Bull. Wash. Agr. Exp. Sta. 560.

STOLL, K. (1941). Forschungsdienst 11, 59.

UITTERLINDEN, L. (1960). De Fruitteelt, 50, 183.

YARWOOD, C.E. (1950). Am. J. Bot. 37, 636.

YARWOOD, C.E. (1957). Bot. Rev. 23, 235.

SPRAY TIMING FOR APPLE MILDEW CONTROL

by R. O. Sharples
(Lenton Experimental Station *)

Summary

Field trials have been carried out at Lenton Experimental Station, to compare the effectiveness of a variety of spray programmes for apple mildew control. The most important period for reducing blossom truss infections is from May until mid-June, when the fruit buds are being formed. Subsequent sprays are of importance for the protection of the vegetative extension shoots and, unless general tip-pruning is resorted to, spraying must be continued until extension growth has ceased and the terminal-bud scales have become suberised.

With a protectant fungicide, sprays should be applied at continuous regular intervals throughout the season to maintain cover of newly emerging foliage. Regular sprays are also necessary when using an eradicant type of fungicide and although intensive early spraying against primary infections reduces the inoculum level in the trees, continued applications are required to prevent a build up of the disease later in the season.

Introduction

Burchill (1958) and Woodward (1927) have shown that P. leucotricha overwinters as resting mycelium in the bud and that the buds are susceptible to infection only until the outer bud scales have become suberised forming a protective cover enclosing the embryonic leaves.

In the mildew-susceptible variety, Cox's Orange Pippin, the fruit buds are formed in May and early June while the vegetative buds are formed progressively throughout the spring and summer until extension growth ceases. Normally the buds are susceptible for the four or five weeks extending from their initiation to the stage at which they become enclosed by suberised scales. Thus the fruit buds and first-formed axillary vegetative buds are susceptible until about mid-June while the later formed axillary and the terminal vegetative buds may remain liable to infection until late August (Burchill, 1958).

Control measures involving the application of fungicides must therefore be aimed at preventing infection of the buds during their period of susceptibility. The buds are normally infected by mycelium growing in from the petiole of a diseased leaf, although some direct infection of the buds by conidia may occur. Hence, in addition to checking the establishment of leaf lesions, sprays should also suppress the production of conidiophores from existing primary infections. The timing of spray applications will therefore depend upon the general mode of action of the fungicide as well as the type and intensity of the infection to be controlled.

---

* Present address, East Malling Research Station, Kent.

Between 1960 and 1961 two detailed field trials were conducted to establish the relative importance of sprays applied at different stages in the life-cycle of the disease.

Experimental

The 1959-60 trial was carried out on eighteen, four-tree square plots separated from one another by single rows of guard trees. The trial was divided into two blocks to compensate for a slight increase in the incidence of mildew towards the upper part of the field and the nine different treatments were randomised within each block. The experimental trees were Cox's Orange Pippin on M.IX rootstocks, and were 9 years old in 1959, while the guard trees were Cox's Orange, Worcester Pearmain or Janes Grieve of similar age. Sprays were applied by hand lance (high volume) at about 100 lb/sq. in. pressure.

The same general design was used for the 1960-61 trial which comprised two blocks, each of six, four-tree square plots.

The fungicides used were: (1) dinocap, as a commercial wettable powder containing 25% of the active material normally used at 1 lb/100 gallon. Where wetter was required, a 60% solution of sodium di-octyl-sulphosuccinate was added at 8 fl. oz/100 gallon pre-blossom and 6 fl. oz/ 100 gallon in later sprays; (2) DNC at 0.1% with 2.9% petroleum oil.

Assessments of primary infection were normally carried out in May immediately the blossom truss infections were evident, and repeated some two to three weeks later on the terminal bud infections. About one hundred trusses or extension shoots were counted on each tree and classified as either mildewed or healthy.

Secondary infections were assessed, from June onwards, on extension shoots, selected at random; the leaves were examined for mildew lesions on their under-surfaces. The total number of leaves on the shoot together with the number showing mildew infection were noted in each case. Where a leaf was missing it was counted as mildewed. At least fifty extension shoots were examined in each treatment. The results were expressed as the percentage of infected leaves on the extension shoots of each plot by averaging the separate shoot counts.

1959-60 Trial

The first trial was intended to determine the effectiveness of spray programmes drawn up in accordance with the evidence (Burchill, 1958) obtained in the West of England on the mode of infection of buds. Thus dinocap sprays were applied throughout May and early June to control fruit bud infection and were then continued for varying periods up to the cessation of extension growth. A further programme was arranged in which no sprays were applied during the period thought to be vital for fruit bud protection and a control plot, receiving no sprays at all, was also included.

Two other programmes were included in this trial to compare the effectiveness of dinocap (at 1 lb/100 gallons) and DNC (at 0.1%) in killing out primary mildew infections. These sprays were applied as the buds were breaking with the aim of freeing the young expanding leaves from the disease. The different programmes are shown in Fig. II. In general the sprays are applied at fortnightly intervals and, because of the dry summer, none were adversely affected by rainfall following application. The guard rows were left unsprayed to provide an even source of inoculum throughout the orchard.

Results

An assessment of the primary mildew infection was made on the 21st April, 1959. All the plots proved to be infected to a similar extent (10 - 13%). Even where dinocap or DNC had been applied at bud burst or where dinocap had been applied at green cluster, no significant differences in primary mildew incidence were evident at this assessment.

A series of secondary mildew assessments were made during the summer of 1959. The results of the assessment made on the 24th August are shown in Table 1 and Fig. I. It is evident that the untreated plots (2) showed a high level of infection and that all the spray programmes gave some measure of control.

The results of the sprayed plots may be grouped as follows:
(a) Approximately 70% reduction in infection. Programmes 4, 5, 7 and 8.
(b) Approximately 50% reduction in infection. Programmes 1, 3 and 9.
(c) Approximately 30% reduction in infection. Programme 6.

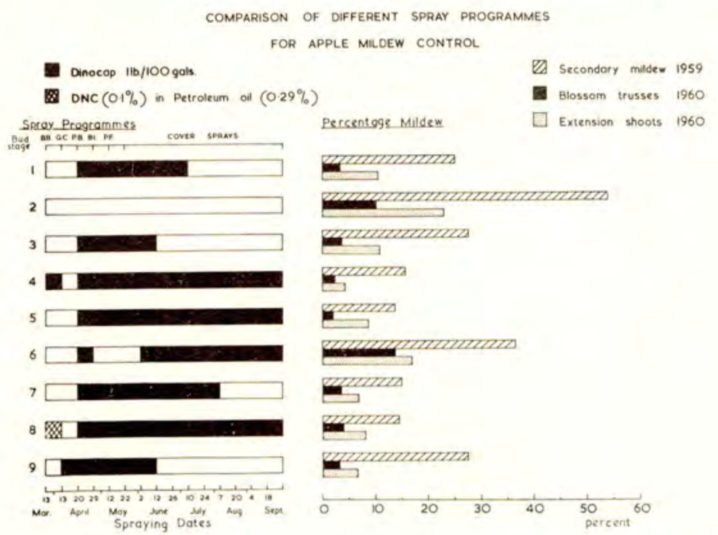


Fig. I

Table 1 Mean percentage mildew infection following different spray programmes

Spray Programme	Secondary Infection Extension Shoot (24.8.59)	Blossom Truss (11.5.60)	Primary Infection Extension Shoot (20.5.60)
1	25.4	3.26	10.54
2	54.0	10.08	23.03
3	27.6	3.72	10.84
4	15.7	2.26	4.23
5	13.8	1.98	8.65
6	36.5	13.85	17.00
7	15.0	3.47	6.84
8	14.5	4.07	8.12
9	27.5	3.13	6.57

In the spring of 1960, the primary mildew infections were assessed. The percentage blossom truss and extension shoot infections are given for each spray programme in Table 1 and Figure I. It is clear that the level of fruit bud infection was unaltered from the preceding season in the untreated plot and in treatment 6. In all other cases the mildew incidence was reduced from 10 - 13% to between 2 and 4%. A later assessment made on the primary extension shoot infections on the 20th May, 1960 reflected the differences already noted at the end of the 1959 season and given by the August assessment of secondary mildew. Although the differences were not so marked at this stage, the untreated plot (2) clearly carried the highest infection and plots receiving programmes 6, 1 and 3 still showed a higher level of infection than the remainder.

Discussion

The even distribution of the disease in the experimental plot is emphasised by the uniformity of the primary mildew counts made in April 1959. The early sprays of dinocap or DNC appeared to have no effect in freeing infected buds from the disease and, in this particular experiment, gave no better control of new infections than a programme omitting these early applications (compare 4 and 8 with 5). Some bud seal was recorded following applications with DNC. The introduction of a spray at green cluster appeared to provide no additional benefit. (compared 9 with 3). Where sprays were omitted during May and early June (programme 6) fruit bud infection was as severe as in the unsprayed plot. (Compare blossom truss assessment for 2 and 6 with remaining programmes).

Finally, the progressive decrease in secondary mildew infections with the application of further sprays from mid-June to mid-August indicates the importance of continuing the protection of the foliage until extension growth has ceased and the terminal bud scales are suberised. Programmes 3 and 9 (concluded in June) and programme 1 (concluded in July) gave inadequate control of secondary mildew. Programme 7 (concluded in August) gave full control and was in no way inferior to the remaining treatments where sprays were continued until the 18th September. Shoot measurements indicated that, in the dry summer of 1959, extension growth ceased in late July and thus sprays applied in September 1959 would have been superfluous for the control of terminal bud infections.

It will be noted from programme 6, where the mid-season sprays were omitted, that although sprays were applied again from mid-June onwards, very little reduction in secondary mildew was effected. The primary extension shoot infections arising in 1960 in these plots were also much higher than in plots receiving protection during May. It is probable that the inoculum rose to a high level in trees receiving treatment 6 during May and therefore subsequent applications of dinocap were inadequate to regain control.

The evidence obtained in this trial confirms the findings of Burchill (1958). The most important period for mildew control is from the pink bud stage until early to mid-June when the fruit buds will normally be closed by suberised scales. Full protection of the vegetative shoots may only be obtained by continuing to spray until the cessation of extension growth but, in drier parts of the country or where tip pruning is practised, the number of cover sprays may be limited according to economic considerations.

1960-61 Trial

The second trial was carried out to determine the value of an eradicant spray programme for controlling mildew. The main purpose of the experiment was to compare routine protectant programmes with programmes in which the sprays were applied at short intervals, (7 - 9 days), until the end of May to suppress sporulation from primary infections. Thereafter, with inoculum at a minimum, no further sprays were applied.

The trial layout was essentially the same as that used in the previous trial. In this case, however, the guard trees were sprayed with dinocap on every occasion to reduce migration of conidia from the guard rows to the experimental trees; only six different programmes were compared.

All the applications were made with dinocap (1 lb/100 gallons), a material which appears to be primarily eradicant in its action. The six different programmes are shown in Fig. II. It will be seen that programme A consisted of an early series of intensive sprays followed by regular applications until the end of July. Programme D did not begin until the petal fall stage but thereafter followed the same schedule as A. Programmes B and C consisted of intensive eradicant sprays only and were discontinued shortly after petal fall. A and B commenced at the mouse-ear stage while C commenced at pink bud. In programme D, the sprays were applied at green cluster, pink bud, blossom, petal fall and thereafter at fortnightly intervals until the end of July.

Results

The immediate effects of eradicant dinocap sprays were recorded by a series of secondary mildew assessments made between 30th May and 27th July. These results are illustrated in Fig. II where the percentage mildew is plotted on a logarithmic scale. Primary mildew assessments were made in the spring of 1961.

A steady increase in mildew infection was shown in the unsprayed plots (programme O). The initial infection incidence of 0.6% per shoot was very much higher than in any of the remaining plots even though only two sprays had been applied in programme D. None of the treated plots became infected to the same extent as the unsprayed and the relative effectiveness of the different treatments is shown in Fig. II. By the beginning of July the results were as follows:

a) Approximately 90% reduction in infection. Programmes A, D and E.
b) Approximately 70% reduction in infection. Programmes B and C.

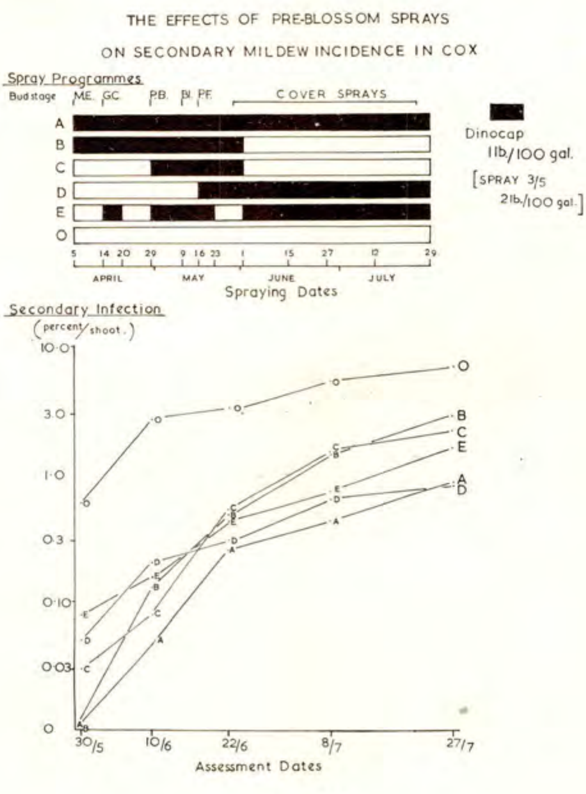


Fig. II

Discussion

Since secondary mildew leaf lesions are caused by germination of mildew conidia alighting on the under surface of the leaf, assessments based on this type of lesion are directly related to the level of inoculum in the tree. The present trial was carried out with a single row of sprayed guard trees and the ingress of inoculum from surrounding plots was sufficiently low not to mask the differences between the various spray programmes. In time, however, the level of inoculum built up in plots receiving no sprays after the 23rd May (when a double strength application was made) and this infection no doubt originated from spores spreading in from other parts of the orchard as well as from diseased shoots which had survived the intensive early spray programme.

It is immediately apparent from Fig. II that a reduction in inoculum was achieved with programmes B and C until the middle of June. However, by the first week in July, the inoculum level was no longer limiting the establishment of fress infections in these plots and, although the incidence of the disease never reached that of the unsprayed plots, control was virtually lost at this stage. A comparison of programmes B and C suggests that the bud burst, mouse-ear and green cluster sprays did not contribute to the reduction in inoculum.

The slopes of the graphs in Fig. II indicate that the build-up rate of mildew in the trees receiving eradicant programmes only was the same as that in the unsprayed plots. The low inoculum level resulting from these early sprays simply caused a delay of about four weeks in the outbreak of secondary infections. The most striking effect is seen by comparing programme A, where sprays were applied continuously from bud burst until July, and programme D, where the first spray was delayed until mid-May. It is evident that the augmentation of a simple protectant schedule (D) by intensive early sprays to suppress sporulation (A) gave no better control of secondary mildew.

In spring 1961, all the treated plots showed at least 70% reduction in the incidence of primary mildew infections compared with the unsprayed controls, but no consistent differences were recorded between the various spray programmes. Blossom truss infections are mainly initiated between the petal fall and fruitlet stages, when the fruit buds are particularly susceptible and it will be seen from Fig. II that all the programmes included sprays which would provide relatively effective control during this period by protection, the suppression of inoculum or both.

This trial has shown that the frequent use of dinocap (or compounds with similar eradicant properties) to suppress sporulation from primary infection does reduce the level of inoculum within the tree. However. once spraying is discontinued the inoculum builds up very rapidly and successive sprays are necessary to maintain a low level. Thus, a series of protectant sprays, applied from late May onwards without a preliminary eradication programme will give a similar degree of secondary mildew control.

General Recommendations

It appears from these results that, whether a fungicide is either predominantly eradicant or predominantly protectant in its action against mildew, sprays should be applied at regular intervals. The intervals should not exceed 10 days for full control (particularly if the material is an eradicant fungicide) and 14 days is the maximum interval for maintaining commercially acceptable control of the disease. Spraying should commence shortly after pink bud and continue at least until early July. Where renewal pruning is practised, it is important to continue mildew sprays beyond this stage until extension growth has ceased.

Acknowledgements

Thanks are due to Mrs. J. Astill and Miss M. Dooley for assistance in spraying and assessing.

References

BURCHILL, R. T. (1958). Ann. Rep. Long Ashton Res. Sta. for 1957, p. 114.

WOODWARD, R. C. (1927). Trans. Brit. mycol. Soc. **12**, 173.

SOME RECENT OBSERVATIONS ON THE CONTROL OF APPLE MILDEW

by D. Hunnam
The Murphy Chemical Company Limited

Apple Mildew on Bramleys

During the last three or four years growers of Bramley's Seedling have become progressively more concerned about the incidence of powdery mildew on this apple variety. Previously Bramleys were relatively mildew-free especially when compared with Cox's Orange Pippin and it was generally assumed that the variety was, to some degree, resistant. What then is the explanation of the increase over the last few years. The evidence seen by the writer and his colleagues suggests that one of the main factors leading to the increase in powdery mildew on Bramleys is inefficient spraying. In many orchards the mildew incidence is much less at 5 ft. to 7 ft. than it is at the top of the trees, both in terms of primary vegetative tip infection in spring (i.e. tips of extension shoots) and in terms of secondary leaf infection in the middle of the season. In some cases the difference between leaf size and colour at the bottom and top of the tree is easy to see, that at the bottom being full sized green and healthy, while that at the top is in general, twisted and wrinkled with mildew.

Spray deposit tests have confirmed this view. Spray applications of a water soluble dye followed by recovery of the dye show that, in several Bramley orchards where air-blower spraying machines are used, the amount of spray in the tops of the trees is minute as compared to that at the bottom. In some tests the difference is five-fold, while in some it is considerably more (20 - 30 x). The inference is that the air blower spraying technique has allowed a progressive build-up of mildew over the years, and the centre and top of the tree has been the seat of this build-up.

There are two steps therefore which should be taken in developing control measures for this newly important mildew of Bramleys: firstly, the method of spraying these trees should be improved to provide a considerable increase in the deposit in the tops and centres of the trees; secondly, a spray programme is required to combat the infection.

During the autumn of 1960 and the season 1961 tests have been made with dinocap in order to determine the most effective dates of application in a programme specially suited to Bramley.

1960 Trial

Examination, in July 1960, of trees severely infected with mildew showed that the mildew was predominantly in the tips of the 1959 extension growth. There was very little primary mildew infection of rosette leaves (that is to say of buds formed early in 1959) and this aspect of the mildew infection appeared to be of relatively minor importance (unlike mildew on Cox).

In view of this infection pattern it was argued that spraying in July and August, to prevent axillary and tip bud infection, might be of special practical value in the control of mildew on Bramleys. If infection was mainly late in the season (later than is the case with Cox) such a programme might be sufficient to reduce the mildew level and in time be sufficient for commercial control.

Accordingly 10 Bramley trees were chosen at random in an orchard for spraying, and a similar group of 10 chosen as untreated controls. Three applications of dinocap at 1 lb of the 25% WP per 100 gallons (plus a wetter), were made by hand lance, the trees being well drenched to ensure, as near as possible, perfect cover. The dates of application were August 8th, August 22nd, September 5th.

In the following spring the trees were examined from time to time until the most suitable time to conduct a count of infection had arrived. This was 21st June. Early examination, it was considered, would not have been suitable as much of the primary infection on vegetative tissue was not readily seen until June was well advanced.

The most convenient way to assess the incidence of primary infection on vegetative (extension) shoots was to count the total number of such shoots both infected and not infected present on each tree below a height of approximately 8 ft. This limitation was imposed in view of the relative inefficiency of the previous spraying. A count, within the same part of the tree, was also made of primary infection of spurs (rosettes) (i.e. buds formed and matured early in the previous season). Results, given in full for each replicate, are set out in Table 1.

As will be seen from these figures, no good whatever was obtained from this late season spraying either against vegetative tip infection or against spur bud infection. The latter could not reasonably be expected but the total failure against the former is somewhat surprising and tends to show that early protection is necessary.

Table 1 Assessments of primary infection

TREATED Applied: Aug. 8, 22 Sept. 5					UNTREATED				
Tree	Infected spurs per tree	Number of tips		% infected tips per tree	Tree	Infected spurs per tree	Number of tips		% infected tips per tree
		Clean	Infected				Clean	Infected	
1	10	137	23	14.3	1	11	136	12	8.1
2	10	116	11	8.7	2	13	116	14	10.8
3	6	89	13	12.8	3	12	139	9	6.1
4	12	103	5	4.6	4	9	105	14	11.8
5	10	128	16	11.0	5	10	128	7	5.2
6	18	117	8	6.4	6	36	117	10	8.6
7	17	141	15	9.6	7	6	91	4	4.2
8	10	105	11	9.5	8	12	113	19	14.4
9	14	125	6	4.6	9	12	146	15	9.3
10	14	110	7	6.0	10	4	63	10	13.6
Total & Mean % age	121	1,171	115	8.94		125	1,154	114	8.99

1961 Trials

Before the above results were available, it was decided to conduct trials designed expressly to determine whether short programmes (of limited number of sprays as compared with Cox programmes), starting relatively late in some cases, would be sufficient for mildew control on Bramleys. In Bramleys, unlike Cox, there is seldom much evidence of true fruit bud infection. Occasional primary fruit bud infection with obvious infected flowers can be seen but this form of the disease is not a serious problem as it is with Cox. There is however a degree of spur-bud infection (i.e. of rosette leaves, normally emerging early in the season) as seen from Table 1. These spurs produce leaves and, depending on the degree of infection, either continue to produce infected leaves for some time or lose all their leaves early on and die. In general these spur infections are not easily seen, their density per tree is not great, and they do not seem to be of great economic importance in themselves. Certainly they are insignificant in producing an impression of mildew later in the season as compared with the extension shoot infections. It was against this background that the seasons spraying trials were arranged.

Later in the season sections for microscope examination were made from a number of these spur infections to see whether they were in fact fruit buds turned blind by infection. Only one out of 10 such buds showed any sign of flower initials; they are vegetative buds unless the infection is so early that it arrests the "flower initial" development - (this would be greatly different from the situation with Cox).

The trials arranged were of two types: (a) commercial, treatment being made in commercial orchards using standard spraying machinery; (b) small scale with replicated single tree plots. In both cases the material used was dinocap at 1 lb 25% WP per 100 gallons or 4 lb per acre.

a) Commercial Trials

Five trials were conducted in which 2 or 3 experimental programmes each of 2 sprays of dinocap were superimposed on a standard scab/mildew programme.

Assessments of primary infection were made in the first fortnight in June by counting 2 x 100 shoot tips (1960 extension growth) on each of 10 trees giving a total of 2000 tips examined per treatment. Assessments of secondary infection were made in late June - July: 10 shoots (1961 extension growth) were examined per tree, on each of 10 trees, 10 leaves per shoot, making a total of 1000 leaves examined per treatment. All counts restricted to the lower half of the trees.

Results, expressed as % tips infected - Primary (P) and % leaves infected - Secondary (S) - are given in Table II.

Table 2 **Assessments of primary (P) and** secondary (S) infection

Site	All programmes 2 applications of Dinocap								
	1. Pink Bud 2. + 7 days		1. Petal Fall 2. + 7 days		1. Petal Fall + 14 days 2. + 7 days		Standard Programme		
	P	S	P	S	P	S	P	S	
1	24.8	39.3	27.9	45.8	31.2	55.6	37.9	62.7	PMN throughout
2	32.8	54.6	34.4	71.8	42.7	58.3	-	-	-
3	23.2	38.8	24.7	56.7	31.9	59.7	35.7	74.9	Lime sulphur preblossom Mercury post-blossom
4	30.9	37.4	36.9	53.4	37.8	52.0	41.3	58.1	Mercury throughout
5	-	-	24.1	18.2	27.8	33.9	27.5	31.2	Lime sulphur throughout
6	5.0	50.1	9.7	48.9	7.8	52.5	7.9	23.7	Dinocap 5 applications

b) Small Scale Replicate Trial

One trial only was conducted, with nine young Bramley trees per treatment. The spray programme compared included two in which dinocap was applied throughout the season and three in which the programme was of two sprays only with one interval of 7 days.

(i) Dinocap 1 lb 25% WP/100 gallons every 14 days from April 13 (Pink Bud) to July 19.
(ii) Dinocap $\frac{1}{2}$ lb 25% WP/100 galllons every 7 days from April 13 to July 19.
(iii) Dinocap 1 lb 25% WP/100 gallons at Pink Bud. Repeat at 7 days.
(iv) Dinocap 1 lb 25% WP/100 gallons at Petal Fall. Repeat at 7 days
(v) Dinocap 1 lb 25% WP/100 gallons at Petal Fall + 14 days. Repeat at 7 days.
(vi) No mildew treatment.

Assessments were of primary infection made in first half of June by counting 2 x 50 tips on each within a treatment making 900 tips examined per treatment. Assessments of secondary infection were made 13th June: 10 new shoots (1961 extension growth) were examined per tree on each of the nine trees, 10 leaves per shoot making 900 leaves examined per treatment. Results are given in Table 3.

Table 3

Treatment Dinocap (25% WP)	Primary Mildew % infected shoots	Secondary Mildew % infected leaves
i 1 lb Full prog. (14 days)	39.4	28.5
ii $\frac{1}{2}$ lb Full prog. (7 days)	35.1	13.6
iii Pink Bud + 7 - 1 lb	44.5	46.1
iv Petal Fall + 7 - 1 lb	38.1	34.8
v (Petal Fall + 14) + 7 - 1 lb	46.4	41.3
vi No treatment	54.8	71.1

A full programme commencing at Pink Bud gave the best control of mildew on Bramley - just as it does with Cox. Also, as with Cox, the 7 days half rate programme is better than a 14 day programme at the full rate.

Of the shortened programmes none approaches the full treatment in efficiency but there is an indication that the sprays applied at Petal Fall and 7 days later are the most efficient. There is also a reduction in apparent primary infection with all treatments. This is an interesting side effect and may be ascribed to the eradication of the infection emerging with the bud. On the other hand it is not always easy to distinguish between an early secondary and a primary infection. Dinocap treatment may have reduced the number of early secondary infections which tends to confuse the operator.

The trials reported tend to show that a good commercial control of mildew on Bramleys cannot be expected from two applications of dinocap when infection is high. A full programme (preferably four or five applications) would be needed in such conditions. There is evidence that relatively early treatment is required for Bramley just as for Cox, and in 1961 the optimum period for satisfactory response to sprays was at Petal Fall and 7 days later.

Apple Mildew on Cox's Orange Pippin

Apple mildew of Cox differs, as mentioned, from that of Bramley in that primary infection of fruit buds is commonly seen. This infection generally destroys the florets, and all parts fall off, leaving a malformed stump, which for a short time is capable of acting as a source of infection. For this reason growers commonly go to much trouble to cut out the infected buds.

For some time now there has been an indication that dinocap applied at the Green and Pink Bud stages at double the normal rate (2 lb 25% WP per 100 gallons) can take the place of this 'cutting out'. The exact manner in which this is done is not fully understood but it is probably through a combination of eradication of the surface sporulation on the shoot, and an enhanced protection of the new tissue.

Small scale trials using single tree plots are not suitable for demonstrating the effect of dinocap in this way owing to cross infection. Only on large areas can the benefit of such a treatment be felt.

In 1961 such a trial was carried out by a grower in Kent. A section of the orchard was sprayed at the Green and Pink Bud stages with dinocap at 2 lb of the 25% WP per 100 gallon rate (double the normal rate). A comparable section was not so sprayed but instead the infected buds were cut out in the traditional way. Both plots received the usual dinocap programme as well as these treatments.

Later in the season casual inspection showed that the plot receiving sprays and no 'cutting out' was the worse of the two, but careful counts of both primary and secondary infections were done to determine the true position.

Ten trees in each plot were chosen for examination. All primary infections whether of fruit buds or of vegetative tip buds were counted and recorded per tree. For the assessment of secondary infection, ten shoots were chosen at random per tree and on each shoot the top 10 leaves were examined for infection, making 1000 leaves examined per plot. Most shoots had 10 leaves only so the sample taken included the first-formed leaves of the 1961 extension growth.

On the trees receiving double-rate dinocap sprays, the number of primary infections per ten trees were 548, on unsprayed trees with 'cutting out' it was 381. The percentage leaves with secondary infection on both treatments was 48.2. 'Cutting out' has therefore reduced primary infection but the number of such infections (38.1 per tree) is remarkably high. Despite the difference in primary infection, secondary infection was similar in sprayed and 'cut out' trees, an indication that the spray application has equalled the 'cutting out' technique in reducing infection sources.

These results are related to those of the 1960 Report of the Luddington Experimental Horticulture Station (p. 4), where cutting out was found to have very little influence on subsequent secondary mildew in the same season. It may be in the trial now reported that neither cutting out nor early double strength spraying had any effect upon the secondary mildew, this being the reason for the lack of difference between them. Either of them may, however, have affected the fruit bud infection which occurs relatively early in the season. Counts at the Pink Bud stage in 1962 will determine this.

THE CONTROL OF SECONDARY INFECTION OF APPLE MILDEW BY DINOCAP AND THE COMPARISON OF VARIOUS METHODS TO ASSESS FORMULATION EFFICIENCY

by H. J. Terry
Horticultural Research Station, Ongar, Essex

Introduction

At the Horticultural Research Station at Ongar we have, since 1958, been seeking methods for assessing the efficiency of certain fungicides and spray programmes in the expectation that any degree of disease control could be related to a change in the general condition and health of a tree. Therefore, our assessment methods were directed towards measuring the appearance, yield, and fruit quality of a tree as well as the actual amount of mildew associated with a treatment. We considered that recording the general appearance of trees was particularly important as this is the factor by which a grower can most easily judge the effect of a programme for mildew control.

Primary mildew in spring and the later summer secondary infection can both be used to measure the level of apple mildew infection. Secondary mildew on leaves was chosen as the most suitable factor because - (1) it is the stage of the disease on which a chemical spray has a direct and immediate effect, (2) it is the stage which has the most direct and obvious effect on the appearance of the tree, and (3) its distribution is fairly uniform and it can be used to indicate disease progress.

This paper describes the method of assessing secondary infection of mildew on leaves and examples of results of field experiments show how these measurements of secondary infection can be related to the number of leaves lost by mildew attack, the appearance of the tree and the russetting of fruit at harvest. In addition, the measure of infection of leaves over whole shoots by the method described by Baker (1961) was used. There are also examples of how this method is associated with the secondary mildew assessments and appearance scores.

Our work started with investigating the activity of a number of compounds, including ethylene 1, 2-di(<u>N'N'</u>-dimethylthiuram disulphide). This compound has, as yet, no British common name, but it will be referred to throughout this report as tecoram, which is the common name used in Holland, its country of origin. Work has also been carried out with dinocap to investigate the effect of volume of application and the addition of certain scab fungicides on final mildew control. Several assessment methods have been used in each case to demonstrate the differences in activity of various mixtures and formulations.

Experimental

All field experiments on apple mildew were carried out in orchards of the variety Cox's Orange Pippin either at the Ongar Research Station or on the farms of growers in Kent and Essex. Usually two or three-tree plots were used with three or four such plots randomised for each compound or programme tested. On these plots spraying was carried out at high volume, 200 gallons per acre, with a modified Craven Machine and hand lances. In the 1961 experiments, designed to compare the activity of dinocap at high and low volume rates of application, the low volume treatments were applied with an experimental machine delivering 30 gallons of spray per acre and the high volume plots received 200 gallons per acre, applied automatically.

The assessments of secondary leaf mildew were made by systematically sampling leaves on specific trees on each plot. These trees were selected at the beginning of the season and used throughout for assessment purposes. Every third leaf was picked from extension shoots over 1" long, every third extension shoot was selected and every third lateral of each branch examined. This method produced about 100 leaves per tree, at each sampling. Leaves in each sample were counted in the laboratory and then graded according to the extent of mildew on their surface. Grades used were as follows:

Clean	-	no mildew
Trace	-	1 - 25% of surface mildewed
Moderate	-	26% - 50% mildewed
Severe	-	over 50%

Leaf assessments were made twice or thrice in a season and used to show the build-up of disease and persistence of effect of various control programmes.

On one site in 1959 a leaf assessment method was used to measure the proportion of leaves lost by severe mildew infection. Trees from which le ves were taken for sampling of mildew could not be used for this, as some leaves would have been removed for previous assessments. In this case, duplicate trees were used which were reserved on each plot for this purpose. The extension shoots were selected in the same way as for the leaf mildew assessments and a count was made of the number of leaf scars and leaves present on each extension shoot.

By mid-August some plots were easily recognised as looking in better condition than others. It was believed that this could be attributed to some plots losing more leaves than others by mildew attack or to the general poorer quality of foliage where mildew control had been less efficient. In these cases individual plots were scored for general appearance by two or more observers according to the following scheme.

General description of tree or plot	Score	Score range
Very poor	x	0.6 - 1.5
Poor	xx	1.6 - 2.5
Moderate	xxx	2.6 - 3.5
Good	xxxx	3.6 - 4.5
Very good	xxxxx	4.6 - 5.0

Fruits were picked from all plots at harvest and graded out for russetting on an absolute scale, disregarding the natural russet commonly associated with Cox's Orange Pippin.

In 1961 the method developed by the N.A.A.S. (Baker, 1961) was used to assess secondary mildew infection over complete shoots. 20 shoots are examined per plot and graded arbitrarily as to whether there are 1%, 10%, 50%, 75% or 100% mildewed leaves.

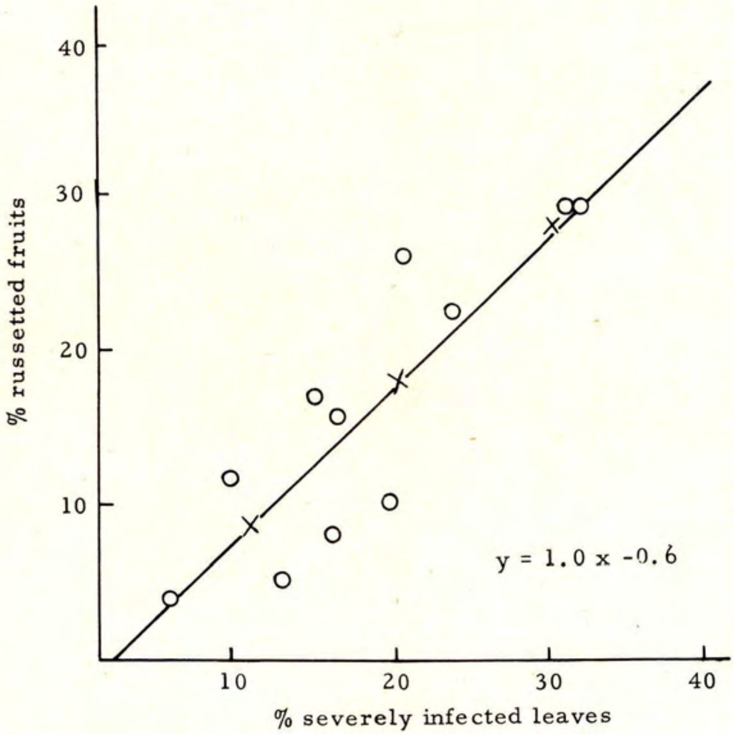
Results

The extent and progress of mildew attack

Table 1 shows the use of the leaf mildew assessment method to distinguish between 3 programmes for mildew control. Three tree plots were used and there were three replicate plots for each programme. Assessments were carried out on each tree of each plot. In this case the leaf gradings for the three assessments were analysed together. The ziram plus dinocap programme gave the significantly highest number of clean and lowest number of severely infected leaves. In this experiment there were also large differences in fruit russetting between some treatments. The figures for the percentage of severely russetted fruits have been plotted against the relative figures for severely mildewed leaves and a significant correlation has been obtained, as shown in Fig. 1.

Fig. 1 1958 Experiments. Site 1. Ongar, Essex.

Correlation between severely russetted fruits and severely mildewed leaves



Correlation highly significant at P = 0.01

Table 1 1958 Experiment

Site 1. Ongar, Essex

Control of apple mildew by tecoram and ziram programmes and related fruit russetting

Variety - Cox's Orange Pippin

Application rate of formulated material lb/100 gal. (4 applications)	Concen. Active compound %	Mean no. of leaves per category per tree from 3 assessments. (% per category in brackets)				% severely russetted fruit at harvest
		Mildew				
		Clean	Trace	Mod.	Severe	
tecoram 2½ lb	0.2	25.0* (32)	15 (19)	25 (26)	13* (16)	18
ziram 1 lb + sulphur 2 lb	0.08 0.14	30** (34)	16 (19)	28 (34)	11* (13)	10
ziram 1 lb + dinocap 1 lb	0.08 0.025	32** (41)	17** (23)	20 (26)	8** (10)	7
Control (unsprayed)	-	18 (26)	11 (15)	23 (32)	19 (26)	22

Coefficient of variation = 69%
L.S.D. between treatment means (numbers of leaves = 6.0 when P = 0.05
8.0 when P = 0.01
Spray applications:- 7th May, 3rd June, 16th June, 30th June.
<u>Formulation</u> - tecam = wettable powder containing 80% ethylene 1,2-di(N'N'-dimethylthiuram disulphide)
ziram = wettable powder containing 80% active compound
dinocap = " " " 25% " "
sulphur = " " " 70% " "

The same leaf assessment method was used the following year to compare a series of programmes containing tecoram, dispersible sulphur, dinocap and captan. In this case spraying was carried out at 80 gal. acre and 12 or 24 tree plots were used, with 3 replicate plots for each programme. 2 trees were marked in each plot at the beginning of the season and used throughout for sampling purposes. The results of the work are expressed in Table 2 as the percentage of severely infected leaves at each count for each treatment. The dinocap containing programmes maintained the best control, while applications were being maintained but there were smaller differences between treatment by mid-August. The figures for the % severely russetted fruit again fell into line with % mildew and a significant correlation was obtained (Fig. 2).

<u>Table 2 1959 Experiment</u>

<u>Site 3. Pearsons Green, Kent.</u>

Control of apple mildew as measured by % of leaves with secondary infection and % russetted fruit at harvest

Variety: Cox's Orange Pippin

Treatment date & application rate of formulated material (lb) in 80 gal. acre				% severely infected leaves		% severely infected leaves		% severely infected leaves	% severely russetted fruit
Spray 3/4	Spray 16/4	Spray 27/4	Spray 4/5.26/5 9/6	1st count	Spray 18/6.6/7 20/7	2nd count 20/7	Spray 29/7	3rd count 19/8	Harvest
tec 4	tec 4	tec 4 sul 4	tec 3 sul 4	19**	tec 3	38**	As for 20/7	49**	52
tec 4	tec 3 sul 3	tec 3 sul 3	tec 3 sul 3	15**	tec 3	35**		58	22
tec 4	tec 4 dino. 1½	tec 4 dino 1½	tec 3 dino 1½	13**	tec 3	32**		50*	20
cap 4	cap 4	cap 4 sul 4	cap 3 sul 4	28**	cap 3	43**		56*	44
Control	-	-	-	51	-	56		74	54

<u>Analysis</u>. L.S.D. for first count when P = 0.05 is 14; 0.01 " 18 — c. of v. = 43%

L.S.D. " second " " P = 0.05 " 9; 0.01 " 12 — c. of v. = 26%

L.S.D. " third " " P = 0.05 " 17; 0.01 " 23 — c. of v. = 30%

<u>Formulations</u>. tec = tecoram as w. powder containing 80 % ethylene 1,2-di(<u>N'N'</u>-dimethylthiuram disulphide)

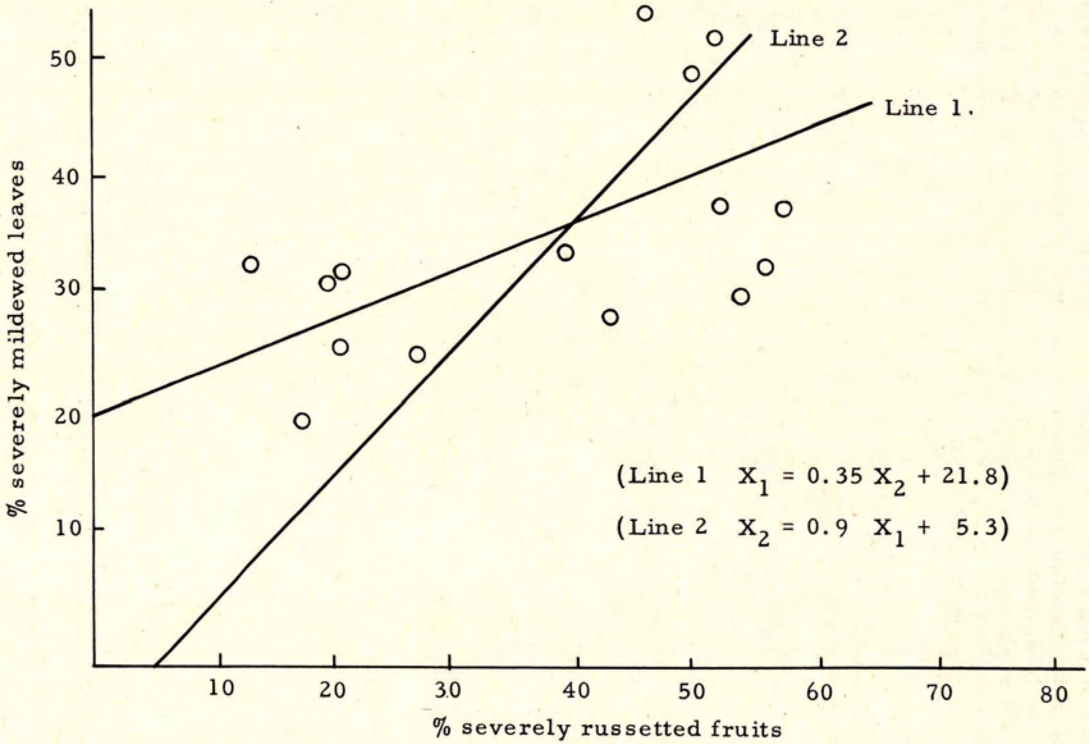
sul = sulphur as a 70% wettable powder

cap = captan as a 50% wettable powder

dino = dinocap as a 25% wettable powder

Fig. 2 1959 Experiments. Site 3.

Correlation between severely russetted fruits and severely mildewed leaves



During the course of the 1958 and 1959 experiments, it became apparent that the assessment of secondary mildew by sampling was costly in both time and labour. Although differences between programmes could be detected it was necessary to take very large samples in order to overcome assessor and 'between tree' variations. It had been observed that by July and August untreated trees could easily be picked out from treated trees by reason of their poor foliage. In an experiment to compare two wettable powder formulations of dinocap, a count was made of the number of leaves missing by mildew attack and the trees were also scored for their general appearance. Dinocap was applied at rates of 0.25, 0.5 and 1.0 lb active material per 100 gal. in two wettable powder formulations, A & C. Results of this work are shown in Table 3.

Table 3 1960 Experiments

Site 3. Pearsons Green, Kent.

Comparison of two wettable powder formulations of dinocap, with or without tecoram for mildew control

Rate of 25% compound in lb/100 gal.	2.0		1.0		0.5		Control	Coeff. of Variation	Least Sig. Dif.
Formulation	A	C	A	C	A	C			
% mildewed leaves 14/7	11	21	22	22	33	31	50	42	14
16/8	17	17	22	21	24	27	52	28	8
Missing leaves 12/8	1.4	4.8	3.5	2.9	5.2	4.5	9.0	47	2.7
Appearance score									
with tecoram	3.7	4.4	3.8	4.2	3.7	3.8	1.8		
Rating	Good	Good	Good	Good	Good	Good	Poor	14	1.5
without tecoram	3.9	3.6	3.9	3.8	3.7	3.6	1.5		
Rating	Good	Good	Good	Good	Good	Good	V. Poor		

It was thought that the assessment of mildew on whole shoots as described by Baker (1961) would be simpler to operate than our own leaf sampling method. Appearance scores, leaf sampling and shoot assessments were all used this year to compare formulations of dinocap.

In the first experiment (Table 4) a 25% wettable powder formulation (No. 5) was compared with four 50% emulsifiable concentrate concentrate formulations, (Nos. 1-4). All were applied at a rate of 0.5 lb active dinocap in 30 gallons water per acre at each of 5 applications. Tecoram at 4 lb of the 80% formulation per acre was applied with each formulation and on its own (No. 6). Treatment No. 7 was unsprayed control. 6 dwarf pyramid trees were used for each plot and there were three replicate plots per treatment, with a guard row of trees between each plot. The ranges of activity as assessed by each method are summarised in Table 6 below.

Table 4. 1961 Experiment. Ongar.

Comparison of methods for assessing control of apple mildew by formulations of dinocap and tecoram applied at low volume

Method	Treatment: grouped in order of activity	5	1	2	3	4	6	7	Coeff. of Variation
Leaf mildew assessment 28.6.61.	% infected leaves	16.0	20.9	24.2	21.9	24.2	39.6	48.6	37
N.A.A.S. shoot assessment 16.8.61.	Total for 20 shoots	57.3	71.0	65.3	65.3	104.3	23.4	427	41
	% infection per shoot	2.9	3.5	3.3	3.3	5.2	11.7	21.3	
Appearance score 31.8.61.	Total for 9 shoots	30.2	30.0	27.5	27.0	27.0	21.7	19.7	5
	Mean per tree	3.4	3.3	3.1	3.0	3.0	2.4	2.2	
	Rating	Mod.	Mod.	Mod.	Mod.	Mod.	Poor	Poor	

Duncan's Range Test (Duncan 1955) was used to test significance; for any one assessment method any two means not underscored by the same line are significantly different. Any two means underscored by the same line are not significantly different.

Treatments:
1., 2., 3. dinocap as 50% emulsifiable concentrate X wetter content at three different rates
4. dinocap as 50% emulsifiable concentrate Y Single concentration of wetter.
5. dinocap as 25% wettable powder A

(Treatments 1–5: dinocap at rate of $\frac{1}{2}$ lb per acre + tecoram (80% formulation) at 4 lb/acre.)

6. tecoram (80% formulation) 4 lb/acre only
7. Unsprayed control.

Spray application dates. 26th April, 9th May, 19th May, 2nd June, 19th June.

Table 5 1961 Experiments. Ongar

Formulations of dinocap

Treatments ranged in order of activity

Assessment Method	1st	2nd	3rd	4th	5th
Leaf mildew	5	1 3	4 2	6	7
N.A.A.S.	5	2 3	1 4	6	7
Appearance	5	1 2	3 4	6	7

In the second experiment, six different formulations of dinocap as wettable powders were compared. All were applied to give the same rate of active material, i.e. 0.5 lb/acre. Each formulation was applied at high and low volume and with or without an additional scab fungicide. Two-tree plots of 10-year-old trees were used in a split-split-plot layout with three fold replication.

Table 6 summarises the result by all methods of assessment, and Table 7 is a breakdown of the 'appearance score' method, showing relative appearance of the formulations with each of the scab fungicides.

Table 6 1961 Experiments. Boreham, Essex

Control of apple mildew with different wettable powder formulations of dinocap

Dinocap applied at 0.5 lb active compound per acre on all treatments

Formulations		A		B		C			Coeff. of Variation	Least Sig. Dif.
Treatment No.		2	3	4	5	6	1	7		
Wetter rate		x1	x2	x1	x2	x1	0	Control		
Leaf mildew (Mean of all plots) 2 counts	% severely infected leaves	41.1	40.5	45.1	44.5	45.8	46.3	62.4	22	6.8
'NAAS' shoot assessment 17.8.61. (Mean of all plots)	Total for 20 shoots	522.8	590.3	617.8	606.9	534.7	545.1	1161.7	29	225.4
	Mean % mildew per shoot	26.1	29.5	30.8	30.3	26.7	27.2	58.1		
Appearance score (Mean of all plots) 23.8.61.	Per plot	3.2	3.2	3.2	3.1	3.2	2.9	1.4	18	0.35
	Rating	Mod.	Mod.	Mod.	Mod.	Mod.	Mod.	V. Poor	-	-
% missing leaves		21.7	29.2	27.4	27.1	30.1	27.5	33.8	N.S	-
Sub. %		3.8	4.4	5.4	4.9	7.1	4.7	6.2	N.S	-

Spray applications on 15th April, 2nd May, 15th May, 27th May, 8th June.

Table 7 1961 Experiment. Boreham, Essex

Effect of adding scab fungicides to activity of formulation of dinocap

Mean appearance scores for High and Low volume plots together

Formulation	A		B		C		
Treatment No.	2	3	4	5	6	1	Control
Wetter rate	x1	x2	x1	x2	x1	x0	
+ tecoram	6.3 M	7.0 M	6.0 M	6.0 M	6.5 M	5.3 M	3.2 P
+ captan	6.8 M	5.8 M	6.2 M	6.2 M	6.7 M	6.2 M	2.8 VP
No scab fungicide	6.0 M	6.2 M	6.5 M	6.5 M	6.0 M	5.8 M	2.2 VP

LSD between any two scab fungicides with the same dinocap formulation = 0.98 when P = 0.05

Discussion

Fruit russetting

The correlations obtained between severely infected leaves and russetted fruit is interesting, but does not necessarily mean that the russet is due directly to mildew growing on the fruit. There are reports especially in the U.S.A., that this is possible, but no attempt was made to isolate the fungus from the fruits. Russetting is more likely to have been caused by exposure of fruits to the wind, cold or excessive heat. The fruit on the trees where foliage was reduced by mildew attack would be more exposed and consequently become more russetted. It is possible that, under the conditions of the experiment shown in Table 2, the high degree of russetting with the first treatment is associated with the higher level of sulphur in this programme.

Advantages and limitations of the assessment methods

The leaf sampling has its limitations, mainly because of the large 'between tree' and 'between plot' differences that a comparatively small sample of 100 leaves will produce. Variations will also arise through 'between block' differences when one assessor samples and grades one block. In the experiments in which the method has been used the coefficients of variation range from 26 to 69%, but generally between 40 and 50%. Variation could probably be reduced by having one assessor to pick samples and grade leaves for all blocks. This would take too long, especially when two or three sites are considered, and the best way is to use three or four assessors, sampling and grading from one site at a time.

The N.A.A.S. 'leaves on shoots' method has the advantage that one assessor can grade a whole site in about the same time that he could pick leaves for the sampling method on one block only. There is the added advantage that once he has examined a tree or plot he has a reading for that unit and does not have to carry out a second operation of examining leaves individually. From the two experiments in which the method has been used it appears that the coefficient of variation is of the same order as with the leaf sampling method. This is probably because of size of sample examined, 100 to 150 leaves in one, and 20 shoots in the other, represents approximately the same proportion of foliage in the tree.

The low variations associated with the appearance scoring are mainly due to the fact that whole plots and not samples are being assessed. Relatively small differences between treatments can be detected, and this is the only method which has enabled some distinction to be made between the effects of adding scab fungicides to dinocap formulations (Tables 3 & 7).

Activity of formulations of dinocap

In the straight comparison of wettable powders (Table 3), the 2 lb rate of formulation A leads to the lowest percentage of mildewed leaves and the loss of significantly fewer leaves than the other treatments. There is a tendency for formulation A to be slightly better than C at both the 2.0 lb and 1 lb levels. By comparing the appearance scores of the 'with tecoram' and 'without tecoram' plots separately it can be seen that there is a tendency for formulation C to be more active at any given rate with tecoram, whereas when no scab fungicide is added, A is the more active.

In the comparison between wettable powder and emulsifiable concentrate formulations (Table 5), treatment No. 5, the wettable powder, is obviously the most active on all counts. A distinction between the emulsifiable concentrates (treatments 1 - 4) is difficult but by scoring each treatment in order of its rating by each method (Table 6) treatments 1, 2 and 3 are grouped together, with treatment 4 as the least active of the group. This is particularly interesting as the basic formulation for treatments 1, 2 and 3 is the same, the only difference being the quantity of emulsifier incorporated. Treatment 4 is an emulsifiable concentrate of a basically different formulation. Tecoram alone (No. 6) has provided a significant control of mildew although it is not as active as dinocap.

In the work on the wettable powder formulation of dinocap all the basic treatments were applied at high and low volume and with or without the two scab fungicides, tecoram and captan. An analysis of variance of the treatment means of the percentage of mildew leaves showed that there was no significant difference between high and low volume applications, nor between the means of scab fungicide plots. The results in Table 6 are therefore expressed as the mean of 18 replicates. By whatever method they are assessed the differences in activity between the dinocap wettable powder formulations are extremely small. Treatment 2 is rated first by four and second by one of the 5 methods. The remaining treatments containing wetter fall into no fixed order of activity, but No. 1, without wetter, is the least active. It could therefore be said that the addition of wetter to a powder formulation of dinocap enhances its activity and that the quantity and type of wetter in treatment 2 is optimum for the control of mildew under these conditions. This treatment also gives best scab control. In the analysis of variance of the appearance score there was a significant interaction between scab fungicide treatments and dinocap formulation. Table 7 shows that for a given dinocap formulation there are significant differences between the scores for the scab fungicide used. For instance treatment 3 appears to be more active when used with tecoram than with captan and there is a significant influence on the appearance of the tree when tecoram is used on the control (no dinocap) treatments. Further work is in progress to see if there is any correlation between these differences and the deposit of dinocap on the leaf surface.

Acknowledgements

I should like to acknowledge the encouragement and advice given to me by Mr. K. Carpenter. My thanks are also due to Mrs. B. Bryant and Mrs. J. Fagg for their help with the statistical analyses, to Miss E. M. Noyes and members of her unit for help with leaf sampling and to the members of the Field Experiments Department under Mr. C. W. Wilson for their part in the actual spraying and assessment work.

References

BAKER, J. V., (1961). Plant Pathology, 10, 32.
DUNCAN, D. B. (1955). Biometrics II, 1.

THE EFFECT OF APPLE MILDEW ON YIELD AND THE RESULTS OF SPRAYING TRIALS FOR ITS CONTROL

by J. Ingram
NAAS Experimental Horticulture Station, Luddington

The significance of apple mildew infection is well recognised but little information is available of the actual effect it has on tree growth and cropping. The first trial carried out was designed to show the effects of allowing the disease to develop and also to compare the control given by spray programmes of dinocap and phenyl mercury nitrate. Phenyl mercury nitrate was included because of observational evidence that it gave some mildew control.

Trial 1

The trial began in 1957 on five year old trees of the variety Lane's Prince Albert worked on M VII rootstock and planted at 15 feet square.

Treatments

Key	Material	Formulation and amount per 100 gal of spray
DN	dinocap at 0.025% + wetter at 0.015%	1 lb 25% wettable powder 4 fl. oz 60% dioctyl sodium sulphosuccinate
PMN	phenyl mercury nitrate at 0.00316%	2 lb of a wettable powder containing 1.58% organically combined mercury.
O	Unsprayed for mildew	

The sprays were applied by hand lance at high volume rate. Four applications were made in 1957 between 3 April and 11 June, five applications in 1958 between 22 April and 19 June and seven applications in 1959 between 31 March and 13 July. To provide uniform control of scab all trees received a captan programme applied separately from the treatments and full control measures were taken against pests. No cutting out of mildew infection was carried out beyond that achieved by the routine light regulated pruning.

Results

Records were taken of the proportion of blossom trusses showing infection at the pink bud stage and of leaves with infection in June/July. Table 1 gives details.

Table 1 Mildew infection

	% of blossom trusses infected			% of leaves infected	
	1958	1959	1960	1958	1959
DN	0.3	0.3	0.1	15.1	9.7
PMN	1.4	4.1	3.7	45.0	46.1
O	1.6	4.9	8.5	59.3	68.4
Sig. diff. at 0.05 level comparing 1 with 2	0.71	1.85	1.85	8.17	4.57
" 1 or 2 with 3	0.80	2.07	2.00	9.14	5.11

Dinocap kept the incidence of mildew down to low levels throughout the trial. The mercury programme gave only slight control of leaf infection and significant effect on blossom truss infection was shown only in 1960.

Table 2 Extension growth per tree

	1958			1959		
	Number of shoots	Shoot length cm	Total growth cm	Number of shoots	Shoot length cm	Total growth cm
DN	159.5	37.1	6205	198.3	29.7	5805
PMN	126.5	28.8	3870	157.9	28.6	4591
O	101.5	25.3	2670	108.8	23.8	2669
Sig. diff. at 0.05 level comparing 1 with 2	50.20	6.55	2274.5	80.98	4.40	2503.7
" 1 or 2 with 3	56.10	7.32	2543.0	90.54	4.92	2799.2

Where mildew infection was not controlled the trees made less than half the total extension growth of those where mildew was effectively controlled with dinocap. The increased growth under dinocap was associated with increases in both shoot length and number. The trees receiving mercury made growth that was intermediate between the dinocap and unsprayed trees but the increase over those unsprayed did not reach significance.

Table 3 Yields bushels (40 lb) per acre

	1957	1958	1959	1960	1957-60	Fruitlet drop as a % of total crop 1959
DN	44	152	280	506	983	39.1
PMN	22	132	77	298	529	75.9
O	44	160	110	256	571	38.5
Sig. diff. at 0.05 level comparing 1 with 2			54.1	90.6	108.8	8.33
" 1 or 2 with 3			60.5	101.2	122.9	9.31

In 1957 and 1958 the yields of the dinocap sprayed trees did not differ from those of the unsprayed trees but the increases in growth being made by the sprayed trees during this time were followed by a highly significant increase in yields from the dinocap trees in 1959 and 1960. The 1960 yields measure residual effect; the treatments were not applied in that year. Fruitlet drop was associated with the mercury programme and this depressed yields in each year. With no mercury application in 1960 the trees previously sprayed with mercury showed their first crop increase over the trees unsprayed for mildew.

Trial 2

In this trial commencing in 1960 a full dinocap programme of eight applications was compared with the first four only, the last four only, and with trees unsprayed for mildew. In addition each plot was split; on one half mildew infection was cut out at the pink bud stage and on the other half no cutting out was done. The dinocap was applied as before at 0.025% + wetter at 0.015%. Spraying began at the mouse ear stage and the first four applications were completed by petal fall. The second four began 12 days after petal fall. The same trees were used as for trial 1 the new treatments being re-randomized over the existing plot layout.

Results

Table 4 Mildew infection

	% of blossom trusses infected	% of leaves infected		
	1961	1960	1961	
			R	NR
1. Full dinocap	0.74	32.0	11.0	11.9
2. Early dinocap	4.4	74.3	72.3	73.5
3. Late dinocap	2.9	54.2	33.9	34.9
4. Unsprayed for mildew	10.1	85.7	87.8	91.4
Sig. diff. at 0.05 level 1 v 4 or 2 v 3	2.59	6.44		
1 or 4 v 2 or 3	2.65	6.59		

R = mildew infection cut out at the pink bud stage. NR = not cut out

The full eight applications gave the best results. The four late sprays gave a better control than the four early sprays. The results suggest that the early sprays were applied too early and the late sprays too late. Although the early sprays are shown to be of less value they do appear to influence the incidence of mildewed blossom trusses in the same year. This was best shown in the first year 1960, when the treatments were imposed on similar existing infection. A record of mildewed blossom trusses was taken on 3 May and where two applications of dinocap had been made (on 1 and 20 April) the level of infection was 2.6% mildewed trusses compared with 4.4% where no early applications were made (Sig. diff. at 0.05 level = 1.54). Little advantage from this early control of blossom truss infection, however, is shown in the level of subsequent leaf infection. Similarly the cutting out of infection at the pink bud stage has not at this stage of the trial, reduced the amount of subsequent leaf or blossom truss infection.

Other trials on the station have shown a neat lime sulphur programme on Cox to be equally as effective against mildew infection as a high volume programme. Both methods of application however increased the incidence of fruit drop. Applications of DNC petroleum on Cox in early March have also significantly reduced the number of mildewed blossom trusses but had little effect on subsequent leaf infection.

Summary

A spray programme of up to seven applications of dinocap with added wetter gave an effective control of powdery mildew infection on the variety Lane's Prince Albert. The trees made more than double the extension growth of those unsprayed for mildew and yields showed a similar increase by the third year. Four late applications of dinocap beginning after petal fall were more effective than four early applications applied between mouse ear and petal fall, but the results suggest that the late applications began too late for good control. Application of dinocap before pink bud reduced the amount of blossom truss infection in the same year but had little effect on subsequent leaf infection. Cutting out of mildew infection at the pink bud stage did not reduce the amount of subsequent leaf or blossom truss infection.

Phenyl mercury nitrate on Lane's Prince Albert gave only moderate mildew control and caused fruit drop which depressed yields.

High volume and concentrate application of lime sulphur on Cox were equally effective in controlling mildew, but both increased fruit drop. DNC-petroleum applied to Cox in early March reduced the number of blossom trusses showing infection but had little effect on later leaf infection.

Details of Discussion

Q. Mr. C. D. Lindley

What level of blossom truss infection affects the yield of apples, and below what level should treatment control infection to prevent loss of yield?

A. Dr. R. T. Burchill

I haven't actually done trials or examinations in this respect. The only observation I can make is that in the Long Ashton trial the percentage of infection on the control trees was about 6% which was nevertheless fairly high. A value below 6% would I feel represent a good control.

Mr. J. Ingram commented:

8 - 9% can harm the crop.

Dr. J. E. Crosse asked:

Several of the speakers have mentioned the importance of reducing primary infections in the orchard by pruning and spraying etc., but none of the experimental evidence indicates that this has any permanent effect on the development of secondary infections during the summer. In how many instances in these experiments has secondary infection originated from the unsprayed control trees? Is it possible in the conventional type of field experiment to demonstrate any relationship between primary and secondary infections?

Dr. R. O. Sharples stated:

I agree that a certain amount of the secondary infection which develops in experimental plots undoubtedly comes in from the unsprayed control plots and from the neighbouring orchards. Unless a completely isolated orchard is available, the prevention of this source of infection presents a very difficult experimental problem. It also involves a great deal of extra labour since the guard rows must be sprayed very frequently. In our trial we randomised all the treated plots except the unsprayed controls, (Programme 2), which were deliberately placed on the corners of the orchard where the prevailing winds would tend to carry mildew spores away from the treated plots. This compromise was justified since we were mainly interested in the effects of the different spray programmes, and the untreated plots were merely included as a guide to the general level of infection in the orchard. When looking at the trees, after applying frequent eradicant sprays, it was apparent that a few primary infections did escape complete eradication. This led me to suggest in my paper that much of the subsequent secondary infection arose from inoculum produced within the treated plots themselves but I believe that we also got some infection coming in from neighbouring orchards. Infection from this latter source may have limited the effectiveness of the eradicant programmes and had we been working in an isolated orchard, the subsequent build-up of mildew in plots which were sprayed up to the end of May only, might have been less. Nevertheless there was still a marked reduction in the inoculum level within these plots during June.

Mrs. Baker

I would like to refer to the trial we did in Suffolk, reported in my second paper, where we had four plots, quite sizeable ones, and within each of these four plots we had four trees only which were thoroughly pruned in spring to get rid of primary infections. In addition, four were left unpruned and the whole of the rest of the trees were commercially spring pruned. It is interesting to note that we found certain differences between the four trees which had had very thorough spring pruning, and the commercially pruned trees, and the unpruned ones. We found differences in the percentage of spur buds distorted in the Autumn, and differences in the amount of shoot infection, and I think there is an important distinction here. Leaf infections seem to occur on a large scale, tending to minimise tree to tree differences, in a 'blanket' infection, whereas spur bud infection (occurring early in the season) and perhaps shoot infection too, seem of a more limited nature, in a more particular type of infection. There this may well be spread from unsprayed control to sprayed trees in trials as far as leaf infections are concerned although clear differences may show up during or immediately after the spray programme is complete. This is why it is of value to do more than one set of records in a trial, on different tree parts, and also why it is so important to discover if possible the conditions of infection in the field, not only for leaves, but for buds and growing points of shoots. Perhaps infection conditions are different for leaf surfaces and for the compacted tissues of buds and growing points, because in our Suffolk trial and in other observations we got effects on spur buds which were not apparent in leaf counts, following spring pruning.

Mr. D. Hunnam commented:

Dr. Crosse's question can be expressed in another way. Sometimes small replicated single tree plots are used to obtain information. Sometimes large single plots of many trees are used: these two methods will give a different assessment of the importance of cross infection.

We have done both ourselves. We have found in small scale plots there is an indication that high rates of Karathane prevented sporulation of the mildew and that this was reflected in the primary mildew in the subsequent year. Bearing in mind that there was cross infection in the same season it is not possible in small plot trials like these to determine the true effect of such treatments upon the secondary mildew. In large plot trials cross infection is reduced, and you find reference to such a trial in my paper, but I didn't get round to it. Pink Bud and Green Bud applications have not had any reflection whatsoever in secondary infections later in the season. In the same way extensive cutting out of mildewed trusses at the pink bud has had no effect upon secondary mildew.

This is not to say both treatments will not affect the primary fruit truss infection.

Dr. R. O. Sharples commented:

We also found that sprays applied at pink bud or earlier did not reduce the incidence of secondary infections later in the season.

Mr. R. W. Marsh asked:

Would you like to comment on the suggestion that the effect of mildew as shown on fruit is an indirect effect?

Ir. G. S. Roosje answered:

In the paper you will see this difference between Mr. Terry's opinion and what I said in my paper. I feel that the russeting is largely due to direct mildew infection. This is supported by our 1960 experiment, where only one spray less resulted in much more mildew russeting on the fruits and one can hardly imagine that a difference of only one spray would have so much influence on the condition of the foliage. I believe we come closer to each other when one bears in mind that my experiments were carried out on Jonathan, whereas the experiment of Mr. Terry was carried out on Cox. Mildew russeting is much more severe on Jonathan fruits than on Cox fruits. With respect to Golden Delicious and Cox, I agree largely with Mr. Terry's findings.

Mr. H. J. Terry responded:

I don't think we disagree at all. All I said was that we hadn't actually shown the direct effect on mildew growing on the fruit surface but that obviously there is a relationship between the russet and the amount of mildew on the tree. In my tables, I think that is probably clearer in Tables 1 and 2 of my paper. The earlier programmes, and the more effective ones certainly are associated with the lower percentage of russeting.

Dr. R. T. Burchill remarked:

I have seen apple mildew growing on Comice pear's but not on Cox's Orange Pippin apples. Frequently it is claimed that mycelial infection of fruitlets (the mycelium later disappearing as the apples mature) is responsible for much of the russeting seen on Cox fruit at harvest. Although this has never been satisfactorily proved it would seem that if this russeting was caused by mycelium then examination of sections from affected areas of the fruit may show the presence of encapsulated haustoria in the cells, thereby providing evidence of a previous mildew infection.

Ir. G. S. Roosje stated:

I found on a few fruits a little mildew mycelium in a very early stage of the fruits. I agree with Dr. Burchill, that usually one starts to look too late for actually finding mildew mycelium on the fruits. The occurrence of mildew mycelium on apple fruits is for instance known from the United States (Washington State) and is also well known in Switzerland, where this fact has been established by Dr. Zobrist and cooperators (see Dr. Zobrist's commentary on the subject).

Dr. R. O. Sharples commented:

Two years ago, at Lenton Experimental Station, we inoculated the flowers of Jonathan trees by dusting them with mildew conidia. The trees were grown in pots in a greenhouse. We obtained infection of all the floral parts and the mycelium grew vigorously on the surface of the sepals. Although, in a few cases, the mycelium later spread to the surface of the fruitlet, just below the sepals, the severity of the infection of the style prevented the fruit from setting. We therefore did not show the growth of mycelium on the fruit itself but it did appear that the fungus will grow on the flowers and young fruitlets of Jonathan. Mycelium was also recorded on the sepals and petals of Cox and Worcester Pearmain flowers following inoculation with mildew conidia in the greenhouse.

Q. Mr. G. D. Angell

The suggestion that the increase in mildew infection in Bramleys is, I take it, where growers are using a specific mildew fungicide. Is it not more attributable to climatic conditions and the turn over from lime sulphur to mercury on an erradicant programme? Few Bramleys growers are at present using a specific mildew fungicide, and although many growers may be turning over to low volume spraying, high volume spraying still finds more favour with many growers of Bramleys and yet the increase in mildew would seem as high with these growers as low volume users.

A. Mr. D. Hunnam

The answer here is that the mildew increase is, I think, directly attributable in part to the simple fact that there is not enough of the fungicide in the right place. Where lime sulphur is being used there is just not enough penetrating up to the tops of big trees. This fact, I should imagine, applies to most of the air application machines which are available and I don't intend to refer to any single make of machine. How important it is I don't know for certain. I imagine it is very important but as we are in the relatively early stages we have got to be careful. I am quite sure that this is something of sufficient importance to be looked into.

Dr. R. T. Burchill answered:

In this country the only approach of this nature has been with D. N. O. C. / petroleum sprays. Dr. M. H. Moore has shown that an application of this spray just before bud-burst resulted in a reduction in the number of primary infections that subsequently emerged.

Recent experiments with December applications seem to suggest that spraying at this time may give an even greater reduction in the amount of overwintering mildew.

Dr. Zorbrist's commentary on his slides:

Apple Mildew (Podosphaera leucotricha) as a cause of russetting apples

Known causes of russetting of apples have been till now: (1) frost damage during or shortly after blossom; (2) cold and adverse weather conditions during the development of the fruit; (3) phytotoxicity from chemicals, such as sulphur and copper.

The russetting resulting from one or several of these causes usually covers a smaller or larger uninterrupted area of the fruit surface. Damages from adverse weather conditions may also lead to cracks, grooves or deformation of the fruit, besides russetting.

With the increased incidence of apple mildew fine, web-like russetting has appeared on the fruit, quite distinct from the russetting from the above mentioned causes. The finish of the fruit is considerably impaired. Growers usually attribute this to "spray injury".

In our experimental orchards we found this type of damage in the years 1958/59/60 in untreated plots as well as in plots without mildew treatments.

Variety	Russetting caused by P. leucotricha % of 22,000 apples examined from 1958 - 1960		
	Untreated check	Treated against scab and insects but not against mildew	Treated against scab, insects and mildew (*)
Golden Delicious	45	37	1
Jonathan	42	37	4
Cox	58	45	5
Gravenstein	15	16	3

(*) 2x wettable sulphur and 3x dinocap beginning at pink-bud.

From these results it follows that there is a connection between the control of P. leucotricha and occurrence of web-like russetting on the fruit. That the mildew is in fact the cause of this russetting was confirmed in a field test at our Coppet experimental station. At the end of May, 1960, 1,611 apples in untreated plots showing microscopic mildew infections were labelled. At this stage the infection shows up as a white fungus layer mainly in the calyx zone. Mildew infections on the fruit only occur during the blossom and fruitlet stages.

P. leucotricha sporulates normally on the youngest apples. It does not, however, spread on the epidermis of the growing fruit. The fungus is probably unable to perforate the epidermis at a later stage.

The 1,611 labelled apples were examined two months later at the beginning of August and it was found: (1), that the mildew infections were confined to the initially attacked area of the fruit surface; (2), that the mycelium was not as easily recognisable as at the time of labelling, except on Golden Delicious; (3), with the growing fruit the epidermis expanded and the infected zones were distinctly russeted, and (4), that of the labelled fruit 20 - 35% had been shed during the physiological June drop.

Variety	% labelled apples from untreated plots examined after harvest, showing		
	visible mildew infections	mycelium with positive plasmolysis reactions	web-like russetting
Golden Delicious	58	25	78
Cox	41	10	97
Jonathan	55	22	81
Gravenstein	63	-	72

The microscopic examination confirmed that the visible mycelium was P. leucotricha. No perithecia were found on the fruit.

In conclusion I would say that our investigations at Dielsdorf and Coppet have shown that: infections by P. leucotricha occur during the blossom or fruitlet stage of the apples; P. leucotricha can live on apples infected during blossom until harvest; the fungus actively penetrates the epidermis of the fruit with its mycelium and haustoria; the perforation of the epidermis by the fungus causes typical web-like russetting of the growing fruit; specific sprays for mildew control during and after blossom prevent the web-like russetting of the fruit.