SESSION III

FORECASTING OF PEST AND DISEASE OUTBREAKS, SPRAY TIMINGS AND ECONOMICS OF CONTROL. POTATO BLIGHT AND ITS CONTROL.

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Ministry of Agriculture, Fisheries and Food

SOME FACTORS INFLUENCING THE CONTROL OF POTATO BLIGHT

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It has been said that potato blight control today is no better than it was thirty years ago. Whether this is true or not, it is certain that the outstanding fact which has emerged from six years N. A. A. S. trials in East Anglis is the failure to achieve any striking and consistent improvement in the control of the disease. In almost every spraying trial, most of the treatments have been significantly better than the unsprayed controls, but very rarely has one treatment been significantly better than the rest. This applies both to trials comparing different fungicides and to those comparing application methods which have ranged from high-volume ground spraying to concentrate spraying from aircraft. These trial results are reinforced by field observations. The average prolongation of growth resulting from three to five sprays seems to be only between a week and a fortnight in a bad blight year, and it is doubtful whether this is appreciably better than the control obtained in the past.

This is not to deny that there have been many advances in the fungicide field, though the advantages of the newer materials often lie in ease of handling, in adaptability to a number of application techniques and, in some cases, in lack of phytotoxicity, rather than in greater fungicidal power. But even among the materials which do possess greater fungicidal activity there is none which has so far shown any marked advantage over Bordeaux mixture in the vital matter of controlling the development of the disease on the haulm.

The most likely reason for this is inadequate fungicidal cover. Leaf prints from crops sprayed with copper fungicides by modern high-volume machines show that even with this technique the cover is far from complete, and unfortunately it is difficult to visualise more than marginal improvements in this respect. Moreover, one cause of incomplete cover, the continuous growth of the plant, is clearly ineradicable. Since the performance of even the best protective fungicide is largely determined by its distribution, and since this appears to be inadequate and likely to remain so, it seems that no striking advance in the efficiency of control can be expected, no matter what further improvements there may be in the materials used. This applies, of course, to protective fungicides of the present type: the advent of a satisfactory systemic fungicide could alter the whole situation at once.

Control measures which are adequate in a season when the weather does not favour the fungus may fail badly in a year when opportunities for spore-multiplication and dispersal are frequent. When spore numbers are relatively low spraying can at least delay appreciably, even if it cannot prevent, the spread of the disease. Hence the importance of timing the earliest applications so as to ensure that the spraying has the best possible chance: that the fungicide is applied before the spore numbers are already too high.

The best available guide to correct timing is the blight forecasting scheme based on Beaumont's weather criteria. But even when spraying follows the forecast warning as quickly as possible it is still exceptional to get more than a fortnight's delay of the epidemic. This is no doubt partly due to the spraying inadequacies already mentioned, but probably also because what is forecast is not the imminent invasion of the crop by spores from outside but the appearance of the symptoms of the disease. In many fields the actual infection will already have occurred during the Beaumont period on which the forecast was based. Until the conditions necessary for distant epidemic spread can themselves be accurately forecast this weakness will remain, and the first spray, if applied according to the system, will often have to contend with already established infections.

The probability that the key to the failure to achieve complete control lies in the great numbers of spores which have to be repelled, even at what is often regarded as the beginning of the epidemic, directs attention to the conditions in which these spore-numbers are built up. A number of workers - among them Van der Zaag, de Lint and de Bruin in the Netherlands and Hirst and Robertson in England - agree in suggesting that the cryptic or smouldering phase of blight epidemics would repay more investigation.

The earliest phase of all, the development of the primary or "initial" foci, has been studied in this country by Hirst and Robertson. But there is very little information about the next phase - about the way an epidemic builds up in a great potato growing area like the Fens. Practically nothing is known about the number and distribution of initial foci, and how these vary from year to year, nor about the importance or otherwise of the early potato varieties as sources of the blight in the maincrops. It seems that it is in this field that further investigations are most urgently needed.

Recording the early development of a blight epidemic from the ground presents almost insuperable practical difficulties. At Cambridge, therefore, the possibility of using aerial photography for this purpose has been investigated and during the past three years preliminary attempts have been made to survey selected areas in the Fens by this means. The original plan was to photograph an early potato district in the Holland division of Lincolnshire, from which very early records of blight had been regularly received during the previous five years, and a maincrop area near Manea in the Black Fen. The photographing has been done throughout by Mr. C. V. Dadd, Crop Husbandry Officer, N.A.A.S., Eastern Region.

For recording blight, infra-red materials have proved far superior to panchromatic, giving a much greater contrast between the diseased and healthy areas in a field. Even with this technique, very light infections cannot be recorded, but patches of badly blighted plants only about two yards across can be clearly seen in photographs taken with a 3¼" focal length lens from about 3,500 ft., at which height the area covered by one photograph is between three-quarters of a mile and one mile square. Serial photographs, with about 50% overlap, such as are used for stereoscopic examination, are usually taken, though stereoscopy has only proved useful very occasionally, for special purposes. It has been found most convenient to examine the photographs as negatives, still on the original 50-foot roll, using an electrically lighted viewing box. The flight track, potato fields, suspected blight patches and anything else requiring checking by ground examination are then marked on a 2½" map. Positive prints are only made if they are needed for record purposes, for stereoscopy, or for making a mosaic composite photograph of a larger area than is covered by one exposure. There are still many difficulties to contend with in the use of the technique, but they are gradually diminishing with increasing experience and none of them should be insuperable.

Unfortunately from the point of view of this work there has been very little blight in East Anglia in two of the last three years, while in the third (1960) the epidemic started not in Lincolnshire but in West Suffolk. Progress has therefore been slower than had been hoped. But in any case the number of foci and the pattern of epidemic development are likely to vary widely from year to year, so that any survey of this kind must be continued for a number of years before any firm generalisations can be made. In one sense, therefore, it is undoubtedly premature to discuss the subject at this stage, but since the few results already obtained appear to throw light on one aspect of epidemic development it is perhaps worth making a very early progress report.

The first infra-red photograph showing the natural spread of blight was obtained in July, 1960. A focus (probably an initial focus, though this could not be proved) in a small field of Red King potatoes in Sedge Fen, Lakenheath, West Suffolk, was reported on July 4th. At that time it comprised a nucleus, about 2 yards in diameter, of badly blighted plants surrounded by many much less badly infected ones so that the total diameter was roughly 20 yards. No blight was noticed elsewhere in the field or in other fields in the district, though it seems likely that some was overlooked. The field was photographed from the air on July 16th, by which time considerable developments had become apparent. The badly infected nucleus of the original focus was now about 10 yards in diameter and what looked at first sight like another focus of about the same size had appeared a few yards away to the South East. Closer inspection of the photograph showed, however, that this new focus was a composite made up of several smaller patches. At intervals throughout the rest of the field, and still more markedly in another field of Red King lying to the north of the first field and separated from it only by a narrow strip of wheat, were fifty or more "daughter foci". These varied in size, some consisting of perhaps three or four badly infected plants, others of as many as ten or twelve. Many of these daughter foci, especially the larger ones, somewhat resembled stumpy comets, the badly blighted plants being the 'heads'. From the 'heads', short ill-defined 'tails' of less badly blighted plants stretched for 10-20 yards towards the south-west before becoming indistinguishable from the rest of the crop.

The most distant of these daughter foci was nearly 400 yards from the initial focus, so that this was undoubtedly air-borne spread, such as is normally associated with a Beaumont period. Beaumont periods were recorded at Lakenheath from June 7th - 9th and from June 23rd - 26th. Bearing in mind the size of the daughter foci it seems likely that the larger ones, at least, resulted from spread during the earlier of these periods - June 7th - 9th. This would allow plenty of time for each new infection to develop into a small focus by July 16th when the photograph was taken. This development would be slow at first, in the comparatively dry conditions between the Beaumont periods, but would increase rapidly during the Beaumont period of June 24th - 26th. This late increase might account for the daughter foci not being noticed on July 4th: infections initiated about June 25th might be hardly visible nine days later. The alternative explanation, that the spread from the initial focus did not occur until June 24th - 26th, would imply the descent of spores in "packets" giving simultaneous infection of up to a dozen adjacent plants. It is of course, possible that the ecoclimates in the areas which developed into daughter foci were more favourable than those elsewhere and that this caused a patchy development of blight to result from a heavy but uniform descent of spores during this later period. On the whole the hypothesis of spread during the early June Beaumont period seems the more likely. If this is accepted the formation of the "comet-tails", which appears to involve a type of spread similar to but more rapid than that which normally occurs in an initial focus, may have occurred during the Beaumont period of June 24th - 26th, when very heavy rain was associated with generally light northerly winds.

This somewhat detailed description of one case of spread is given as an example of the kind of evidence that aerial photographs of blight may yield and of the kind of analysis which should be possible. The photographs reveal patterns of blight distribution in a field which could only be perceived from the ground with great difficulty, if at all, still less recorded. Some of these particular interpretations may well be mistaken, but in any case two points of interest emerged from this one photograph alone. The first is that although there was a falling-off in the frequency of daughter foci with increasing distance from the initial this falling-off was by no means steep, and the photograph suggested that had the susceptible crop extended further, the spread might have reached to considerably more than the 400 yards recorded. The second point is that this spread occurred during a Beaumont period (whichever one it was) which would, quite correctly, have been regarded as occurring too early to justify forecasting a general outbreak. Even within a mile or two of the fields described, the characteristic sudden appearance of scattered blight in a high proportion of fields only occurred after the next Beaumont period, that of July 9th - 12th.

The warning issued after this period referred to the Sedge Fen focus (then the only case of blight recorded in East Anglia) and prophesied that other outbreaks would occur in the eastern counties before the end of the month. This was entirely correct, but it gave no indication - and could give none on the information then available - of the virulence of the outbreak which was about to occur in this area where W. Suffolk, W. Norfolk and the Isle of Ely join. The rapid development of blight in this district was presumably due, at least in part, to the fact that it was launched not from one initial focus but from some fifty daughter ones as well.

No national forecasting system could possibly cater for the innumerable local variations in climate and in the number of initial foci which must inevitably occur. In this case it is clear that though the national forecast was well timed for East Anglia as a whole it was too late to help the owner of the field in which these daughter foci developed. Further, the very large spore-source which these fields constituted must have diminished the chances of achieving a reasonable check to the epidemic, by spraying, for a considerable distance around.

A similar development of daughter foci at the beginning of the epidemic was seen in one of the very few cases of blight photographed this year. This was again at Sedge Fen, Lakenheath. In a photograph taken on July 25th, two small foci could be seen in a crop of Craig's Royal. They were about the same size and it is uncertain whether they were both initial foci, both daughter (having arisen by spread from some undetected initial) or whether one was an initial which had given rise to the other at an early stage. A smaller patch of blight could also be seen in a narrow strip of King Edwards in the same field, and two, hardly distinguishable, in another King Edward crop in an adjoining field. By August 18th, when the next photograph was taken the Craig's Royal had been lifted, but a number of very clear daughter foci had developed in the second Kind Edward field. This particular case of spread is of interest in that it occurred in weather less humid than a true Beaumont period. No full Beaumont period was recorded at Lakenheath throughout the season.

Only further survey work can determine whether or not this establishment of daughter foci, - occasionally at least well before the general epidemic outbreak - is a common occurrence, though the fact that it has been recorded twice in so short a period and in the very limited areas which have been photographed suggests that it may be one of the normal ways in which epidemics develop. The present evidence shows that it can occur during Beaumont periods in June and sub-Beaumont conditions in July: it is presumably because they are initiated in these border-line conditions for air-borne spread that the daughter foci remain distinct long enough to justify the use of the word "foci".

It remains to consider the bearing of these facts on the control of the disease. The survey has revealed one way in which spore numbers are built up to a dangerously high level before the general epidemic spread begins and so indicates a possible way of improving the general level of control. If these breeding-grounds of blight - the groups of daughter foci - could be found and eliminated sufficiently early it might well delay the onset of general epidemic spread, or at least reduce the numbers of spores then dispersed to a level with which spraying could deal successfully.

Meanwhile the survey gives some help in answering the perennial question about the value of precautionary spraying before the general outbreak warning. The photographs make it clear that in the fields containing initial foci, or those in which the daughter foci develop, only very early spraying could be of any use. Early spraying should be of value, as an insurance premium, in areas where the risk of being near an initial focus is high - i.e. in intensive potato-growing areas where Kind Edward constitutes a high proportion of the main crop acreage. It is even more justified in such areas if many earlies and second earlies are also grown, for van der Zaag's work in the Netherlands and field experience in this country both suggest that the proportion of initial foci is likely to be higher in earlies than in maincrops. In less intensive areas, and where Majestic is the most common variety, early precautionary spraying is probably too high a premium to pay in view of the comparatively low risk. In districts such as the West Suffolk fenland, where the risk appears to be high, it may also be desirable to supplement the national forecasting system by issuing local warnings after a Beaumont period earlier than that which would be valid for a larger area such as East Anglia as a whole.

Another possible control measure, which would not be popular because it cuts across a convenient practice, would be to isolate the earlies from the maincrop potatoes. Failing this, farmers who grow both side by side should be encouraged to spray them both from a fairly early stage, to inspect the earlies regularly for signs of blight and, if they find it, to destroy the haulm as quickly as possible even at the expense of some loss of crop.

Whether it will ever be practicable to control blight epidemics at or near their source is a question that cannot yet be answered. It will depend largely on how many dangerous sources there are and whether they tend to be sufficiently concentrated in particular areas to make the necessary close search and treatments possible. But if such attempts to reduce the inoculum-potential of blight epidemics are ruled out it seems likely that, so long as we are limited to the use of non-systemic protective fungicides, we must resign ourselves to only marginal improvements in the control of disease.

THE CHEMICAL CONTROL OF POTATO BLIGHT IN THE U.K.

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The number of compounds currently in use for the control of potato blight in the U.K. is limited and the main objective of this exercise is to present some of the difficulties met in the evaluation of these materials. This is normally done either on a large scale non-replicated basis, or else on a fully replicated statistically designed small plot system. Economic factors do not always permit large scale field trials, but even when this is done, the value of the recorded data must be cautiously assessed. It is traditional to record either yield data or else disease ratings based on some arbitrary key such as that drawn up by the British Mycological Society (1947). Experience with both large and small scale trials in the United Kingdom during the past seven years, has shown that neither method is completely satisfactory, and a compromise system has, therefore, been evolved.

Unless there are application difficulties to be overcome, statistically designed small plot experiments have been found to give the most reliable data. Spray applications are generally started at two weekly intervals well ahead of the blight warnings, and continued regularly until untreated control areas register approximately 5% disease. Regular blight recordings are then made every 3-4 days. Normally the plot size is standardised to 20 square yards and applications are made by means of a hand lance at 50 or 100 g.p.a. Each experiment is always replicated on different sites.

Since the relative amount of disease present in the different treatments varies throughout the epidemic, blight progress curves are drawn for each treatment, using the arithmetic mean of all replicates as points of reference. Two sets of data are then selected for further analysis: (a), an early set of recordings showing maximum difference between the various treatments and the untreated controls; (b), a later set showing maximum differences between treatments, often with certain treatments being not statistically different from the untreated controls. The reason for this procedure is that sometimes the potato crop dies back before treatments reach even the 50% disease level, and therefore further statistical elaboration becomes impossible.

From time to time attempts have been made to take yield data from the small plot trials, but unfortunately this exercise has never proved satisfactory. The data recorded are generally extremely variable even under the apparently uniform soil conditions of the Fenlands, and a statistical analysis of this data rarely shows any significant difference between treatments. The procedure, therefore, has been to estimate yield increases on the basis of the date of 75% defoliation and the published data of Large (1952). It is realised that there are many pitfalls in this procedure, for the published evidence is confined to one variety of potato. However, on the assumption that other varieties yield a similar pattern of yield increase with time, the relative performance of any two chemicals might be expected to remain fairly constant. Furthermore, this procedure ignores any stimulating or phytotoxic effects that the fungicide may possess.

Table 1 Treatments examined in field trials on potatoes in 1958 & 1960

Active ingredient	Rate of active ingredient per acre	Rate of product per acre
Copper oxychloride	2 or 2.5 lb of combined copper	4 or 5 lb
Zineb	1.3 lb	2 lb
Maneb	1.05 lb	1.5 lb
Copper oxychloride/ zineb	1.125 lb copper + 0.49 lb Zineb	3 lb
Copper oxychloride/ maneb (1958)	1.25 lb copper + 0.525 lb Maneb	3 lb
Copper oxychloride/ maneb (1960)	1.125 lb copper + 0.39 lb Maneb	3 lb

Table 1 lists the treatments examined in 1958 and 1960, and Tables 2 and 3 give the results of four trials carried out in 1958 and four others in 1960. The products used were all orthodox wettable powders, applied according to the recommendations of the manufacturers.

Table 2 Field Trials 1958

Braunton, Devon. Variety- Majestic

Treatments	% disease at point of maximum divergence	Date of 75% defoliation	Estimated % increase in yield over untreated control
	L. S. D. = 16; P = 5%		
Untreated	94%	7th August	0
Copper oxychloride/maneb	38.2	17th "	19.5
Copper oxychloride	50	16th "	19.5
Copper oxychloride/zineb	53	15th "	18.0
Zineb	75	13th "	13.8
Instow, Devon. Variety - Dunbar Standard			
	L. S. D. = 13; P = 5%		
Untreated	95.5	5th August	0
Copper oxychloride/maneb	50	16th "	25.4
Copper oxychloride	67.5	15th "	23.9
Copper oxychloride/zineb	71.5	14th "	21.6
Zineb	90	13th "	19.4
Christow, Devon. Variety - Majestic			
	L. S. D. = 15; P = 5%		
Untreated	93.5	17th August	0
Copper oxychloride/maneb	28.8	26th "	11.8
Copper oxychloride/zineb	34.5	26th "	11.8
Copper oxychloride	37.5	25th "	10.7
Zineb	53.0	25th "	10.7
Ashburton, Devon. Variety - Majestic			
	L. S. D. = 13; P = 5%		
Untreated	90	6th August	0
Copper oxychloride/maneb	23.3	18th "	24.4
Copper oxyc oxychloride/zineb	41.0	17th "	24.4
Copper oxychloride	50	16th "	22.5
Zineb	53.0	16th "	22.5

Table 3 Field Trials 1960

Ashburton, Devon. Variety - Ulster Dale

Treatments	% disease at point of maximum divergence	Date of 75% defoliation	Estimated % increase in yield over untreated control
	L. S. D. = 18; P = 5%		
Untreated	96	31st July	0
Copper oxychloride/maneb	12.5	10th August	30.8
Maneb	26.5	9th "	28.0
Copper oxychloride/zineb	42	8th "	25.2
Zineb	50	7th "	22.0
Meeth, Devon. Variety - Dunbar Standard			
	L. S. D. = 16.6; P=5%		
Untreated	80	8th August	0
Maneb	28.5	13th "	13.6
Copper oxychloride/maneb	32.5	12th "	8.7
Zineb	53.5	11th "	6.5
Copper oxychloride/zineb	68.5	10th "	4.5
Chesterford Park. Variety - Majestic			
	L. S. D. = 10.2; P=5%		
Untreated	85	30th August	0
Copper oxychloride/maneb	15	11th "	9.2
Copper oxychloride/zineb	28.7	10th "	8.5
Maneb	40.6	10th "	8.5
Zineb	50	8th Sept.	6.9
Chatteris. Variety - Ulster Supreme			
	L. S. D. = 17.5; P=5%		
Untreated	92.9	25th August	0
Maneb	15	1st Sept.	7.4
Copper oxychloride/maneb	19.2	1st "	7.4
Zineb	34.2	1st "	7.4
Copper oxychloride/zineb	50	31st August	6.6

The data given in Tables 2 and 3 show quite clearly that the relative performance of the different products varies from trial to trial; any true evaluation of these products must therefore include a consistency factor as a further criterion on which to make a final assessment. From this point of view the performance of mixtures of copper and dithiocarbamates appear to have some advantage over the use of either constituent alone.

In discussing the significance of synergism as a possible tool in the conservation of fungicides, Dimond & Horsfall suggested, as early as 1944, the possibility of synergism between certain copper and zinc compounds. It appears, however, that the first field experiments with mixtures of copper and dithiocarbamates were not reported until 1953 when Lafon & Couillaud in Europe, and Strong in the U.S., published their results on Downy Mildew of vines, Plasmopara viticola, and various diseases of tomatoes respectively. At that time they suggested that the enhancement of activity of the mixture of copper and zineb was possibly related to the solubility of the copper ingredient. Lafon & Couillaud claimed that the mixture of copper oxychloride and zineb showed synergistic activity, but Strong made no such claims. Since 1953 synergistic effects of copper/zineb mixtures have been reported by Payen et al. (1954), Agulhon & Amphoux (1955), Bisson & Larrieu (1958) and Cole (1957). In these studies on mixtures of various copper preparations with zineb, stress was given to the fact that the greatest improvement in activity was obtained with a mixture containing a high proportion of copper and that mixtures of low copper content were not as effective (Agulhon & Amphoux, 1954; Bisson & Larrieu, 1958 and Boubals et al., 1956).

The use of mixtures naturally suggests the possibility of chemical interactions between the ingredients. Strong (1955) thought that the copper salt of the dithiocarbamate might be formed when these mixtures were prepared, and proceeded to demonstrate that the copper salt of nabam gave results equal to that of maneb against Septoria leaf spot of tomatoes. In 1957 this work was repeated with Early Blight and Late Blight of tomatoes and again the possibility of a copper salt being formed was mentioned. Since that time mixtures of copper and zineb have successfully been employed for the control of Leaf Spot Disease of bananas (Cercospora musae), Guyot 1954, and Late Blight of potatoes (Phytophthora infestans), Calbeck 1960.

At the dosage rates used in these experiments it is perhaps prudent to note that maneb gave consistently better control than zineb and similarly copper oxychloride/maneb mixtures gave better control than copper oxychloride/zineb mixtures. However, despite the claims of previous workers that certain mixtures show synergistic activity there is no evidence presented here that this is so. There is, however, a suggestion that the performance of a copper product is favoured by a certain kind of epidemic and that the dithiocarbamates perform better under another set of unknown conditions. Although not presented in this document, the pattern of the blight progress curves for each of these trials suggests that the dithiocarbamates are favoured by the more rapidly advancing epidemics, whereas the more prolonged epidemics favour the performance of copper products.

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TRIALS OF COPPER FUNGICIDES ADAPTATION OF BORDEAUX AND BURGUNDY MIXTURES FOR LOW VOLUME SPRAYING

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Experiments made to adapt Bordeaux and Burgundy Mixtures to low volume spraying have shown that Bordeaux Mixture can be sprayed through nozzle booms at 1 lb copper in 10 gallons, by rotary atomisers at 1 lb in 4 gallons. These rotary atomisers will spray Burgundy Mixture at 1 lb copper in 4 gallons or the new Potash Burgundy at 1 lb in 2 gallons.

Costs of these mixtures are found to be from half to three quarters of those of wettable powders for same copper content.

Mixing procedures are described and suggestions made for minimising difficulties.

The original Bordeaux Mixture announced by Millardet in France in 1885 contained about 6 lb copper sulphate 11 lb quick lime and 10 gallons water which it was advocated should be applied with a brush made of twigs. A few years later with the appearance of the first knapsack spraying machines the mixture underwent modifications to make it sprayable through these machines and a 10:10:100 (10 lb copper sulphate, 10 lb quicklime, 100 gallons water) quickly emerged as a more or less standard mixture.

About 1927 in this country hydrated lime was suggested in place of quick lime and the present Ministry of Agriculture recommendation for a good Bordeaux Mixture for potatoes, for example, is one containing 10 lb granulated copper sulphate and 12½ lb of best hydrated lime in 100 gallons of water, (10:12½:100). If allowance is made for the smaller calcium oxide content of the hydrated lime it will be seen that the ratio of copper sulphate to calcium oxide has not materially changed over the passage of the past 70 years or so.

Burgundy Mixture was introduced only a year or two later than Bordeaux Mixture. It is made by mixing solutions of copper sulphate and sodium carbonate (soda ash or washing soda) and may therefore be described as a Bordeaux Mixture made with soda instead of lime.

In spite of their antiquity it seems to be generally agreed that freshly prepared Bordeaux and Burgundy Mixtures are the most effective of the copper fungicides. (Beaumont, Bant & Storey, 1953; Moore, 1955; Narayanan, 1955; Grainger, 1957; Saltzman, 1957. There is no doubt this is mainly due to their adhesiveness and consequent resistance to wind and rain.

The reduction in the volume of spray normally used from the original 100 or more gallons per acre to 50, 20 or less together with the higher cost of farm labour and perhaps its lack of skill has produced a marked but unfortunate tendency to use less effective but more easily applicable copper fungicides in spite of their higher cost. It seemed desirable therefore to try to find ways of overcoming difficulties in the use of these more effective mixtures.

If the same quantity of copper is to be applied per acre in a much reduced quantity of water the thickness of the mixture will obviously be correspondingly increased. This sets a limit to the reduction of volume that can be used and we have investigated what this limit might be in practice.

As a first step in keeping the more concentrated mixtures of a consistency fluid enough to spray the quantity of lime was considered. The conventional use of a large excess of lime was probably dictated by uncertainty of its quality although there have been suggestions that it had some effect in reducing phytotoxicity. Actually 100 lb of copper sulphate ($CuSO_4$, $5H_2O$) requires only $22\frac{1}{2}$ lb of chemically pure hydrated lime $Ca(OH)_2$ to precipitate all copper. Good proprietary brands of hydrated lime are now freely available but as even these deteriorate on storage it was thought safer to adopt a ratio of copper sulphate to hydrated lime of 2:1 and this was found to thin the mixture materially. Burchfield *et al.* (1956a, b) have shown that such a reduction has beneficial effects on the adhesiveness and persistence of Bordeaux Mixture. We applied such mixtures to potatoes at 9 difference sites in the seasons 1958/61 inclusive without any copper damage being detected by ourselves or the N.A.A.S. in co-operation with whom most of the trials were carried out.

The use of a small quantity of wetting agent was found to increase the free flow of the mixture and was used in some cases at 4 oz per 100 gallons of Bordeaux. That used was of the polyethylene oxide type and was chosen as it had been found to be one which did not materially reduce the deposit (Somers, 1957) and which was very similar to, or identical with, the one adopted for use in Bordeaux Mixture applied to bananas.

Bordeaux Mixtures of formula 8:4:x were sprayed by machines of the following types: (1), Spray boom, pump operated, generally applying 20 to 60 gallons/acre; (2), Tractor drawn, fitted rotary atomisers, applying under 8 gallons/acre; (3), Aeroplane, fitted with rotary atomisers; (4), Motorised, shoulder mounted machines of about 2 gallons capacity in which the spray mixture is fed into a rapid fan-produced jet of air, and (5), Aeroplane, fitted with spray boom, used for Potash Burgundy only.

The practical limits of sprayability of Bordeaux Mixture were considered to be, after several trials:- (1), 8: 4: 20 (= 1% w/v Cu); (2) & (3), 8: 4: 8 (= 2.5% w/v Cu) and (4), (: 4: 4 (= 5% w/v Cu).

With a wetting agent Bordeaux Mixture 8: 4: 4 was used successfully also in type 2 but stoppages at this concentration cannot be ruled out and it is not recommended.

The preparation of Bordeaux Mixture in the field conjured up a vision of a number of men blue from head to foot laboriously poling barrels of thick liquids. This view however is quite out of date. Some quick and simple procedures are detailed in the appendix but these are obviously capable of many modifications to suit the facilities available. Copper sulphate is now normally supplied in granulated form and this dissolves very much more quickly than the large crystals once standard. For spraying at 20 or more gallons per acre sufficient water is available to dissolve the necessary quantity of granulated copper sulphate in 2 or 3 minutes. For spraying at under 10 gallons per acre time is saved by preparing the copper sulphate before hand, conveniently the night before. Where much spraying is to be done the provision of some storage vessels raised sufficiently to deliver into the sprayer is a matter of comparatively little difficulty and the time required then to make the mixture is no greater than that required to mix a wettable powder. Another way which may appeal to the smaller user is to buy copper sulphate in solution, now available in plastic containers from suppliers of agricultural chemicals.

The sprayability of Burgundy Mixture in concentrated form is considerably greater than that of Bordeaux Mixture. We made it to a formula of 8: 5: x where the second figure refers to soda ash (anhydrous sodium carbonate). The solubilities of the two ingredients (copper sulphate and soda) in cold water limit the concentration in practice to 8: 5: 8 (theoretically about 8: 5: $5\frac{1}{2}$). This mixture sprayed easily through machines fitted with rotary atomisers and more easily than the Bordeaux Mixture of same copper content. No higher concentration than 8: 5: 20 was tried in boom sprayers as this is equivalent to 2 lb of copper in 20 gallons below which volume per acre they are not normally operated with fungicides. If washing soda is used instead of soda ash 12 lb will be required instead of 5 lb of soda ash, and the formula becomes 8: 12: 8.

The practical limits of concentration found for the two previous mixtures (8: x: 8) would in most cases be too weak for economical use by aeroplane. To apply 2 lb of copper per acre would necessitate the application of 8 gallons of mixture and this would limit the acreage per flight to 5 for the machines commonly in use here.

As already pointed out the solubility of the ingredients is the limiting factor in the case of the Burgundy and, of the two ingredients, the soda is the less soluble. Potassium carbonate is very much more soluble than sodium carbonate and the substitution of this enabled a mixture to be made of formula 8: 5: 4 where the second figure refers to potassium carbonate 96/98%. This was found to have good suspension properties and much less tendency to build up on filters than Bordeaux Mixture or even than Burgundy Mixture.

This Potash Burgundy was applied without any trouble by rotary atomisers at 8: 5: 4 and by aeroplane fitted with a spray boom at 8: 5: 5. It was also sprayed from the ground by boom at 8: 5: 16. No higher concentration being tried with the two latter.

Effectiveness of the Mixtures.

During four seasons the above concentrated mixtures were sprayed on potato crops, using the machines metnioned, as part of the N.A.A.S. trials and alongside trials of other products and other concentrations specified by N.A.A.S. whose pathologists evaluated results. Owing to very bad weather in some seasons and absence of blight in others evaluation had to be based mainly on the distribution and persistence of copper on the leaves. The method used was to press the leaves on absorbent paper previously wetted with acetic acid (to dissolve the deposit) and a sensitive reagent for copper (bis cyclohexanone oxalyl dihydrazone). On exposing the paper to ammonia gas any part of the leaf which has a copper deposit leaves a blue mark and after a satisfactory spraying the outlines and ribs of the leaves are clearly printed together with blue speckles on their surfaces wherever copper had been present. This was systematically done by the N.A.A.S. and ourselves both just after spraying and again a week or two later (generally just before the next spraying). Comparisons of the two sets of prints enabled the persistence of the deposit to be judged. This method showed the distribution and persistence of these concentrated sprays to be equal to, and often better than, those of other copper fungicides or of those sprayed at higher volumes.

Costs

The following figures are approximate only as costs vary with market prices, quantities involved, delivery site and other factors. They are based in each case on an application of 2 lb of copper (8 lb copper sulphate) per acre, and prices, per lb, of copper sulphate, 9d; lime, 1d; soda ash, 2d and potassium carbonate (96/98%), 8d.

Bordeaux mixture		6: 4d per acre
Burgundy mixture		7: 0d per acre
Potash Burgundy		10: 0d per acre
Copper Oxychloride	4 lb at 2/9d	11: 0d per acre
Cuprous Oxide	4 lb at 3/2d	12: 8d per acre
Proprietary Powders	Up to	30: 0d per acre

The Potash Burgundy is more expensive than the soda Burgundy but the potash it contains has fertiliser value which though small, may be of significance applied to the foliage when the crop is bulking.

APPENDIX

Mixing Procedures

Bordeaux Mixture

(A) 1. Place the hydrated lime on the strainer and wash in with the bulk of the water.

2. With the agitator working pour in the pre-dissolved copper sulphate solution taking care to avoid any of it coming into direct contact with the steel sides of the spray tank.

(B) 2. Place the finely granulated 'instant' copper sulphate on the strainer and wash in with about half to two-thirds of the water with the agitator working so that any small particles which may fall to the bottom of the tank are dissolved.

3. Place the hydrated lime on the strainer and wash in with the remaining water still with the agitator working.

Method (A) will of course have to be employed where the spray tank is made of steel.

Burgundy Mixture

Dissolve separately 8 lb of copper sulphate in half the water or just a little less and soda ash $4\frac{3}{4}$ lb (or 12 lb washing soda) in the remainder of the water. Stir the copper solution and slowly add the soda solution allowing time for froth to subside.

Potash Burgundy Mixture

(A) For solutions up to 5% of copper sulphate
Place the potassium carbonate on the strainer of the spray tank and wash in with half to two-thirds of the water. If the sprayer tank is efficiently agitated the potassium carbonate may be put straight into it. Dissolve the copper sulphate in the remainder of the water and add it to the spray tank while stirring.

(B) For solutions stronger than 5% (up to 20%) copper sulphate
Dissolve the potassium carbonate in water using about 1 pint per lb. Separately dissolve the copper sulphate in the remainder of the water. Add the potassium solution to the copper sulphate solution slowly with stirring allowing time for frothing to subside.

The vessel used for mixing B should have about twice the capacity of the final volume to avoid loss.

For the preparation of copper sulphate solution use always granulated copper sulphate ('instant'). Iron or galvanised vessels must not be used. Wooden barrels are suitable. Plastic vessels now freely available are light and very convenient. To make strong solutions hang a jute sack of copper sulphate so that the bottom of it dips a few inches only into the water. The copper sulphate will dissolve overnight and it will be necessary only to stir the solution once or twice next morning to mix top with bottom. Copper sulphate will dissolve in water to the extent of about 3 lb per gallon. If more than this is put into the sack described above then overnight (or later) a nearly saturated solution will be obtained and it may be used without serious error on the basis that it contains 3 lb of copper sulphate per gallon. This is a convenient method.

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Details of Discussion

Q. Mr. H. C. Mellor

Could Mr. Brenchley give any blight figures on the resultant tubers from the crops featured in the aerial survey photographs? Also what differences were observed between the ground estimates of blight incidence and the aerial photograph technique?

A. Mr. G. H. Brenchley

We have concentrated so much on the early stages of blight that we have not followed through with the later stages. As regards the difference between this kind of recording and field recording by observers, I can only say that when we have sent people out to survey a field from the ground they come back with something that is recognisable but often wrong in proportion and with a great deal of detail missing.

Q. Mr. O. H. P. Wood

Mr. Brenchley stated that the newer types of organic fungicide introduced for potato blight control over the last few years showed little advance on traditional spraying of copper based sprays. Mr. Brenchley mentioned phytotoxicity of copper, but only briefly, inferring that this was of little importance. Recently introduced maneb formulations have been shown to be equivalent to copper in fungicidal activity without phytotoxic effects on the crop - would Mr. Brenchley please comment on this?

A. Mr. G. H. Brenchley

I would agree entirely. What I said, or what I meant to say, was that there was no appreciable improvement in the control of the disease on the haulm. In fact, we have found that when the control of the blight on the haulm is the same, zineb and maneb may give a slightly higher yield than copper. To sum up, if persistence is important, copper may stand you in good stead, but otherwise the choice will be with the dithiocarbamates on the score of their lack of phytotoxicity.

Dr. E. Evans added to this:

The Fenland soils are as standard as you get in this country and yet we get variations there. We grew potato plants in standard compost in drums out in the open, artificially watered through all the hot weather we had earlier in the season, using an early variety of potatoes. We sprayed every 10 days through the whole period - we made 8 applications in all. We harvested and hoped to find differences in the yield, but we did not find them. This is indeed a problem!

Q. Dr. James B. Loughnane

Could the inconsistent results in your experiments be explained on the basis of the particular race of Phytophthora infestans involved or on varying conditions such as temperature or relative humidity at the time the sprays were applied?

A. Dr. E. Evans

We have not found anything startling with any of these factors ourselves, but possibly what accounts for much of this variation may be the different yields from any one potato plant. We standardised the number of eyes on a potato tuber when it was planted, but we found that the number of stems produced from one tuber varied from 6 - 16 and the yield from potatoes in one treatment varied immensely. Whether we can pick potatoes that will yield more uniformly I do not know, but I think this should be possible.

PEA MOTH ON DRY HARVESTING PEAS

Investigations into the Timing of Sprays, the Economics of Control Measures and Forecasting the Levels of Attack

by
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One of the main changes in the pattern of entomological advisory work in recent years has been the increased emphasis given to the assessment of pest damage and to the economics of control measures. This usually calls for accurate information about the loss caused by a pest and the benefit obtained from the use of pesticides. More attention has also been given to means of forecasting the severity of attacks to enable the grower to take the necessary precautions and to prevent unnecessary spraying.

The pea moth investigations described below were done with these considerations in mind. This paper presents an outline of the whole programme and some of the more important results obtained covering its three main aspects: (1) assessment of the economic importance of the pest; (2) timing and the efficiency of sprays and the economics of control measures; and (3) spray warnings and forecasting the severity of attacks.

The Economic Importance of Pea Moth

Surveys of pea pests in 1957-1959 indicated that in the Eastern Region pea moth was the most important pest on dry harvesting peas (Gould, Legowski and Mason, in press). The surveys were made in three of the main pea growing counties of the Region: Essex, Isle of Ely and Lincs. (Holland) growing about 40 per cent of the total dry pea acreage in England and Wales. A summary of the results is given in Table 1.

Table 1 Summary of the Survey Results, 1957-1959

Year	No. of fields visited*	No. of fields sprayed	Estimated % loss of peas due to pea moth	
			Sprayed fields	Unsprayed fields
1957	53	12	6.5	6.5
1958	29	6	6.0	9.5
1959	111	47	5.8**	11.3

* Fields visited within about 14 days of harvest
** Significantly lower than unsprayed fields at p = 0.05

The data obtained during the surveys included the percentage of pods infested, the number of larvae per pod, the number of peas damaged by one larva and the number of peas per pod. Using this information and knowing the prices paid to the grower, which depended on the cleanness of the sample, it was possible to estimate the losses due to pea moth in terms of money and in equivalent acres. The estimate was (Legowski and Gould, 1960) that on the annual average during 1957-1959, the growers in the three counties lost about £100,000 or approximately 10 per cent of the value of the crop, representing between 6 per cent and 9 per cent of the dry pea acreage. This loss was sustained in spite of the control measures taken which were estimated in 1959 to have cost some £30,000.

Timing and the efficiency of sprays and the economics of control measures

Table 1 indicated that the control obtained by spraying was unsatisfactory, which was also the opinion of many growers. (The majority of growers who sprayed used one application of DDT although in 1959, about 20 per cent of the growers visited used other materials, mainly parathion).

Field and observations and trials in 1958 (Gould and Legowski, 1959) and in 1959-60, suggested that incorrect timing of sprays was one of the main reasons for the poor control. Growers sprayed at or soon after flowering which is correct for peas sown in April and May (Wright and Geering, 1948). In East Anglia, however, the normal sowing time for dry harvesting peas is in February or early March and they usually flower before moths are about and well before eggs are laid. Correct timing is particularly important where only one instead of two sprays is being used and even with two sprays, better results could be expected if the first spray was timed by the presence of moth or eggs in the crop (Table 2).

Table 2 Timing and efficiency of DDT sprays on dry harvesting peas

	% reduction in pod infestation with high volume DDT sprays				
	1958		1959		1960
Timing of first spray	Flowering	First moths	First moths	First eggs	First eggs
Two sprays	42*	71*	62*	62*	70*
One spray	-	40*	-	50*	-
% infested pods on controls	21.0		23.75		18.3

* Significantly different from controls at p = 0.05

The importance of correct timing of pea moth sprays indicated an immediate need for information on the date of moth emergence and egg laying so that growers could be advised of the best time to spray.

The results of our insecticide field trials in 1958, '59 and '60 (Table 2) showed, however, that even with good timing the control obtained with the available insecticides was far from perfect. At the most, a 70 per cent reduction in the percentage of pods infested was obtained with two sprays and 50 per cent with a well-timed single spray. Surveys indicated that about 50 per cent control was also obtained by the growers, mostly with a single spray of DDT, in 1959 and probably an even poorer control in 1957 and 1958.

To assess the economics of spraying, it was necessary to consider the efficiency of the treatments, cost of different methods of application, including the damage to the crop, the actual loss of peas at different levels of pod attack, the price structure for peas according to the level of pea moth "wastage"* and the final yields. Taking these factors into account, it was possible to assess the approximate levels of pod attack at which spraying could be expected to pay for itself (Legowski and Gould, 1960). Table 3 shows this figure for fields with an expected yield of 23 cwt per acre.

Table 3 Minimum pod attack necessary to recover the cost of spraying at an average yield of 23 cwt per acre

	One spray (50% control)			Two sprays (70% control)		
	Grower	Contractor		Grower	Contractor	
		Air	Ground		Air	Ground
Average cost of spraying per acre (including wheeling damage)	70s.	70s.	95s.	110s.	140s.	150s.
Minimum % pod attack needed to recover costs	18	18	23	21	28	

Improvement in the control obtained would obviously affect the economics of spraying. Thus, with a 90 per cent control, the minimum levels of pod attack at which two sprays should pay for themselves would be reduced to about 16 per cent if done by the grower and 23 per cent if done by the contractor.

The data in Table 3 would not be greatly affected by a change in the price for peas if the scale of price reductions for wastage remained the same.

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* "Wastage" is the factory term for loss of peas due to staining, splitting or pea moth damage.

It appears that with existing materials and prices, the economics of control measures are not very favourable to the grower, especially in areas or years of average or low yields. Pod infestations of at least 21-28 per cent are necessary to justify two sprays and such levels of attack are not very common. It was estimated that in 1959, a year of heavy attack, on about half of the sprayed fields the cost of spraying probably out-weighed the likely gain (Legowski and Gould, 1960).

In these calculations no allowance has been made for the possible effects of pea moth sprays on other pests of peas, e.g. thrips, midges or aphids. During the three years' surveys, none of these pests appeared to be widespread and economically important on dry harvesting peas, although occasionally thrips and aphids may play a part. It is difficult to evaluate the long-term effect of existing control measures on residual populations of pea moth in any area. However, with the poor control obtained it is unlikely that spraying would be an important factor.

Spray warnings and forecasting the severity of attacks

Spray Warnings

In view of the importance of correct timing of sprays and the economic implications, a warning service to advise the grower when to apply the first spray was introduced in 1959 and continued in 1960-61. The warnings were based on the early presence of eggs on peas and were issued each year through the county N.A.A.S. advisers, through the press and lately through Anglia Television. This information has also been passed to the Pea Growers Research Organisation and to some of the canning firms and spraying contractors.

Since spray warnings should preferably be based on field rather than on artificial cage conditions, our observations on moth emergence and egg laying have been made in the field. The early moth emergence was determined by sweeping and searching for moth on suitable days, twice weekly from late May, on several fields previously under dry harvesting peas and in the adjoining hedgerows (emergence sites). After the first moth was found, similar observations were made on fields of early drilled peas which had reached or passed the flowering stage. At the same time, samples of 10 plants were taken from the headlands of each field for examination for eggs in the laboratory. When eggs were found, note was also made of their stage of development (Hanson and Webster, 1936).

Spray warnings were issued when the first eggs had been found on the majority of sites under observation. The actual dates for 1959-61 are shown in Table 4.

Table 4 Observations on pea moth emergence and egg laying

Year	First moths in cages	Emergence sites		Pea fields			Approximate time of 'peak' egg laying	Date of warning
		Number visited	First moth	Number visited	First moth	First egg		
1959	26.v	12	2.vi	12	5.vi	5.vi	Last week of June	15.vi
1960	23.v	13	30.v	18	7.vi	7.vi	Last week of June	18.vi
1962	19.v	13	23.v	20	5.vi	9.vi	First week of July	14.vi

The spray warnings were issued on the understanding that they did not necessarily imply a need to spray and were only intended to help those growers who wished to spray. It was also made clear that they applied only to crops which had reached or had past flowering.

Sampling for eggs was continued throughout the summer to establish the approximate period of 'peak' egg laying (Table 4). Eggs have been found on peas through to late July when the crop is usually beginning to dry off. The work has also shown that results based on sweeping or searching for moths in peas can be unreliable as on some field eggs have been found before moths were detected.

Forecasting of Attacks

The economic aspects of control measures also led us to explore the possibility of forecasting the severity of attack so that growers might be advised whether sprays were likely to be needed or not.

To this end, the correlation of egg numbers and the final pod infestation at harvest was examined. In 1960, samples of 10 plants were taken from the same part of one unsprayed headland on 27 fields once or twice weekly from flowering to harvest and the number and stage of development of all eggs recorded. Some idea of the errors involved in relying on a 10 plant egg sample was obtained by comparing the number of eggs found on 10 lots of 10 plants from the same part of the headland on two sites. The mean number of eggs per 10 plants with their respective standard errors were as follows:- 2.6 ± 0.75 and 25.2 ± 1.9. Samples of 100 pods were taken from the same areas at each of the 27 sites just before harvest to assess pea moth damage and the number of larvae.

The total number of eggs (hatched and viable) per site found over the sampling period ranged from 0-98 (eggs were found on all but one site): the maximum numbers ('peak' eggs) per 10 plants on any one date ranged from 1-36 and the percentage pod infestation on the 27 sites varied from 2% - 52%.

All possible relationships between the egg numbers and final pod infestation have not been analysed but the total number of eggs found at each site and the 'peak' number (hatched and viable) found at any one time have been compared with the number of larvae found and the percentage of pods infested. The best relationship (correlation coefficient 0.9) existed between the 'peak' number of eggs per 10 plants and the percentage of infested pods. Based on the square root transformation of these variates, the regression equation for the 27 sites in 1960 was:

$$Y = (0.98 \pm 0.1)X + 1.51$$

where (Y = sq. root of % infested pods and X = sq. root of 'peak' no. of eggs per 10 plants)

Using this formula a pod infestation of 10% - 30% could be expected with 10 eggs per 10 plants, at the 5% probability level.

Similar data were obtained for 15 sites in 1961 but on 12 of these, the pod infestation was below 12 per cent. More work is needed to test the formula in other seasons and to examine further possible relationships between egg numbers and pod attack. Further work may show that in some years there will be no clearly defined 'peak' but a continuous level of egg laying. In these circumstances a regression based on 'peak' numbers would probably be of little value.

Again, the degree of attack on the headland is likely to be different from the rest of the field and it may be necessary either to investigate this relationship or to collect larger samples from the field. There is some evidence that pea moth attacks develop earlier on the headlands than on the rest of the field (Franssen, 1954): sampling on the headlands could thus give an extra period of time in which to issue the forecast.

It would clearly be impracticable to apply this method of forecasting for large scale advisory purposes as the quantity of plant material to be examined is not easily coped with. However, it might be possible to obtain forecasts for a limited number of fields in areas where pea moth is known to be a serious pest on dry harvesting peas on which to base more general advice.

Summary

Surveys of pea pests in 1957-59 showed that pea moth was an important pest on dry harvesting peas in East Anglia. It was estimated that on average approximately £100,000 is lost annually through this pest in three of the main pea growing counties. The control of pea moth was unsatisfactory. Trials in 1958 showed that incorrect timing of sprays was one of the main reasons for the poor control and that some knowledge of the date of the moth's emergence and egg laying was necessary to help growers spray at the correct time. Spray warnings based on field observations of moth emergence and egg laying were given to growers in 1959-61.

Chemical control trials showed that even with reasonably good timing of sprays the control was far from perfect and it has been shown that the economics of control measures are not very favourable to the grower. Even on fields where yields are in the region of 23-30 cwt. per acre, infestations of 20 per cent or more are necessary to justify the application of DDT sprays.

Preliminary work on forecasting levels of attack from egg laying has been started and a relationship between 'peak' egg numbers and pod in-

festation has been shown for 1960.

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