Opening Remarks

by

Sir Frederick Bawden

President of the British Crop Protection Council

Mr. Chairman, Ladies and Gentlemen, it is my first pleasant task to welcome you to the 5th British Insecticide and Fungicide Conference. It is the first under the British Crop Protection Council, and regrettably, the first organised without the help of Mr. Morris, who died in March after an illness borne with great fortitude. Bill Morris was a founder member of the British Weed Control Council, the chairman of the British Insecticide and Fungicide Council, and he played a leading part in organising all the past conferences of the two councils here at Brighton. His services have been great and he is sorely missed.

The programme committee has obviously done an excellent job, for they have attracted a record attendance of 1,080 registered delegates, of whom one third are from overseas, from 26 different countries. The increased number of delegates means we have had to arrange for Plenary Sessions to be relayed to the Norfolk room. I regret this is by sound only, but we did not know that attendance would exceed the capacity of this room in time to arrange for closed-circuit television. We will do better next year. The simultaneous translation provided for the Weed Control Conference last year has been dispensed with because delegates from overseas considered it unnecessary.

The programme gives me especial pleasure because it contains so much new information about fungicides, which by comparison with insecticides have been slow to develop. The need for good systemic fungicides has long been evident and it seems this need is about to be met. The time is very opportune because it is also becoming increasingly evident that the efforts and ingenuity of plant breeders to produce varieties of cereals resistant to such air-borne pathogens as cause mildew and rusts is matched by the ability of the pathogens to produce variants able to attack the resistant varieties. Fungus diseases are, of course, important in all crops, but with cereal growing becoming increasingly intensive, it is with cereals that problems from both soil-borne and air-borne pests and diseases are perhaps most threatening. Hence the first two sessions of our programme are devoted to these problems.

We have, too, sessions on nematodes, with prospects of dealing with these major pests, which are important also as vectors of viruses, by soil fumigants or other chemicals, and of the potato root eelworm by a combination of pesticides and resistant varieties.

These conferences have always been conscious of the need to consider unwanted side-effects of using pesticides, and, as customary, we have sessions dealing with possible hazards to wild life and with toxicological testing. We have a less customary session on birds and molluscs as pests, and one on the important subject of disease assessment and the profitability of pest and disease control. Again, as customary, we end our conference, with sessions dealing with new pesticides and techniques.

The programme is full, and I hope you will also find it valuable and your attendance here rewarding.

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FOLIAR DISEASES AND PERFORMANCE IN CEREAL PRODUCTION

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Summary Losses due to foliar diseases were lower in 1969 than in previous years but these diseases must be controlled if reliable yields of good quality grain are to be achieved. Herbicides and fertilizers may be able to supplant two of the benefits claimed from rotational cropping of the land but effective methods of controlling diseases and pests have yet to be developed under current methods of cereal growing. The occurrence of new races of disease organisms has led to a re-appraisal by plant breeders of their programmes for breeding resistant varieties. It has also resulted in the physiologic race survey in which breeders, pathologists and advisers are co-operating, with the N.I.A.B. acting as the co-ordinating centre. Surveys are made each year so that any new races of the important cereal diseases can be identified at an early stage and crop variety testing stations can take the necessary steps to find which varieties may be recommended as resistant to these new races. The possibilities of using certain chemical fungicides to counter some of these diseases are of great interest.

INTRODUCTION

The long spells of wet weather between February and April this year delayed drilling: this invariably causes lower yields, but from June onwards we experienced warm dry weather, which in the end appears to have resulted in a better harvest than was at one time feared. The British weather is of course notoriously fickle but, the important point this year, was that apart from the direct effects of sun and warmth on plant growth, the weather influenced the disease pattern. So we were free from the epidemics of yellow rust and Rhynchosporium troublesome in previous years and, although the higher temperatures resulted in high levels of mildew, these occurred too late to affect yield severely.

If we could rely on such a year as 1969 being typical it might be inappropriate for me to assert the importance of foliar disease. Last year however the National Agricultural Advisory Service estimated losses from barley diseases alone cost the farmer 50 million pounds. Until five years ago, national average yields had showed an increase from year to year. Indeed the annual average increase of 2% was higher than in industrial production, but in this last three to four year period yield increases have been less marked. Factors other than disease influence yields but control of diseases is vital if yields are to be increased further - especially as it is generally agreed that production needs to be increased in the 1970's.

REVIEW OF THE CEREALS FOLIAR DISEASES OF ECONOMIC IMPORTANCE

The traditional system of crop rotations practised for the past two hundred years is undergoing rigorous revision. Although herbicides and fertilisers may be able to supplant two of the benefits from rotational cropping, the control of pests and diseases have yet to be achieved by alternative methods.

For a disease to develop into an epidemic which will significantly reduce yield, a susceptible host plant, a vigorous pathogen, and an environment favourable for the development and spread of the pathogen are required. Temperature, rainfall and humidity are the main environmental factors affecting disease development and our climate is such that in most years conditions are suitable for the build-up of one or more of the common cereal diseases.

POWDERY MILDEW

Mildew of cereals (Erysiphe graminis) occurs every year throughout the country but its intensity varies from year to year and from district to district. Plant breeders have developed resistant varieties and at the present time at least one or more of six sources of resistance, derived from exotic sources of plant material, are represented in current commercial barley varieties. Resistance has become ineffective in many varieties because of the development of new physiologic races of the pathogen.

But varieties with resistance derived from one or more of these six sources have a considerable advantage over susceptible varieties when mildew is prevalent. Large and Doling (1962, 1963) have shown that the percentage yield loss due to infection by mildew may be expressed as a formula i.e. for barley and oats percentage yield loss is equal to 2.5 times the square root of percentage mildew infection at growth stage 10.5 For wheat the factor for loss of yield equals 2.0. On spring barley a 50% infection of mildew can reduce the yield by approximately 18%. Even then the harvested grain may contain a high proportion of "tail" corn. A recent survey conducted by the Plant Pathology Laboratory indicated that there was an average mildew infection of 25 to 50% of the leaf area recorded on plants from spring barley in 1967, at the critical stage. Using the yield formula the national loss of spring barley would thus be estimated as 13 to 18%.

YELLOW RUST OF WHEAT

Yellow rust of wheat caused by the fungus Puccinia striiformis, is one of the most important diseases in this country. It appears frequently on susceptible spring and winter wheat varieties throughout the country. Appreciable amounts of yellow rust occurred in 7 years of the decade between 1956 and 1966 (Doling and Doodson, 1968).

Weather has a marked influence on the development of this disease and it is almost impossible to predict epidemics. The latest information we have indicates that a wet period after harvest can be an important factor in determining the extent of infection the following year (Doling and Doodson, in the press).

Yellow rust is of course an obligate parasite and must survive on living green plant tissue such as volunteer seedlings growing after harvest. Long periods of high temperatures, such as those experienced this summer, will reduce if not eliminate for a period the yellow rust fungus.

Yellow rust severely reduces photosynthesis, disrupting the leaf surface and the metabolic processes within the plant. The flow of carbohydrates and minerals to the ear is impeded resulting in low yields of only partially filled grain.

Severe losses of up to 50% have been recorded from commercial crops when the leaves and ears are infected. The relationship between yield loss and infection has been calculated and the percentage loss in yield may be equal to three times the square root of the percentage yellow rust infection at growth stage 10.53 so that when the foliage is fully infected the yield will be reduced by 30% (Doling and Doodson, 1968). As the green area of the ear is an important contributor of photosynthestic material to the grain greater losses of yield occur when the ear is also infected.

Many commercial wheat varieties are moderately to very susceptible to yellow rust infection (N.I.A.B. Farmers' Leaflet, 1969). However the detection of new races of this fungus by the physiologic race survey clearly indicates that more attention must be paid to the control of this disease (Report of Committee, 1969).

RHYNCHOSPORIUM

Leaf blotch caused by *Rhynchosporium secalis* is a cause of great concern to barley growers particularly in the south west. This disease became prominent with the advent of mildew resistant barley varieties some ten years ago when leaf blotches were noticed on the mildew free leaves. Thus the control of one foliar disease may be a factor in promoting the spread of another! I would like to see more attention paid to the changing pattern of diseases induced by the various methods of control. The upsurge of Rhynchosporium may have been the result of several factors. Oats have been replaced by barley in the wetter areas, continuous barley growing has become widespread and the acreage of susceptible winter barley varieties has increased.

The symptoms of this disease are quite characteristic under warm humid conditions as pale grey oval spots with purple margins develop on all parts of the plant and often at the junction of blade and leaf sheath.

The disease progresses rapidly with favourable conditions until the foliage is entirely destroyed. Yield losses can be high. A linear relationship between the percentage level of disease on the upper two leaves and the yield has been established by James et al (1968). The percentage loss in grain yield is equivalent to $\frac{2}{3}$rds of the percentage of the infected area on the flag leaf or $\frac{1}{2}$ the percentage area infected on the second leaf. The predicted loss in grain yield is the mean of these two values. In addition to the loss of yield there may be serious effects upon the quality of grain through insufficient development of the kernels.

Most of the two row spring barley varieties grown in this country are susceptible to the two races of Rhynchosporium prevalent here i.e. U.K.1 and U.K.2. Proctor is the exception, having some non-specific or field resistance. Foreign varieties, such as La Mesita, Osiris and Trelii are resistant to both the U.K. races and are being utilized by breeders in their attempts to produce resistant varieties suitable for this country. Six row winter barley varieties have shown specific resistance to race U.K.1.

BROWN RUST OF BARLEY

Another disease of barley, brown rust *Puccinia hordei* has been prominent this year. The brown rust fungus thrives under high temperatures and this may be why it is usually described as of little economic importance. However it may be necessary to revise this opinion in view of the high levels of infection recorded in recent years together with results from the spring barley disease survey which show that brown rust is the second most frequently occurring disease. This is a case where the essential scientific evidence is so far lacking and it is most desirable that precise measurements of yield loss should be obtained. There are as many as five races of the pathogen present in this country. As yet no specific resistance to this disease has been noted in the present commercial varieties, although some may be more susceptible than others.

SEPTORIA OF WHEAT

Septoria has been commonly recorded on wheat throughout the country this year and these infections often consist of two closely related fungi species. Both Septoria nodorum and S. tritici occur on the leaves and S. nodorum can also attack the ears causing glume blotch.

The development and spread of Septoria is closely associated with periods of wet weather. Differences in the levels of infection on wheat varieties can be recorded although under conditions of severe infection these differences are slight. It is likely to be some years yet before breeders succeed in producing resistant varieties incorporating sources of resistance in material available for instance from South Africa and Germany.

THE BASIS FOR RESISTANCE

Breeding for disease resistance has been an aim since Professor Biffen showed that resistance to yellow rust was an inheritable character in wheat and produced the rust resistant Little Joss. Biffen considered that yellow rust could be readily controlled by the use of resistant varieties. But physiologic races had not then been identified and the development of such races has bedevilled the work of breeding and of variety testing as well as the commercial production of cereals. Perhaps the most dramatic incident in recent years was the occurrence of a new race of yellow rust, race 60 (Macer and Doling, 1966), which attacked one of the leading new varieties on the Institute's Recommended List and resulted in yield losses of up to 40%. There had been a similar occurrence in Holland in 1956 when Heines VII was similarly affected and earlier still with Nord Desprez in 1952. The frequent occurrence of new races of disease organisms has led to a reconsideration of several aspects of policy. In the first place, breeders are considering whether the method of resistance breeding adopted in recent years is adequate. It is thought provoking that trials at the N.I.A.B. and at the Plant Breeding Institute, Cambridge, indicate that Biffen's Little Joss and the old variety Squareheads Master, still show a lower susceptibility to new races of yellow rust than many modern varieties such as Cappelle-Desprez and Champlein, despite our better understanding of the yellow rust organism. Breeders have tended to rely on utilising genes for resistance to specific races in the development of their new varieties. We are all very conscious of the need to include varieties on the N.I.A.B. Recommended Lists with a high level of non-specific resistance so that resistance is not limited to a particular race of the parasite.

Cappelle-Desprez has dominated the national wheat acreage for 14 years and this has always appeared to present a hazard in case a new race of yellow rust becomes established. Fortunately this has only occurred recently but Cappelle-Desprez is now susceptible in the field to the complex of races known as 3/55 and to a race recently identified as race 58C. This has made the introduction of the new varieties, Joss Cambier and Maris Ranger, especially significant as they both possess resistance to the more important of the present known races of yellow rust.

PHYSIOLOGIC RACE SURVEY

The cereal foliar diseases exhibit a remarkable ability to evolve new physiologic races which may be virulent on hitherto resistant varieties. The race pattern has changed over the years with the introduction of cereal varieties possessing specific resistance to the major cereal diseases. Earlier this year the N.I.A.B. reported that the majority of wheat yellow rust samples obtained in 1968 belonged to the race 3/55 group and showed an increase of 18% over 1967. Race 60 was less frequent than in previous years. A new race was also identified at an early stage and preliminary tests indicate that it is capable of severely infecting several current commercial varieties.

The Cambridge Plant Breeding Institute also reported that thirteen races of wheat mildew were identified from samples received in 1968. Races 3, 13, 16 and 26 were the most frequent but no new races were identified. A total of seven isolates of barley mildew were identified from the previously resistant spring barley variety Sultan but the resistance of this variety is generally still very good. The majority of the barley mildew isolates reported by the P.B.I. belonged to the Impala race group and were capable of attacking plants possessing the Ml-a6 and Ml-g genes for resistance. This means that the majority of barley varieties grown in this country are susceptible.

Barley brown rust samples were divided into five virulent groups by the Welsh Plant Breeding Station. None of the commercial barley varieties grown in this country exhibit major gene resistance to these races, though some varieties apparently have some non-specific resistance. The main crown rust race on oats was identified as race 229. Race 2 was found to be the prevalent oat mildew race during 1968. There was no major change in the oat mildew race spectrum when compared with that for previous years. Only one sample (identified as race 2) was identified from the resistant variety Mostyn. A report from Reading University showed that two common races of Rhynchosporium,U.K.1 and U.K.2, were evenly distributed throughout Britain.

This pattern of physiologic races and the development of other new races may be changed with the introduction of chemical control of cereal diseases. It has been shown (Noble et al, 1966) that the organo-mercurial formulation which previously controlled the fungus causing leaf spot of oats Pyrenophora avenae are now ineffective. There is a report from the United States that a race of powdery mildew (Sphaerotheca fulginea) resistant to the systemic fungicide benlate has developed on cucumber plants (Schroeder and Prowidenti). The authors suggest the possibility of the fungus becoming dependent upon the chemical. This type of problem may arise with the advent of systemic fungicides of cereal disease. The widespread use of systemic fungicides offer an exciting opportunity to overcome losses due to disease, and taken in conjunction with the breeding of resistant varieties offer scope for the production of consistent and increased crop yields.

References

DOLING, D. A. and DOODSON, J. K. (1968) Trans. Br. Mycol. Soc. 51, 427.
DOLING, D. A. and DOODSON, J. K. (1970) Plant Pathology - in the press.
JAMES, W. C., JENKINS, J. E. E. and JEMMETT, J. L. (1968) Ann. appl. Biol. 62, 273.
LARGE, E. C. and DOLING, D. A. (1962) Plant Pathology 11, 47.
LARGE, E. C. and DOLING, D. A. (1963) Plant Pathology 12, 128.
MACER, R. C. F. and DOLING, D. A. (1966) Nature 212, 643.
NOBLE, M., MACGARVIE, QD., HAMS, A. F. and LEAFE, E. L. (1966) Plant Pathology 15, 23.
SCHROEDER, W. T. and PROWIDENTI, R. (1969) Plant Disease Reported 53, 271.
N.I.A.B. Farmers Leaflet No.8, 1969.
Report of the Physiologic Race Survey Committee (Cereal Pathogens) 1969.

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EFFECT OF BENOMYL ON SOME DISEASES OF SPRING BARLEY

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Summary A series of exploratory replicated trials on spring barley has shown that benomyl has a broad spectrum of activity towards several diseases of this crop. As a seed dressing benomyl controls the foliar pathogen (Erysiphe graminis) for some time after emergence, but the effect of this on yield remains to be established. Evidence is provided that spray treatments of benomyl, when correctly timed may control brown rust (Puccinia recondita) and leaf blotch (Rhynchosporium secalis). Benomyl sprays applied to the more susceptible barley varieties at growth stages 7-10 gave excellent control of mildew (Erysiphe graminis) in 1969, with consequent yield increases of approximately 15 to 20%. The appearance of both grain and straw was also greatly improved by the reduction of sooty moulds on the harvested crop. These yield increases were attributed primarily to there being less unfilled grain at the base of the heads from benomyl treated plots than from those in untreated plots.

INTRODUCTION

Spring barley suffers from a variety of seedborne, soilborne and airborne diseases of varying economic importance. The identity of the pathogens concerned are now well established but their economic importance remains debatable. Doling (1963) reviewed this subject in some detail and James (1969) has shown how rapidly the disease pattern can change. James et al (1968) also discussed the difficulties of assessing the effects of plant diseases on cereal yields and showed that chemical treatments could control certain of these pathogens with a consequent increase in yield. With this background to the problems and knowing the broad spectrum of activity of benomyl (Delp and Klopping, 1968), the present programme of work was initiated using benomyl both as a seed dressing and as a spray.

METHOD AND MATERIALS

Seed dressings Seed of Zephyr barley was dressed by incorporating the calculated amount of benomyl, formulated as a 50% wettable powder, with the appropriate quantity of seed in a mechanically rotated drum (Evans, 1968). This method was also used for treating seed with carboxin and organo-mercury. The majority of this seed was then planted in the field in fully replicated randomised block experiments. In most cases emergence counts were taken and disease assessments made as appropriate thereafter. Dressing seed with high dosages of benomyl w.p. proved difficult and it became necessary to pre-treat with a 1% solution of polycell before applying the dressing. Seed dressed with these high dosages reduced drilling rates by approximately 20%. The dressed seed was planted on five different sites in East Anglia (Levington, Harston, Shelford, Chesterford Park and Fordham). The treatments examined included:

1. Benomyl 50% w.p. (I) at 16.00 oz a.i./cwt seed
2. " " (II) at 10.66 " " "
3. Carboxin 75% at 3.33 oz a.i./cwt seed
4. Organo-mercury (1% Hg) at 0.04 oz (Hg)/cwt seed
5. Untreated control

These high rates of benomyl dressings selected for trial were intended to examine the effect of mildew control on crop yield.

Seed dressing treatments of barley Five field experiments were planted out, using a variety of plot sizes ranging from 60 x 4 yd strips to 10 ft x 4 ft plots, on different soil types.

Disease control with spray treatments Because of the dynamic nature of foliar disease epidemics, the size of the experimental plots in use might be expected to affect the pattern of results achieved. For this reason spray treatments of benomyl were investigated with three different plot sizes,

1. Small plots (30 ft x 7 ft) used for multiple treatment investigations.
2. Medium plots (30 ft x 14 ft) used for investigating limited numbers of treatments.
3. Large scale 30 yd wide strips of varying length for investigating single treatments on a semi-practical basis (usually triplicate alternate treated and untreated plots/site).

All trial sites were dependent on natural infection of the pathogens, thus the frequency with which a given disease was recorded was dependent on chance although some attempt was made to cover regions where certain organisms were most likely to occur.

Spray treatments on spring barley in 1969 A total of 28 trial sites were treated with early (GS 4-5)* or late (GS 7-10) sprays of benomyl at rates of either 1 or 1.5 lb a.i./acre. The chemicals were applied with an M.D.M. Knapsack Sprayer at approximately 20 gal/acre or with the farmers sprayers. Disease assessments were made at GS 10.5 or 11.1 according to the N.A.A.S. key (James et al., 1968). Whenever possible every effort was made to distinguish between necrosis due to the pathogen and that not obviously associated with the fungus. Brown rust and Rhynchosporium appeared on only two of these sites and the commonest pathogen by far was mildew. At growth stage 10.5 disease assessments were individually recorded for each of the top three fully expanded leaves, but with heavy infections at 11.1 it was often only possible to score the top two leaves. Standard comparative treatments varied from site to site, as listed below.

Sites	Variety	Standard Treatments
Waterden	Maris Badger	Sulphur
West Wickham	Proctor	Dichlofluanid
Arundel	Zephyr	Drazoxolon
Newquay	Sultan	Dichlofluanid
Layer Marney	Zephyr	Drazoxolon
Birch	Zephyr	Sulphur
Worthing	Zephyr	Drazoxolon
Cirencester	Proctor	Thiram
Crediton	Zephyr	Dichlofluanid
Harston	Zephyr	Dinocap
East Rudham	Golden Promise	Dichlofluanid

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* Growth stages according to Feekes scale used throughout this report

The experimental sprays other than standards were the same on all sites and included the following treatments.

1. Benomyl 1.5 lb a.i./acre sprayed early at GS 4-5
2. " 1.5 " " " " late at GS 7-10
3. " 1.5 " " " " early and late
4. " 1.0 " " " " early at GS 4-5
5. " 1.0 " " " " late at GS 7-10
6. " 1.0 " " " " early and late
7. Standards (a) Sulphur 80% w.p. at 2.4 lb a.i./acre sprayed early and late
    (b) Dichlofluanid at 1.5 lb a.i./acre sprayed early and late
    (c) Dinocap at 0.1 lb a.i./acre sprayed early and late
    (d) Drazoxolon at 1.0 lb a.i./acre sprayed early and late
    (e) Thiram at 3 lb a.i./acre sprayed early and late
8. Untreated control.

(0.05% of non-ionic surfactant was added to all benomyl treatments).

Yields were taken either with a small combine or by the use of a small plot cutter and static thresher.

RESULTS

Mildew Control with Seed Dressings

Using small plot trials it was possible to show that all benomyl treatments gave marked control of mildew during the establishment of the crop. This is illustrated in Table 1 which gives a typical early assessment (GS 4-5) on one trial site. By contrast neither carboxin nor the organo-mercury had any effect on this disease.

Table 1

Early assessment of mildew in a typical seed dressing trial

(expressed as mean % disease at GS 4-5)

Seed treatment	Mean % disease/leaf		
	Leaf 1	Leaf 2	Leaf 3
Benomyl I	0.0	0.1	1.2
Benomyl II	0.2	0.6	2.9
Carboxin	0.0	6.4	14.3
Organo-Hg	0.0	2.9	11.9
Untreated control	0.0	4.7	12.9

The differences between treatments which are obvious in Table 1 at GS 4-5 were not distinguishable when plants were assessed at GS 10.5. This is clear from the data presented in Table 2 which gives a summary of that recorded on three separate trial sites where early differences were obvious.

Table 2

Mean % mildew recorded at GS 10.5 on three seed dressing trial sites

Seed treatment	Levington			Harston			Shelford		
	Leaf numbers								
	1	2	3	1	2	3	1	2	3
Benomyl I	0.8	17.1	51.7	0.1	0.6	2.7	0.7	5.6	43.6
Benomyl II	0.2	15.9	56.7	0.0	0.4	3.0	0.5	6.1	46.1
Carboxin	0.4	18.9	63.3	0.1	1.4	10.0	0.3	2.7	43.9
Organo-Hg	0.2	17.9	69.7	0.1	0.3	7.6	0.0	5.5	52.7
Untreated control	1.0	22.0	68.0	0.2	1.5	7.7	0.7	3.6	53.0

Yields from seed dressing treatments The plots used in two of the three sites listed in Table 2 (Levington and Harston) were later harvested and yield assessments made. The data obtained are summarised in Table 3.

Table 3

Yields from replicated trials where benomyl, mercury and carboxin seed treatments were compared

Seed treatment	Harston (low mildew) yield in cwt/ac.	Levington (high mildew) yield in cwt/ac.
Benomyl I	26.9	33.4
Benomyl II	30.6	34.0
Carboxin	33.8	31.4
Organo-Hg	26.4	30.9
Untreated	31.7	31.9

The adverse effect on drilling of the high rates of dressing has already been mentioned and where mildew was minimal (Harston) this reduction in seeding rate diminished overall yields. However where mildew was severe (Levington) adequate disease control by benomyl tended to compensate for this effect.

Control of brown rust with foliar sprays The effect of benomyl on late infection with brown rust is recorded in Table 4. Data are taken from small plot, multi-replicated trials.

The data presented in Table 4 gives little evidence of any effect on brown rust in the present trials. It should be stressed however that infection only appeared very late in the season, by which time minimal amounts of benomyl remained in the crop. Brown rust was the only disease of any note on the West Wickham site but the Waterden trial was severely infected with mildew, and owing to the good control of this disease by benomyl the foliage was much greener and thus became infected with rust. Other treatments were so badly affected by mildew that little healthy tissue remained for infection at this late stage.

Table 4

The effects of benomyl and other spray treatments on brown rust (% rust/leaf at GS 11.1)

Treatment			Trial Sites			
			Waterden		West Wickham	
Compound	lb a.i./ac.	Time of spraying	Leaf 1	Leaf 2	Leaf 1	Leaf 2
Benomyl	1.5	E	13.6	18.7	2.1	5.3
Benomyl	1.5	L	11.1	20.7	1.0	2.7
Benomyl	1.5	E & L	13.1	24.5	0.6	1.7
Benomyl	1.0	E	14.1	28.2	1.5	8.9
Benomyl	1.0	L	10.7	22.4	1.6	3.4
Benomyl	1.0	E & L	12.5	25.4	1.1	1.6
Sulphur	2.4	E & L	11.8	23.2	-	-
Dichlofluanid	1.5	E & L	-	-	0.7	2.1
Untreated control	-	-	13.4	23.4	1.9	8.9

	Waterden	West Wickham
E = early (GS 4-5) on:	16.5.69	28.5.69
L = late (GS 7-10) on:	12.6.69	23.6.69

Control of *Rhynchosporium* leaf blotch with foliar sprays This disease only appeared at high levels on two of the trial sites, Arundel and Newquay, and occurred very late in the growth of the crop. On the Arundel site no obvious level of control was recorded, possibly because chemical residues were minimal. By contrast, at the Newquay site, where good control of *Rhynchosporium* was recorded, the control may be related to the fact that the site was infected much earlier in the season when some benomyl should have been present in the crop.

Table 5

Benomyl control of *Rhynchosporium secalis* as assessed at GS 11.1
(expressed as % leaf area infected)

Treatment			Trial sites			
			Arundel		Newquay	
Compound	lb a.i./ac.	Time of spraying	Leaf 1	Leaf 2	Leaf 1	Leaf 2
Benomyl	1.5	E	6.2	21.0	5.5	8.7
Benomyl	1.5	L	4.2	19.9	2.2	9.3
Benomyl	1.5	E & L	3.4	27.5	3.2	6.9
Benomyl	1.0	E	5.8	31.4	5.2	10.5
Benomyl	1.0	L	3.6	22.7	2.3	5.7
Benomyl	1.0	E & L	3.7	24.2	1.9	6.8
Sulphur	2.4	E & L	5.1	18.2	13.9	18.3
Standard		E & L	3.7	20.2	5.0	13.7
Untreated control		-	4.0	24.4	13.4	39.9

	Arundel	Newquay
Sprayed E = Early (GS 4-5)	3.6.69	24.5.69
" L = Late (GS 7-8)	19.6.69	12.6.69

Control of mildew with foliar sprays Table 6 gives a sample set of data from three trial sites in East Anglia. A similar set of records are presented from trial sites in the South and West (Table 7) where the pattern of results was very similar. These two tables provide a selection of data from a total of 16 trial sites where high levels of mildew were recorded. Approximately half of all trial sites examined in 1969 showed high levels of mildew (15 to 68% infection on leaf 2 at GS 10.5).

Table 6

Control of mildew on East Anglian sites (expressed as % leaf infection at GS 11.1)

Treatment			Trial sites					
			Layer Marney		Waterden		Birch	
Compound	lb a.i./ac	Time of spraying	Leaf 1	Leaf 2	Leaf 1	Leaf 2	Leaf 1	Leaf 2
Benomyl	1.5	E	0.7	12.5	1.7	33.7	1.4	22.4
Benomyl	1.5	L	0.0	3.2	0.6	28.6	0.0	1.3
Benomyl	1.5	E & L	0.0	0.1	0.8	22.0	0.0	1.3
Benomyl	1.0	E	0.2	8.9	1.3	38.2	0.4	26.3
Benomyl	1.0	L	0.0	1.5	1.0	23.6	0.1	5.6
Benomyl	1.0	E & L	0.0	1.0	1.0	22.5	0.1	2.9
Sulphur	2.4	E & L	-	-	3.8	46.0	0.4	31.0
Drazoxolon	1.0	E & L	0.6	4.4	-	-	-	-
Untreated control			1.5	16.5	15.0	39.5	2.1	35.7

	Layer Marney	Waterden	Birch
E = Early (GS 4-5)	29.5.69	19.5.69	19.5.69
L = Late (GS 7-8)	18.6.69	12.6.69	17.6.69

Table 7

Control of mildew in South and West of England (expressed as % leaf infection at GS 11.1)

Treatment			Trial sites					
			Worthing		Cirencester		Crediton	
Compound	lb a.i./ac	Time of spray	Leaf 1	Leaf 2	Leaf 1	Leaf 2	Leaf 1	Leaf 2
Benomyl	1.5	E	16.6	40.5	34.6	44.0	14.4	51.3
Benomyl	1.5	L	9.4	44.7	1.4	4.8	1.2	11.2
Benomyl	1.5	E & L	6.2	33.6	3.5	4.8	0.9	6.6
Benomyl	1.0	E	21.8	55.1	38.3	48.8	11.0	48.4
Benomyl	1.0	L	9.1	34.2	13.3	9.1	1.2	12.6
Benomyl	1.0	E & L	4.5	32.5	7.3	7.2	1.6	10.2
Sulphur	2.4	E & L	20.8	42.9	27.0	50.7	20.0	53.1
Standards	3.0	E & L	12.6	47.3	33.7	60.7	15.3	40.5
Untreated control			20.5	52.8	35.1	52.9	28.3	68.7

	Worthing	Cirencester	Crediton
E = early (GS 4-5)	21.5.69	5.6.69	4.6.69
L = late (GS 7-8)	10.6.69	16.6.69	18.6.69

The pattern of results given in Tables 6 and 7 is extremely constant in that late spray treatments of benomyl gave consistently good control of mildew when assessed at GS 11.1. Plots sprayed both early and late were sometimes marginally better than those sprayed late only. All the standard products with known effectiveness against mildew such as sulphur, dinocap and drazoxolon were sprayed twice and where mildew was severe this gave a reduction in the incidence of mildew. In general, however, the benomyl treatments were more effective in controlling mildew than any of the standard products.

Yields from plots given foliar spray treatments The effects of the various spray treatments on disease levels recorded in Tables 6 and 7 are largely reflected in the yield increases given in Tables 8 and 9 . The greatest increases in yield were achieved by spraying benomyl both early and late in the growing season. The performance of individual early and late treatments was less consistent than that seen in disease control although there was some tendency for the late sprays to be more effective than the early sprays. This latter effect is most clearly seen in Table 10 where large plot yield data show how yield increases of approximately 15 to 19% were achieved with the late sprays when compared with the two early treatments, irrespective of whether the pathogen involved was Erysiphe or Rhynchosporium. By harvest time all straw and grain from benomyl treated plots was free from the abundant growth of Alternaria sp./Cladosporium sp. which covered other samples. This effect was most spectacular at the higher rates of benomyl and was not recorded with any other fungicide.

Table 8

Yield increases in replicated trials in Southern England (medium plot size)
(% increase in yield over that in untreated control)

Treatment			Mildew infected sites		Rhynchosporium infected sites	
Compound	lb a.i./ac	Time of spray	Worthing	Crediton	Arundel	Newquay
Benomyl	1.5	E	7.2	5.3	4.3	16.4
Benomyl	1.5	L	10.5	9.3	7.5	16.9
Benomyl	1.5	E & L	10.3	12.1	12.7	17.2
Benomyl	1.0	E	11.3	11.8	13.8	14.7
Benomyl	1.0	L	14.6	6.8	6.7	11.9
Benomyl	1.0	E & L	14.1	7.7	6.2	12.1
Sulphur	2.4	E & L	4.7	3.4	6.0	5.4
Standard		E & L	11.5	0.9	11.2	17.5
Untreated control			0	0	0	0
E = early (GS 4-5)			21.5.69	4.6.69	3.6.69	24.5.69
L = late (GS 7-8)			10.6.69	18.6.69	19.6.69	12.6.69

Table 9

Yield increases in replicated trials in East Anglia (small plot size)
(% increases in yield over that in untreated controls)

Treatment			Mildew infected sites			
Compound	lb a.i./ac	Time of spray	Layer Marney	Harston	Waterden	E. Rudham
Benomyl	1.5	E	9.6	12.3	6.7	17.0
Benomyl	1.5	L	5.2	6.7	10.6	15.8
Benomyl	1.5	E & L	19.7	17.0	11.0	27.4
Benomyl	1.0	E	11.2	8.6	8.4	0.3
Benomyl	1.0	L	9.8	9.6	7.7	8.2
Benomyl	1.0	E & L	13.8	8.6	11.6	2.3
Standard		E & L	7.2	6.9	-0.2	7.1
Untreated control			0	0	0	0
E = early (GS 4-5)			29.5.69	5.6.69	16.5.69	15.5.69
L = late (GS 7-8)			18.6.69	17.6.69	12.6.69	12.6.69

Table 10

Grower trials - disease assessments and yield benefits

(% area of 2nd leaf infected and % yield increases from benomyl (1.5 lb/ac.) sprayed plots)

Date of spray	Site	Time of spray (GS)	% diseased tissues (GS 11.1)				% yield increase with Benomyl
			Mildew		Rhynchosporium		
			Benomyl 1.5 lb a.i./ac.	Control	Benomyl 1.5 lb a.i./ac	Control	
22.5.69	Levington	4-5	31.7	43.2	-	-	2.7
22.5.69	Ringwood	4-5	9.2	27.4	-	-	7.0
13.6.69	Shelford	9-10	2.2	30.2	-	-	15.8
13.6.69	Stockbridge	7-8	9.2	37.5	-	-	16.4
13.6.69	Exeter	7	34.5	68.7	-	-	17.1
13.6.69	Newquay	9-10	-	-	9.8	14.7	18.9
13.6.69	Newquay	8	-	-	2.4	55.1	17.3

DISCUSSION

By largely confining this programme of work to the two major susceptible varieties of spring barley (Zephyr and Proctor) approximately 50% of the trials described in this paper encountered severe mildew epidemics in 1969 which may suggest that the incidence of mildew is closely associated with widespread planting of susceptible varieties; a hypothesis postulated by Doling in his disease survey prior to 1963 (Doling, 1963). Since then, the subject of barley mildew has been studied in considerable detail and a variety of chemicals have been shown to reduce the level of this disease and to provide a corresponding yield increase (Kradel and Pommer 1967). Increases in yields following the control of Rhynchosporium and brown rust have been reported previously by Jenkins & Jemmett (1967), and, Delp and Klopping (1968) have stressed the broad spectrum of activity of benomyl.

As with all other fungicides, the timing of the chemical treatment seems critical to its effective performance. It has been shown that while seed treatments, early sprays (GS 4-5), and late sprays (GS 7-10), all effectively control mildew for some time the late sprays tend to give greater benefit in terms of yield. This feature would agree with the reports that 50% grain dry matter accumulates within 4 weeks of ear emergence (Thorne, 1963), as freedom from disease in the later stages of growth gives the biggest yield increases. A compound, such as benomyl, with a broad spectrum of fungicidal activity has obvious possibilities as a therapeutant for several of the commoner diseases of barley, but this conclusion must be thoroughly investigated on a quantitative and qualitative basis before such a recommendation is possible.

These increases in yield could not be accounted for in terms of 1000 grain weights, but simple observation of heads from treated and untreated areas showed less unfilled grain at the base of the heads in benlate treated areas.

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References

DELP, C.J. and KLOPPING, H.L. (1968). Proceedings of First International Congress of Plant Pathology, 44.

DOLING, D.A. (1963). Proc. 2nd Insectic. Fungi. Cong., 27

EVANS, E. (1968). Plant Diseases and their Chemical Control, Blackwell Scientific Publications

JAMES, W.C. (1969). Ann. appl. Biol., 63, 253

JAMES, W.C., JENKINS, J.E.E. AND JEMMETT, J.L. (1968). Ann. appl. Biol., 62, 273

JENKINS, J.E.E. and JEMMETT, J.L. (1967). Proc. 4th Insectic.Fungic. Conf., 108

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SEED AND SOIL-BORNE PATHOGENS OF CEREALS

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I do not propose in this paper merely to review what has happened during the past few years in research dealing with seed- and soil-borne pathogens of cereals. I propose also to consider the state of affairs existing at present. Obviously it is impossible within limited time to consider the whole field and so the topics to be discussed will be restricted.

The main objective of the plant pathologist must, in my opinion, be to assist the grower to obtain healthy, or least healthier, crops so that the highest possible yield, both in terms of quantity and quality, can be secured. Bearing this objective in mind we may ask what is the significance on a national level of each of the soil- or seed-borne diseases to which cereals are liable. One major shortcoming to-day in our understanding of this group of diseases is our lack of knowledge of their effect on yield. We are really unable to associate the incidence of disease as determined by crop surveys with a measured yield loss in national terms. In consequence it is difficult, if not impossible, for us to state authoritatively the relative significance of particular diseases. Too often information is confined to records of the number of diseased plants in a crop though account may also have been taken of the severity of attack on individual plants. It is when we try to relate data of this kind to crop yields that difficulty is experienced.

I do not wish to suggest that we have no information about the effects of diseases on crop yields. From data collected at Rothamsted over a nine year period Slope (1967) estimated that, for wheat cv. Cappelle, the incidence of take-all in crops grown after wheat or barley results in a loss of 0.3 cwt of grain per acre for each 1% of straws infected when the potential crop yield was about 50 cwt/ac. Similarly, for data relating to Proctor barley Slope suggested that for each 1% of the plants showing moderate or severe infection with Ophiobolus graminis the grain yield was reduced by about 0.3 cwt/ac in crops having a potential yield of about 45 cwt/ac. In recent replicated trials in Ireland, where soil was inoculated with O. graminis, losses of 50% and 24% in the grain yields of spring wheat and barley respectively have been recorded when the number of severely infected straws was 62-64% (Cunningham et al. 1968). This data raises the question of the relative susceptibility of wheat and barley and its relationship to yield losses.

At present I suppose most workers would consider take-all to be a more significant disease on a national scale than eyespot. We may, however, bear in mind that, according to Glynne (1953), control of eyespot could increase the grain yield of crops by as much as 50%. It is important that we should consider also the extent to which the effects of eyespot on yield may at present be somewhat concealed by the acreage under a relatively resistant cultivar. If new less resistant cultivars are grown on a fairly large scale we may expect greater losses from eyespot than occur at present.

Estimates of losses in yield due to species of Fusarium which are both soil- and seed-borne vary considerably. Reports of reductions of up to 50% exist but as a result of unpublished experiments at Manchester I suggest that in Britain losses exceeding 10-20% are very rare, and where losses of this extent occur they are associated with thin stands due to seedling death.

Pitt (1966) rarely encountered losses due to Rhizoctonia solani amounting to more than 5 cwt/ac in crops with a potential yield of 40-50 cwt/ac. This pathogen is not usually responsible for serious yield reductions at present.

It is exceedingly difficult to say what level of losses is caused by seed-borne diseases. It is, however, possible that the losses in yield from the lesser known diseases may in the aggregate be larger than is imagined. While more information is badly needed it would be helpful if the effects of interactions between different soil- and seed-borne diseases in respect of yield losses could be studied intensively.

Very substantial consideration in recent years has been given to the occurrence of take-all and to take-all decline in connection with the continuous growing of wheat or barley. The occurrence of serious losses due to Ophiobolus in the first two cereal crops grown after the drainage of polders in the Netherlands came as a surprise to most workers. In the reclamation of these polders reed and grasses provided a cover immediately after drainage. When a wheat crop directly follows reed it is suggested that the inoculum which leads to widespread infection of the wheat is provided by the infected reed roots. If a crop of rape intervenes between reed and wheat the grasses at the border of the field are thought to provide the inoculum leading to a patchy distribution of the disease. Although these suggestions may provide an answer regarding the source of the inoculum leading to the infection of wheat it is nevertheless important that we should consider how the grasses or reed came to be infected when these were grown in land just reclaimed from the sea.

Evidence obtained suggests that the initial infection of grasses in the reclaimed polders came from air-borne ascospores. However, Garrett (1939) had reported that he was unable to secure infection of wheat seedlings by inoculation with ascospores of O. graminis when the seedlings were growing in unsterilized soil or sand although infection resulted if the soil or sand was sterile. More recent work at Cambridge by Brooks (1965) showed that ascospores can infect the exposed proximal parts of the seminal roots of wheat seedlings sown on the surface of unsterilized soil. Brooks further showed that the normal soil microflora inhibits ascospore infection of roots growing in the soil. The ability of ascospores to infect plants has also been considered by Gerlagh (1968) who has shown that in a glasshouse such infection may occur when seedlings are grown in fresh subsoil from a polder. His results also indicate that in the open air spread of Ophiobolus occurs by ascospores. Gerlagh suggests that a developing soil microflora which is not yet regarded as complete and adapted to the new soil conditions, allows ascospore infection to occur in these polder soils.

When a crop is grown for successive years in the same land sharp increases in some soil-borne pathogens occur. In some diseases when monoculture is continued disease incidence may decrease after a few peak years and the population of the pathogen declines. This decline phenomenon is well demonstrated by take-all and has certainly been recognised in Britain for at least 35 years (Glynne, 1935).

Although many workers have interested themselves in the cause of Ophiobolus decline we are still without a satisfactory explanation of its cause. A technique for measuring the inhibition of the parasitic ability of *O. graminis* in soils has been developed by Lester & Shipton (1967). This technique is based on the assessment of root infection in wheat seedlings in uninoculated soil samples compared with that in samples inoculated with *O. graminis*. Results obtained by use of this method show that inhibition of the parasitic activity of *Ophiobolus* in soils is of widespread occurrence and may develop as a natural consequence of wheat or barley monoculture. Later in this session Dr. Hornby will be describing how a quantitative estimation may be made of the soil-borne inoculum of *O. graminis* on the basis of host infection tests. By use of these techniques we may hope to learn considerably more about populations of *Ophiobolus* in soils.

The decline of take-all in the new polders in the Netherlands after the third crop of wheat was attributed by Oort (1965) to an increase in antagonists which may have been lacking in the virgin soil. More recently, Gerlagh (1968) has discussed the results of his experiments made in the Dutch polders. In glasshouse experiments with soil from polders decline of take-all was induced only by application of virulent *Ophiobolus* inoculum to the soil and Gerlagh concluded that wheat-growing itself and the application of avirulent *O. graminis* or some other fungi was ineffective. Indeed, Gerlagh considered that the following two factors may operate in soils to bring about a decrease in the intensity of the incidence of take-all.

1. A non-specific action of the general soil microflora may lead to a small reduction in the severity of the disease as the number of microorganisms increases.
2. Specific antagonism attributable to a quantitative change in the microflora induced by the previous presence of *O. graminis* may result in bringing about a sharp reduction in disease severity.

Gerlagh considers that decline is caused by specific antagonism although the disease is slightly moderated by the non-specific action of the general soil microflora. It is well recognised that the antagonistic property of soil can be considerably decreased by interruption of continuous growing of wheat or barley by introducing another crop for one season. Gerlagh's results show that antagonism is governed by the production of antibiotics by soil organisms but the antagonists have still to be specified. It may well be that we are not concerned with antagonism between *O. graminis* and one or a few organisms but rather with a balanced association of microorganisms.

It was shown by van Schreven (1962) that bacteria increase in numbers in a maturing polder and actinomycetes are of frequent occurrence. However, Pugh and van Emden (1969) have suggested that because of their faster growth fungi may be more effective than bacteria and actinomycetes for raising the resistance of an unbalanced soil to pathogens. These workers have suggested that *Gliocladium roseum* should receive special consideration as an antagonist. They also suggest that a study should be made of the possibility of artificially increasing the abundance of this fungus during the first two years of cultivation of new polder soils when its occurrence is fairly low. It is certainly true that if we wish to enjoy the economic advantages which arise from monoculture of cereals we must do everything possible to prevent a build-up of pathogenic organisms in the soil irrespective of whether we are dealing with new polders or soils which have been cultivated for long periods.

Studies of *Fusarium* diseases of cereals have been fairly prominent in a number of countries recently. In Britain *F. nivale* has been shown (Colhoun, Taylor & Millar, 1963) to be frequently present in cereal crops and it is, of course, recognised as a seed-borne pathogen in this country. From the work of Sprague (1950) and Gordon (1952) it may be inferred that seed-borne infection does not occur in North America. This conclusion may now have to be modified since Cook (1966) has discovered the perfect state of this fungus on wheat in the Pacific North West of the United States. There are few records of the successful isolation of F. nivale from soil and those which exist usually relate to soils carrying susceptible grasses. Nevertheless, the fungus is regarded as a soil-borne pathogen in some areas of North America and in Finland where it causes severe losses in cereal crops exposed to prolonged snow cover. It is interesting that Gordon (1954) failed to isolate F. nivale from 1674 soil samples from cereal plots in Canada although undoubtedly it attacks grasses there. Recently Snyder & Nash (1968) have studied the occurrence of Fusarium spp. in soil at Rothamsted and reported that, although high populations of F. culmorum occurred, F. nivale was not recovered from the soil. They associated this finding with the fact that F. culmorum produces abundant chlamydospores whereas F. nivale normally does not do so. Rawlinson & Colhoun (1969) have shown that when oat seeds not infected with F. nivale are sown in field or pot experiments this fungus can often be recovered from the roots or mesocotyls of seedlings which do not show disease symptoms. These observations indicate that the fungus is present in the soil. Further unpublished work at Manchester has demonstrated that F. nivale can survive in soil from one season to another on infected stubble. It may also find its way to uncontaminated land in infected cereal straws in farmyard manure. Soils can be tested for the presence of F. nivale by growing cereal seedlings from healthy seeds in them and later making isolations of the fungi present on the roots and hypocotyls. Alternatively, parts of seedlings may be added to soil as bait for the fungus. It is now clear from work of this nature that F. nivale frequently exists in arable soils including those at Rothamsted although the populations are low when compared with those of F. culmorum. Our information shows that although seed treatment with organo-mercury reduces infection of seedlings it does not eliminate it when the inoculum is either seed- or soil-borne

It has been stressed by Wilhelm (1959) and Patrick & Toussoun (1965) that, as more knowledge about plant root diseases is obtained, the demarcation line between pathogens and saprophytes becomes increasingly indistinct. A similar conclusion has been reached by Rawlinson & Colhoun (1970) who have found that when oat seeds not carrying any known pathogen are treated with organo-mercury the seedlings show greater vigour than those from untreated seed. This increase in vigour is sufficiently marked for it to be obvious in field inspections, but it can also be demonstrated in the fresh and dry weights of the plants, plant height, leaf area and in other measurements. The effect of seed disinfection on plant vigour is associated with the occurrence of periods of frost and the growth of plants under low winter light conditions. The fungicide appears to protect the mesocotyls of seedlings from contamination or invasion by certain soil-borne fungi normally regarded as saprophytes, with the result that normal development of the mesocotyls and seedlings can take place. F. sambucinum and Cylindrocarpon radicicola are thought to be implicated and, of course, both fungi are common contaminants of the underground parts of cereal plants, but hitherto they have been regarded as of little or no importance as cereal pathogens. It should be made clear that the increase in plant vigour following seed disinfection of healthy seed rarely persists longer than seven or eight months after autumn sowing. As we learn more about the interrelationships between crop plants and the soil microflora it is perhaps not impossible that toxins from saprophytes may, as Graniti (1970) suggests, help to predispose plants to attacks by weak parasites and, if the toxins can accumulate in soil, then plant disorders may result.

Some recent work on seed-borne pathogens reminds us of the significance of fungal variability. Some years ago it was clearly demonstrated that the primary phase of leaf stripe of oats caused by *Pyrenophora avenae* could be well controlled by seed treatment with organo-mercury. It has now become apparent that this fungus has developed resistance to the materials used so that poor control of the disease results (Noble, MacGarvie, Hams & Leafe, 1966; Malone, 1968). It is not only in relation to the effects of seed disinfection that we should be thinking of the variability of seed-borne fungi. For example, *Septoria nodorum* exhibits physiologic specialization, according to Thomas (1962), but we have no knowledge of how this may affect British crops. As a result of recent experience with this fungus it seems to me not unlikely that there may be surprises in store for us unless we pay attention to its variability.

There is little doubt that, although seed- and soil-borne diseases of cereals continue to be important, foliar diseases have in recent years been regarded by many workers as being of greater significance on a national scale. If, through the use of systemic fungicides, perhaps combined with other control measures, the damage resulting from cereal mildew can be greatly reduced in the near future, we have to ask what part will soil- and seed-borne pathogens then play in reducing yields. Certainly if continuous wheat or barley growing is in future to occupy an important place in farming practice it is clear that seed- and soil-borne pathogens are likely to be of great importance. The situation could, of course, be greatly changed if systemic fungicides exercising a control of a wide range of pathogens can be produced, or if through the study of soil microbiology we are enabled to make use of antagonism in soils as a means of achieving disease control.

References

BROOKS, D.H. (1965) Trans. Br. mycol. Soc. 48, 237.
COLHOUN, J., TAYLOR, G.S. and MILLAR, C.S. (1963) Nature 200, 597.
COOK, R.J. (1966) Phytopathology 56, 1100.
CUNNINGHAM, P.C., SPILLANE, P.A., FOREMAN, B.T. and CONNIFFE, D. (1968) Ir. J. agric. Res. 7, 183.
GARRETT, S.D. (1939) Ann. appl. Biol. 26, 47.
GERLAGH, M. (1968) Neth. J. Pl. Path. 74, Suppl.2.
GLYNNE, M.D. (1935) Ann. appl. Biol. 22, 225.
GLYNNE, M.D. (1953) Ann. appl. Biol. 40, 221
GORDON, W.L. (1952) Canad. J. Bot. 30, 209.
GORDON, W.L. (1954) Canad. J. Bot. 32, 622.
GRANITI, A. (1970) Annls Acad. scient. Fennicae (in the press)
LESTER, E. and SHIPTON, P.J. (1967) Pl. Path. 16, 121.
MALONE, J.P. (1968) Pl. Path. 17, 41.
NOBLE, M., MacGARVIE, Q.D., HAMS, A.F. and LEAFE, E.L. (1966) Pl. Path. 15, 23.
OORT, A.J.P. (1965) Neth. J. Pl. Path. 71, 183.
PATRICK, Z.A. and TOUSSOUN, T.A. (1965) In Baker, K.F. and Snyder, W.C. (Ed.) *Ecology of soil borne plant pathogens*. Univ. California Press, Berkeley.

PITT, D. (1966) Ann. appl. Biol. 58, 299.
PUGH, G.J.F. and EMDEN, J.H. van (1969) Neth. J. Pl. Path. 75, 287.
RAWLINSON, C.J. and COLHOUN, J. (1969) Pl. Path. 18, 41.
RAWLINSON, C.J. and COLHOUN, J. (1970) Ann. appl. Biol. (in the press)
SCHREVEN, D.A. van (1962) Van Zee Ld. 32, 34.
SLOPE, D.B. (1967) Ann. appl. Biol. 59, 317.
SNYDER, W.C. and NASH, S.M. (1968) Trans. Br. mycol. Soc. 51, 417.
SPRAGUE, R. (1950) Diseases of cereals and grasses in North America. Ronald Press Co. New York.
WILHELM, S. (1959) In Holton, C.S. (Ed.) Plant pathology, problems and progress 1908 - 1958. Univ. Wisconsin Press, Madison, Wisconsin.

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STUDIES ON THE INTERRELATION OF THE CEREAL CYST NEMATODE (HETERODERA AVENAE) AND THE TAKE-ALL FUNGUS (OPHIOBOLUS GRAMINIS) ON BARLEY

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Summary. The results of field observations on a range of barley fields suggest an inter-relationship between the cereal cyst nematode (*Heterodera avenae*) and the take-all fungus (*Ophiobolus graminis*). Low levels of the nematode appear to be associated with high levels of the fungus. This is supported by pot experiments on natural and artificial nematode populations, whose multiplication rates are decreased by high levels of take-all.

INTRODUCTION

This study was initiated in the light of two observations on population changes of the cereal cyst nematode. The general observation that field populations often decline for no apparent reason under susceptible host crops was reported by Collingwood (1962). The second observation was reported from Rothamsted where the application of formalin, as a soil sterilant before sowing spring wheat, led to an increased final egg population of the nematode. The formalin appeared to release some sort of check on the potential increase of the nematode. One of the more noticeable observations associated with this build up was the decrease in take-all on formalin treated sites (Williams, 1967).

The present work investigates the occurrence together of take-all and cereal cyst nematode in field soils, and their effects on each other under experimental conditions.

METHOD AND MATERIALS

Field observations, 1967. In 1967, 24 fields in Hampshire and Berkshire were sampled in spring, summer and autumn. All the fields were growing spring barley and had previously grown up to 11 consecutive cereal crops. In spring plant samples were taken from each field at about 5 weeks after crop emergence. Fifty 4 in lengths of drill were lifted at random from each field and single plants were selected at random from each length. The roots were washed free of soil, examined for take-all and then stained in acid fuchsin/lactophenol and examined for cereal cyst nematode. A second plant sample was taken at harvest and the level of take-all infection was recorded. In late autumn the nematode populations (eggs/g soil) were determined from cysts extracted from soil samples.

Field observations, 1969. In 1969, the field sampling programme was confined to one field in order to avoid, as far as possible, differences in factors other than the levels of take-all and cereal cyst nematode. The field selected had grown 5 consecutive cereal crops. Initial soil samples were taken from 35 marked points in an area of this field measuring 50 x 70 yd. The soil samples were examined for take-all by recording the infection on the roots of 50 barley plants grown in 1 kg of the soil for 3 weeks. Cysts were extracted from these soil samples and the initial nematode populations determined as eggs/g soil. In spring plant samples were taken from the field at 4 weeks after crop emergence, and one plant from each marked point was examined to assess the degree of infection by take-all and cereal cyst nematode. At harvest a final plant sample consisting of a 4 in length of drill was taken from each point. These samples were allowed to dry and the soil

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*Present address: Welsh Plant Breeding Station, Aberystwyth from around the roots of one plant was gently removed. The root system was examined for take-all and the final nematode population was determined from cysts extracted from 100 g of the soil.

Glasshouse experiments. Three pot experiments were made, two using field soil naturally infested with cereal cyst nematode, and one using sterilized soil inoculated with hatched larvae. All the experiments were carried out in pots containing 1 kg soil sown with a single pre-germinated barley seed (cv Proctor). The pots were plunged into washed sand ballast for the duration of an experiment. All fungus inoculations were made with one month old sand-wheatmeal cultures of *Ophiobolus*. These were prepared and mixed with the soil, before potting, by the techniques described by Lester and Shipton (1967). Autoclaved cultures were added to controls. At the end of each experiment (4 to 5 months after sowing) the pots were allowed to dry out in the glasshouse. The soil was then shaken and brushed from each root system. The roots were washed, weighed and examined for take-all infection. Cysts were extracted from a 200 g sample of soil taken from each pot and number of eggs/g soil estimated. In one experiment the number of nematode larvae per root system was assessed at 3 weeks after sowing by staining the roots in acid fuchsin/lactophenol.

RESULTS

Field observations, 1967. The results of the 1967 spring samples suggest a relationship between the cereal cyst nematode and take-all. The scatter diagram (Figure 1), shows the relationship between % plants infected by take-all and those infected by the nematode. The same relationship was found when the measure of infection was assessed as % roots infected by each organism or the number of take-all lesions and cyst nematode larvae per root system. The final nematode population and % plants infected by take-all in the spring also show this relationship (Figure 2). These data suggest that there is an association of high levels of nematode with lower levels of take-all. There was no such relationship between the final nematode population and the level of take-all on the summer plant samples.

Field observations, 1969. The 1969 spring plant samples showed a similar relationship between cereal cyst nematode and take-all as that found in 1967. In this field initial nematode populations in the 35 samples ranged from 1.3 to 50.9 eggs/g soil and the final populations ranged from 3.5 to 91.8 eggs/g soil. Take-all levels (as % roots infected of those plants on which the final nematode population was produced) are shown in Figure 3, where they are plotted against the nematode multiplication factor (final eggs/g/initial eggs/g). The correlation coefficient ($r = -0.494$) is significant at the 1% probability level. This suggests that the multiplication rate of cereal cyst nematode is depressed in the presence of high levels of take-all.

Glasshouse Experiments

Experiment 1. The effects of increased levels of take-all on 8 natural populations of cereal cyst nematode. For this experiment soil was collected from 8 fields included in the 1967 field sampling programme, and the initial cereal cyst nematode populations determined (Table 1). Take-all inoculum was added to 3 pots of each soil at the rate of 100 g of culture/pot (10%), and an equal number of controls were set up.

The results of this experiment support the hypothesis, derived from the field observations, that high levels of take-all depress multiplication of the cereal cyst nematode. The multiplication factors of the eight populations are also given in Table 1. Four of the multiplication factors were significantly lower in those treatments with artificially increased take-all than in the respective controls. A further two were reduced but the reduction was not statistically significant. The multiplication factors of the other two populations were not depressed by the addition of take-all inoculum to the soil.

Figure 1
Relationship between take-all and cereal cyst nematode (spring 1967)

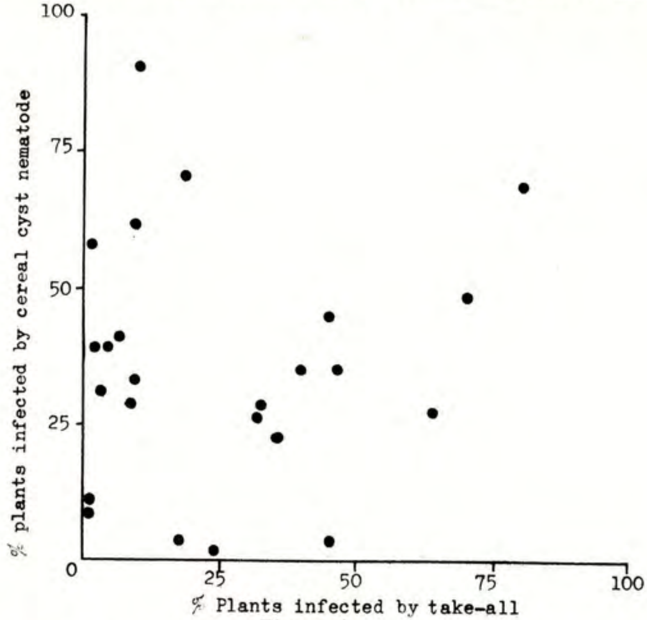


Figure 2
Relationship between take-all and final cereal cyst nematode populations

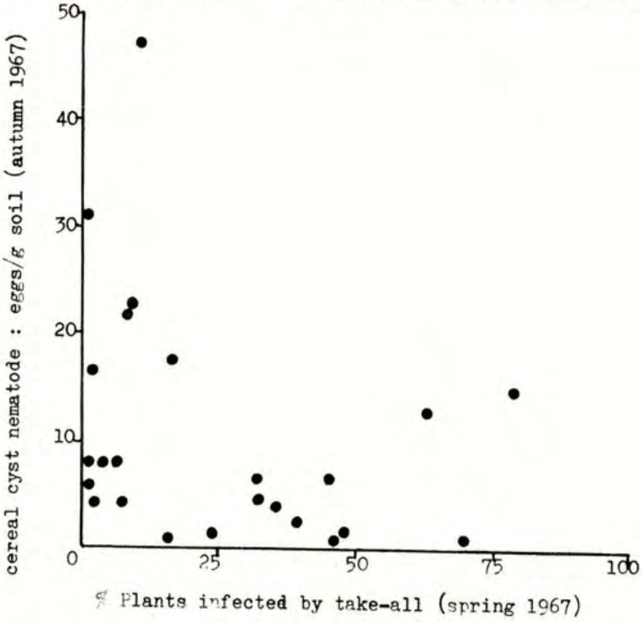
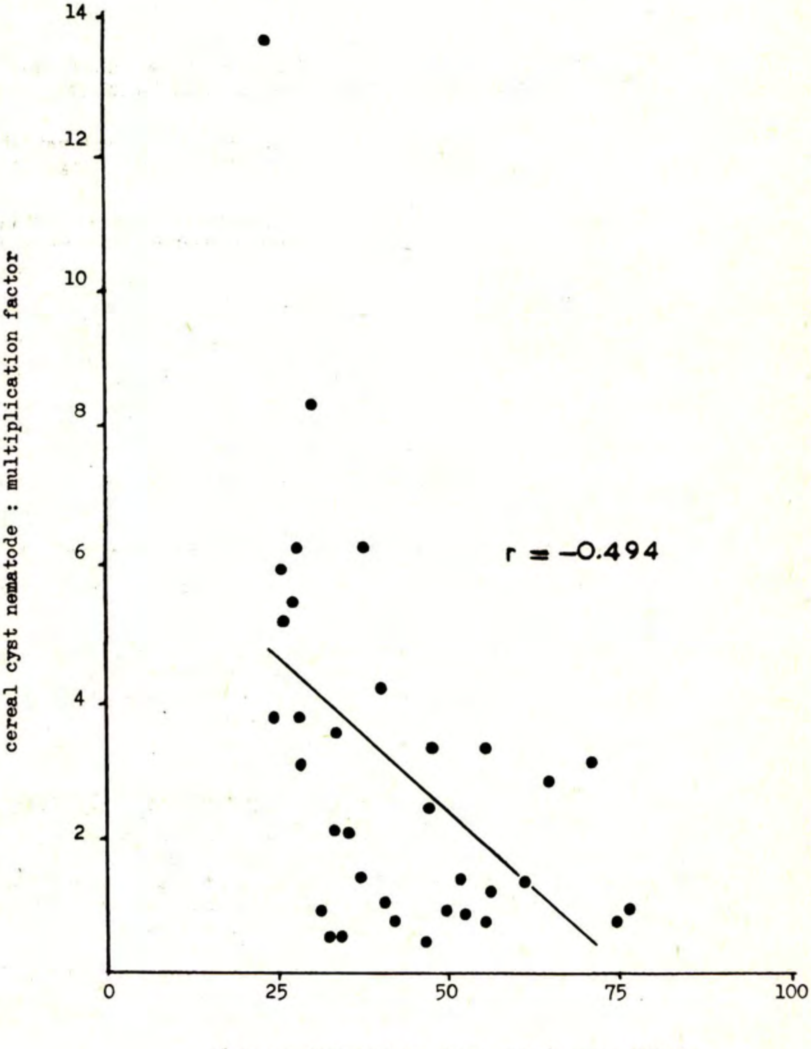


Figure 3

Relationship between take-all and multiplication of the cereal cyst nematode (1969)



% roots infected by take-all (summer 1969)

The % roots infected by take-all (Table 1) shows that the addition of take-all inoculum to soil did increase the levels of take-all on roots, compared with the natural levels on the roots of control plants. At the higher natural levels of take-all, there was no statistically significant reduction in the nematode multiplication factor by the addition of the experimental inoculum. The root weights, which are also recorded in the table, do not offer an explanation of the depression in nematode multiplication since the final weights were actually higher in five of the additional take-all treatments than in the respective controls.

Table 1

Effect of increased take-all on the multiplication of 8 natural populations of cereal cyst nematode (means of 3 replicates)

	Multiplication factor				% Roots infected with take-all		Root weights (mg)	
Initial eggs/g	Control		Treatment	S.E. of means ±	Control	Treatment	Control	Treatment
46.4	0.75	N.S.	0.85	0.111	79	89	120.2	136.3
5.6	1.41	N.S.	1.01	0.261	76	85	120.0	91.2
22.2	0.85	N.S.	0.88	0.124	46	65	104.4	177.7
3.9	0.77	*	0.55	0.054	44	67	115.0	157.2
21.7	0.38	*	0.21	0.043	39	64	104.3	120.3
16.2	0.42	*	0.21	0.029	39	63	146.6	200.6
7.3	1.69	N.S.	1.41	0.163	25	65	388.6	290.4
30.5	0.46	*	0.28	0.031	4	65	174.1	115.6

(*or N.S. marks significance or non-significance respectively, between adjacent means at $P = 0.05$)

From the multiplication factors, it can be seen that, of the 8 nematode populations, 6 declined from their initial level in both control and take-all treated pots (a multiplication factor of 1 indicates maintenance of the initial nematode population). However, the increase in take-all resulted in further depression of the cereal cyst nematode population.

Experiment 2. The effects of increased levels of take-all on invasion and multiplication of 3 natural populations of cereal cyst nematode. For this experiment soil was collected from 3 points in the field sampled in 1969 to provide three natural infestations of cereal cyst nematode (1, 5 and 47 eggs/g soil). No take-all was detected in the three samples by the tumbler test method used in the field sampling programme. Take-all inoculum was added to 6 pots of each soil at the rate of 100 g culture/pot, and an equal number of controls were set up.

The numbers of larvae found in the roots after three weeks are shown in Table 2. Take-all had not developed at this stage on the plants in the controls, but was present on plants in the take-all treated pots. There was no effect of take-all on invasion by the nematode.

Table 2

Effect of increased take-all on the invasion of roots by 3 cereal cyst nematode populations (means of 3 replicates)

Initial eggs/g	larvae/root system ± S.E.		% roots infected with take-all		Root weights (mg)	
	Control	Treatment	Control	Treatment	Control	Treatment
1	52.0 ± 15.9	38.0 ± 6.7	0	47	159.7	91.3
5	47.3 ± 4.5	42.0 ± 7.8	0	22	102.2	120.3
47	53.0 ± 3.1	47.7 ± 7.9	0	29	151.1	133.7

Table 3 shows the effect of the increased levels of take-all on the multiplication of the cereal cyst nematode. The final levels of take-all were higher on plants in the take-all treated pots than in the controls. The final eggs/g soil were significantly reduced at all initial nematode levels by the presence of increased take-all. Of the three nematode populations only the highest initial level declined in the control and in this case there was a further depression in the treatment, attributable to the additional take-all. As in experiment 1, it was not possible to relate the effect of a decrease in multiplication of the cereal cyst nematode to any reduction in final root weight due to the take-all.

Table 3

Effect of increased take-all on the final level of 3 cereal cyst nematode populations (means of 3 replicates)

Initial eggs/g	Final eggs/g ± S.E.		% roots infected with take-all		Root weights ± S.E. (mg)	
	Control	Treatment	Control	Treatment	Control	Treatment
1	6.14 ± 0.81	1.40 ± 0.46	52	82	458.3 ± 97.3	434.0 ± 60.3
5	13.63 ± 1.58	6.11 ± 0.28	50	77	399.7 ± 79.7	488.3 ± 39.3
47	21.33 ± 1.00	8.96 ± 0.72	50	80	450.3 ± 72.2	555.7 ± 74.5

Experiment 3. The effect of 3 levels of take-all on the development of cereal cyst nematode in sterilized soil. This experiment was made using nematode larvae inocula added to steam sterilized soil. Three levels of nematode inoculum were added to soil at 0, 1,000 and 5,000 hatched larvae/pot. Take-all was added at three rates 0, 10 g and 100 g of live culture/pot (0, 1%, 10%) to give 9 treatments in all. The experiment was replicated 4 times.

The effects of take-all on the development of the nematode in sterilized soil are shown in Table 4. The results were examined by an analysis of variance and the critical differences calculated. An unexplained deviation from the previous pattern of depression of cereal cyst nematode populations by increased levels of take-all was found in this experiment where, at the inoculum level of 1 larva/g soil, the numbers of cysts produced were higher at increased levels of take-all. However, the numbers of eggs/cyst were significantly reduced by the fungus and, consequently, there were no significant differences in the final level of eggs/g soil. At the higher nematode inoculation rate (5 larvae/g) both numbers of cysts produced and the numbers of eggs/cyst were reduced by increasing take-all. Moreover, at this level, final nematode levels (eggs/g soil) were significantly lower at each increase in fungus inoculum.

Table 4

Effect of 3 levels of take-all on development of the cereal cyst nematode (means of 4 replicates)

Rate of take-all added	Final eggs/g		Cysts/200g		Eggs/cyst	
	Initial larvae/g					
	1	5	1	5	1	5
0%	14.18	29.55	22.38	39.38	126.8	150.1
1%	14.48	19.90	30.00	32.88	96.5	121.1
10%	13.03	13.47	32.88	24.13	79.3	111.7
@ P = 0.05	C.D. = 3.96		C.D. = 2.32		C.D. = 11.2	

The final eggs/g produced at the higher nematode inoculum levels were significantly higher than those at the lower nematode inoculum levels, except at the 10% rate of take-all where there was no significant difference between the nematode levels. The numbers of cysts produced were similarly higher at the high nematode inoculum levels except for the 10% take-all + 5 larvae/g soil treatment where significantly fewer cysts were found than at 10% take-all + 1 larvae/g soil.

The root weights were decreased by increasing levels of take-all at all nematode inoculation rates (Table 5). At 0 and 1% take-all the inoculum of 1 larvae/g soil caused a significant reduction in root weight. The 5 larvae/g inoculum levels also reduced root weights in comparison with controls (0 larvae/g) but significantly increased root weight when compared with the corresponding 1 larvae/g inoculum levels. At the highest level of take-all (10%) each increase in nematode inoculum led to a decrease in root weight.

Table 5

Effect of take-all and cereal cyst nematode on root weight of barley (mg means of 4 replicates)

Rate of Take-all	Initial larvae/g		
	0	1	5
0%	499.4	460.5	484.9
1%	479.8	420.2	435.3
10%	409.6	382.9	350.3

@ P = 0.05 C.D. = 9.56

There was no effect of cereal cyst nematode on the level of take-all infection. The level of take-all at the 10% inoculum rate was higher than that at the 1% rate. (Table 6).

Table 6

% roots infected by take-all (means of 4 replicates)

Rate of take-all	Initial larvae/g 0	1	5
0%	-	-	-
1%	65.4	64.6	64.9
10%	74.7	72.5	75.7

@ P = 0.05 C.D. = 3.97

DISCUSSION

The field observations and pot experiments demonstrate that take-all does depress cereal cyst nematode populations on barley. However, it is clear from the experiments with naturally infested soil that other factors also depress nematode populations. Observations on decline of this nematode at Ruthin by Cotten (1969), where no take-all was detected, and by Gair, et al. (1969), where the decline began on oats which are resistant to the more common Ophiobolus graminis, also suggest that take-all is not the only factor involved. High levels of take-all can not be regarded as a cure for cereal cyst nematode problems, since the levels of take-all responsible for reductions in nematode population are in themselves high enough to cause considerable yield loss to a crop.

The effect of take-all on cereal cyst nematode cannot be related to measurements of final root weight as measured at harvest. At this late growth stage, root weight reflects the balance between growth, (which may well have stopped), and decay. Consequently it does not provide a real estimate of the size and, perhaps more important, the vigour and physiological state of the roots at the earlier stages in plant growth, when the nematode is feeding in the roots and is perhaps vulnerable to adverse conditions. The possible mechanism by which take-all depresses the population of cereal cyst nematode cannot be decided from the results in the present paper. However, the results of the third pot experiment suggest that cysts are not able to develop to such a large size on take-all infected plants.

In other fungus-nematode interactions effects of the fungus on invasion of the host roots by the nematode have been recorded. Thus there is an increase in invasion of alfalfa roots by Pratylenchus penetrans when they are infected by Fusarium oxysporum or Trichoderma viride (Edmunds and Mai, 1966). On the other hand, Ketudat (1967) reports a decrease in invasion by Heterodera rostochiensis on tomato roots infected with brown root rot. The observations on invasion suggest that under the present experimental conditions take-all has no effect on the invasion of barley roots by the second stage larvae. This seems a reasonable conclusion, since there is no direct competition for invasion site, Heterodera larvae invading just behind the root tip whilst the take-all fungus invades above the zone of elongation (Davis, 1925). However, should a root become infected by take-all, before penetration by the second stage larvae has taken place, there is then a likelihood of the fungus affecting the suitability of the root for nematode invasion. I hope in a later paper to present some results which show that take-all does depress invasion in this case.

In interactions of fungi and *Heterodera rostochiensis*, Ketudat has reported effects of the fungus in increasing the ratio of males to females produced by the nematode. Trudgill (1967) has demonstrated that the sex of developing larvae of *H. rostochiensis* can be determined by environmental conditions, adverse conditions resulting in the production of increased numbers of males. On the other hand, Johnson and Viglierchio (1969) claimed that environment has no effect on sex determination of *H. schactii* larvae, although under adverse conditions more females than males failed to mature. Cotten (1967) suggests that in resistant barley varieties the development of *H. avenae* males is less affected than that of females. Thus take-all infection of roots may well constitute an adverse environmental condition and affect either sex ratio alone or sex ratio and sex determination of *H. avenae*.

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References

COLLINGWOOD, C. A. (1962) N.A.A.S. Quart. Rev. 58, 70.
COTTEN, J. (1967) Ann. appl. Biol. 59, 407.
COTTEN, J. (1969) (A. A. B. Summer School, Aberystwyth).
DAVIS, R. J. (1925) J. agric. Res. 31, 801.
EDMUNDS, J. E. and MAI, W. F. (1966) Phytopathology, 56, 1132.
GAIR, R., MATTHIAS, P. L. and HARVEY, P. N. (1969) Ann. appl. Biol. 63, 503.
JOHNSON, Ruth N. and VIGLIERCHIO, D. R. (1969) Nematologica 15, 144.
KETUDAT, U. (1967) Ph.D. Thesis, Univ. London.
LESTER, E. and SHIPTON, P. J. (1967) Pl. Path. 16, 121.
TRUDGILL, D. L. (1967) Nematologica 13, 263.
WILLIAMS, T. D. (1967) Rep. Rothamsted exp. stn. 1966, 142.

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SOME PROBLEMS CONNECTED WITH MONITORING FOR RESISTANCE

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Summary Insects can become resistant to most insecticides provided their usage is sufficiently prolonged; a sudden loss of effectiveness of the insecticide because of resistance may cause severe economic loss, making early detection and monitoring for resistance vital. However, early detection of resistance in field populations which are often heterogeneous poses problems and difficulties in interpreting resistance from results of bioassays through lack of standardized methods of measurement, and knowledge of the original susceptibility of the field populations. These difficulties and the necessity to examine for cross-tolerance patterns at the earliest possible opportunity are examined and discussed.

Judging from experience it is now taken for granted that insects can become resistant to any insecticide to which it is exposed for long enough. This is obvious from the ever increasing list of insect species resistant to chemicals (Brown 1960, Anon. 1967, 1968, 1969, Smith 1960, Glass 1960, Chapman 1960) and the ever decreasing list of insecticides against which resistance has yet to be reported. Adequate warning of development of resistance is therefore essential if we are to continue to control insects with insecticides and decrease the danger from any sudden loss of effectiveness of pesticides (Coaker, T.H. et al. 1963, Roussel 1960). Early warning is best done by monitoring, that is, testing regularly field populations for the first signs of resistance.

Before discussing problems connected with monitoring, we must be quite clear of what we mean by resistance, because this term is used in many ways, which often leads to confusion. Natural tolerance which some species of insects show to some insecticides, and behaviouristic resistance, that is the development of the ability to avoid a dose that could be lethal (Brown 1958), are excluded from this context. Resistance can be discussed in the academic sense by laying down criteria of when an individual insect or a strain is susceptible or resistant, or in the practical sense when there is a lack of control after using the insecticide. Resistance can also be referred to when discussing genetically or biochemically distinct mechanisms that occur in individual insects, and the degree of resistance the mechanism confers can then be stated in the heterozygous or homozygous condition. Finally, we can talk about the resistance of a whole population, that is the amount of the resistance of the individual insects and the proportion in which they occur in the population. In monitoring, the attempt should be to measure, presumably from random samples, the proportion of insects resistant and their degree of resistance before resistance becomes obvious in the practical sense.

The first thing therefore is to know when an insect is resistant. There is unfortunately no ideal definition of resistance to insecticides, because resistance implies comparison with the standard susceptible condition of the species (Hoskins 1967), a condition, as we shall see later, difficult to define.

FAO's definition of resistance, i.e. "a decreased response of a population of animal or plant species to a pesticide as a result of their application" (Anon. 1967) unfortunately fails to indicate what is a decreased response, and sometimes it must remain unknown, because no adequate tests of the response of populations to insecticides were made before applying the poisons (Reynolds 1960), or there are no susceptible insects for comparison (Harris, C.R.et al. 1962). Difficulties in defining where resistance begins also arise when there is no apparent discontinuity in tolerance between susceptible and non-susceptible insects, and various terms, e.g. vigour tolerance (Hoskins and Gordon 1956) intermediate resistance (Hoskins 1967) or tolerance (Harris, C.R. et al. 1962), have been used to describe the stage between susceptibility and definite resistance. It can be argued that, for monitoring purposes, an insect is resistant when its tolerance is such that when present in field populations controlling with the pesticide becomes difficult. However because extrapolation from results of bioassays to field conditions is uncertain, it is practically impossible to fix an acceptable level of tolerance for which to monitor. Sometimes surprisingly small degrees of resistance make control unattractive; a four-fold difference in tolerance to DDT between a susceptible and a field population of the eye gnat (Hippelates collusor Townsend) precluded the use of this compound as a control agent because it made control uneconomic (Mulla 1962). This is why monitoring as interpreted here should be sufficiently accurate to detect tolerant insects in susceptible populations even when the differences in response to an insecticide are small. Because this implies a comparison with the standard susceptible condition of the species, this property, often referred to as the base-line (Hoskins 1967) must be determined accurately.

World Health Organization workers using standard methods of bioassay pioneered by this organization (Quarterman 1960, Anon. 1963) have determined the base-lines or tolerance ranges of several populations for each of several species to different insecticides. For individual species this variation may be as much as 10-fold, but is usually less and seldom exceeds the 4-5-fold range. However, this is enough to make an accurate distinction between susceptibility and resistance difficult if not impossible where the resistance mechanism confers little resistance. The variations yet measured in range of susceptibility among agricultural pests, such as the western corn root worm, Diabrotica virgifera LeConte (Hamilton 1965) are about 4-5-fold and for aphids is even less (Needham and Dunning 1965), but for most other agricultural pests base-lines or tolerance ranges are yet to be determined and the choice of the population from which the base-line is to be established may present problems.

Although for obvious reasons laboratory-bred insects offer very great advantages over those collected from the field, it is very important to know the differences between the tolerance ranges of the insects from these sources. For example, Keiding (1963) reported that three laboratory-bred strains of M. domestica L. did not differ significantly in their response to many insecticides but all three were from 2-5 times more susceptible than the field populations. Similarly, Busvine and Harrison (1953) found field populations of M. domestica vicina Macq. up to 5 times less susceptible than laboratory populations. Also, different susceptible strains do not always show equal susceptibilities to the same insecticides and for this reason Keiding has used the mean tolerance or mean LD50 of his three laboratory strains of houseflies for the base-line.

Where laboratory insects are not available, and so far relatively few insect pests of agricultural importance have been bred in the laboratory for more than a few years, tests must be done on insects collected in the field. The choice of the collecting sites is then of great importance but even when all precautions have been taken there is no certainty that the insects collected are susceptible (Blair, B.D. et al. 1963). However, with a few exceptions, such as in areas where cyclodienes have been used repeatedly for several years and have become concentrated in the soil (Harris, C.R. et al. 1966), resistance is seldom universal and pockets of fully susceptible individuals can be found close to areas containing very resistant populations; Hamilton (1965) found fully susceptible North corn root worms less than two miles from a site containing very resistant individuals. Therefore, the difficulties in finding susceptible populations in the field may often be more apparent than real and usually resistance almost, but never quite, disappears when selection pressure stops (Keiding 1963).

The determination of the base-line not only rests on the choice of the population but also on the bioassay technique, and to be worthwhile the baseline must be determined with an accurate standard method that is generally accepted and used. Standard testing methods have until recently been sadly lacking for pests of agricultural importance but are now developed for the Food and Agriculture Organisation of the United Nations by a panel of experts (Anon. 1968). This should not only stop what Busvine calls "the thoughtless or anarchistic attitude of the experimenters each of whom likes to devise his own particular test" (Busvine 1968) but also make monitoring on a large scale less of a problem.

To be really useful, test methods should answer the following questions :- Are there any resistant insects in the population and, if so, what proportion do they constitute and how resistant are the resistant individuals? The first question is probably best answered by treating the sample of insects with the smallest amount of poison that kills the susceptible insects, i.e. the discriminating dose. Any survivor is then potentially resistant, provided the discriminating dose has been determined correctly. This technique has been used successfully in many areas, and Davidson (1960) considers that it is especially useful where there are relatively few resistant individuals in the population, that is, where resistance might be missed were logarithm-dose-probit lines used. Discrimination need not only apply to doses that kill the susceptible individuals but may also be used to distinguish other differences between susceptible and resistant insects, such as the rate of knock-down (Milani 1960), and wherever possible should emphasize the differences between susceptibility and resistance (Barnes, M.M. et al. 1954). For example, to detect resistance against DDT in the house fly, the insecticide should be in acetone rather than kerosene, even when kerosene is used for spraying in the field, because DDT resistant house flies treated with this insecticide dissolved in acetone are nearly 20 times more resistant than when treated with DDT dissolved in kerosene (Busvine 1951). Also with cross-tolerant insects, it is preferable to discriminate between susceptible and resistant individuals with the insecticide against which resistance is greatest, and not necessarily with the insecticide against which the insects developed resistance in the field; e.g. dieldrin was used in preference to γ-BHC to detect resistance in cocoa capsids in West Africa, because dieldrin gave clearer differences between susceptible and resistant insects than γ-BHC (Telford 1963, Gerrard 1964).

Discriminating doses determine the presence of resistant insects, but the degree of resistance is determined from the log-dose probit line, which describes the complete range of tolerances of the population and measures if the maximum level of resistance conferred by the resistance mechanism is within the control limits set for the insecticide. The log-dose probit line also provides additional information, such as the shape and position of the line that describe the population investigated. For example, Harris, C.R. et al. (1966) were able to determine the proportions of cabbage root flies (Hylemyia) heterozygous and homozygous for resistance in various parts of Canada because the different resistance genotypes showed specific ranges of tolerance indicated by a series of definite steps on the log-dose probit line. This example shows that the common practice of presenting calculated log-dose probit lines in resistance work, without any indication of the points, can hide valuable information, and the practice of quoting LD50s with enormous standard errors is even worse. The ridiculous result

LD50 7.95 ± 8.34 µg/insect, quoted in the literature, was almost certainly obtained by calculating log-dose probit lines for a population containing almost two equal fractions of widely different tolerances with a very wide gap in between, which appears on the log-dose probit line as a plateau at about LD50. This is only one of the many examples of the misuse of statistics in the published work on resistance, and hides important information rather than giving, as intended, clear summaries.

So far, I have discussed some of the more academic problems of detecting resistance early. I wish now to consider some of the more practical aspects, such as whether to start monitoring before or after the appearance and confirmation of resistance in the field.

First reports of resistance usually come from areas using the largest quantities of insecticide and individual reports, once confirmed, are soon followed by numerous complaints of control failure, often from widely separated areas. This pattern is because of the way resistance builds up. How resistance starts initially is not clear, but it is considered to be a process of selection acting on genes that increase in frequency in the population through selective killing by the insecticide (Crow 1960). The speed of selection differs because it depends on many factors (Hamon and Pal 1968), but almost every laboratory selection experiment (Decker and Bruce 1952), or quantitative field test, shows that there is a period of several generations during which there is little apparent change in the susceptibility of the population. This is followed by a rapid change in resistance once enough insects have become resistant. If, for example, the presence of the resistance gene doubles the survival of its carrier, then it takes fifteen generations to change the proportion of resistance genes in the population from 1 in 10,000 to 1 in 30, but only seven more generations for every other individual to be resistant. Thus it takes twice as long to go from a frequency of 1 in 10,000 to 1 in 30 than from 1 in 30 to 1 in 2 (Crow 1960). This is why first reports of resistance are rapidly followed by a flood of complaints. Because it takes on average at least two growing seasons between the first confirmation of resistance and the introduction of alternative insecticides or methods of control, during which time considerable economic losses may occur, the detection of resistance should be as prompt as possible. This is seldom easy. For this reason monitoring should be done before resistance becomes obvious in the field, to detect its development as soon as possible, but this too is far from easy and raises the problem of when to start monitoring.

If we assume perfect independent random selection of each individual tested and a perfect testing technique, to find one resistant individual in 100 the sample number must be 300 and to detect one resistant individual in 1,000, 3,000 insects must be tested, and so on. This is assuming that each test individual is collected from a different site, the sites being selected at random, and evenly distributed over the region. Any departure from this will require an unpredictably greater number of test individuals. The rather small sample number could be encouraging but testing is never perfect. Suppose there is a small chance, say 1 in 300, of an individual being classified as resistant in error, then to find 1 resistant individual in 100, the minimum sample to establish resistance is 670, 1 in 1,000 is 29,000 and to detect 1 resistant individual in 10,000 the minimum sample is 3,000,000. The actual situation is likely to be rather worse than this because it is most probable that there is a small chance of error and this chance is not exactly known.

Also, when a chemical is used over a large region, resistance may, and often does, develop in a small part rather than gradually throughout the region. For effective monitoring each sub-region (small enough to be regarded homogeneous for practical purposes) should be sampled separately as above.

The detection of resistance before it becomes evident in the field, therefore, presents many problems. Moreover some resistant populations may remain sufficiently controllable to prevent serious economic difficulties. For this reason monitoring is more likely to be restricted to confirming suspected resistance, surveying areas where resistance is likely to occur, as it has been done up to now (Blair and Davidson 1966, Dunn 1963, Gostick and Baker 1968, Hamilton 1965, Harris, C.R. et al. 1966, Roussel 1960, Reynolds 1960), and determining the likely useful life of the insecticide, because there is no way of stopping resistance once it has appeared (Keiding 1963).

Considerable time and money could be saved if both manufacturers and prospective users had some idea of how rapidly resistance to a new pesticide may develop and what degree of resistance is likely to be reached. Jeppson (1960) suggested that the "screening program should include laboratory evaluation to ascertain the relative number of selections required to obtain evidence of resistance" and based his suggestion on the 4 to 5 years it takes in the USA to obtain information required to establish the usefulness of a potential acaricide. This is a very attractive idea and has been used successfully by Keiding in Denmark in very special circumstances, that is in testing new insecticides for control of houseflies on Danish farms and by Ziv, M. et al. (1969) against mosquitoes. But this type of investigation would have to be limited to a few of the more important pests that can be readily bred in the laboratory and would, if successful, give no more than an indication of a possible trend. With laboratory-bred populations whose genic pool is usually small, resistance may not develop, and a negative answer can only prove that the compound has failed to elicit resistance in the population tested.

Yet attempts to develop resistance artifically to candidate insecticides are well worth doing, if only to determine the possible cross-resistance patterns elicited by the candidate insecticides. This is of very considerable practical importance because cross-resistance patterns, especially with organophosphorus insecticides, are unpredictable (March 1960, Winteringham and Hewlett, 1964) and often an insecticide may act as selector for resistance to other insecticides without the opposite occurring. The use of insecticides in a predetermined rather than haphazard sequence should overcome this difficulty. It has been fortunate that DDT was used against houseflies before the organophosphate insecticides were introduced, because flies do not become resistant to organophosphate insecticides when they become resistant to DDT, but become resistant to DDT when they are resistant to organophosphate insecticides. The problem of cross-resistance in acarines, where acaricides act to various extents as selectors for most other compounds (Gasser 1965), is even greater and the establishment of cross-tolerance is almost as important as the detection of resistance and should be done simultaneously. Indeed Dittrich (1962) proposed the institution of mobile laboratories to test resistance and cross resistance *in situ* and determine the control measures for a given orchard or district.

This brief account shows how difficult early detection of resistance can be, but because the problem can only become greater as more insects become resistant to insecticides, at least some of the problems of monitoring for resistance outlined here need solving soon.

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References

ANON. (1963) World Health Organisation, Technical Report Series No. 265, Geneva.
ANON. (1967) Report of the First Session of the F.A.O. Working Party of Experts on Resistance of Pests to Pesticides, 4-9th October 1965 Food and Agriculture Organisation of the United Nations, Rome
ANON. (1968) Report of the Third Session of the F.A.O. Working Party of Experts on Resistance of Pests to Pesticides, 11-18th September 1967 Food and Agriculture Organisation of the United Nations, Rome
ANON. (1969) Report of the Fifth Session of the F.A.O. Working Party of Experts on Resistance of Pests to Pesticides, 19-26th August 1968 Food and Agriculture Organisation of the United Nations, Rome
BARNES, M.M., FLOCK, R.A. and GARNUM, R.D. (1954) J. econ. Ent. 47, 238
BLAIR, B.D. and DAVIDSON, R.H. (1966) J. econ. Ent. 59, 608
BLAIR, B.D., TRIPLEHORN, C.A. and WARE, G.W. (1963) J. econ. Ent. 56, 894
BROWN, A.W.A. (1958) Insecticide Resistance in Arthropods, World Health Organisation, Palais des Nations, Geneva
BROWN, A.W.A. (1960) Bull. ent. Soc. Am. 7, 6
BUSVINE, J.R. (1968) Wld Rev. Pest Control 7, 27
BUSVINE, J.R. (1951) Nature, Lond. 168, 193
BUSVINE, J.R. and HARRISON, C.M. (1953) Bull. ent. Res. 44, 729
MARCH, R.B. (1959) Misc. Publs ent. Soc. Am. 1, 13
CHAPMAN, R.K. (1960) Misc. Publs ent. Soc. Am. 2, 27
COAKER, T.H., MOWAT, D.J. and WHEATLEY, G.A. (1963) Nature, Lond. 300, 664
CROW, J.F. (1960) Misc. Publs ent. Soc. Am. 2, 69
DAVIDSON, G. (1960) Misc. Publs ent. Soc. Am. 1, 293
DECKER, G.C. and BRUCE, W.N. (1952) Amer. J. trop. Med. Hyg. 1, 395
DITTRICH, V. (1962) Anz. Schädlingsk. 35, 70
DUNN, J.A. (1963) Entomologia exp. appl. 6, 304
GASSER, R. (1965) Bull. Zool. agr. Bachic. s. II, 7, 1965, 245
GERARD, B.M. (1964) Ghana J. Sci. 4, 133
GLASS, E.H. (1960) Misc. Publs ent. Soc. Am. 2, 17
GOSTICK, K.G. and BAKER, P.M. (1966) Agriculture, Lond. 70
GOSTICK, K.G. and BAKER, P.M. (1968) Ann. appl. Biol. 61, 447
HAMILTON, E.W. (1965) J. econ. Ent. 58, 296
HAMON, J. and PAL. R. (1968) WHO/VBC/68.106
HARRIS, C.R., MANSON, G.F. and MAZUREK, J.H. (1962) J. econ. Ent. 55, 777
HARRIS, C.R., HITCHON, J.L. and MANSON, G.F. (1966) J. econ. Ent. 59, 1483
HOSKINS, W.H. (1967) Document Vector Control WHO/VBC/37/26
HOSKINS, W.H. and GORDON, H.T. (1956) A. Rev. Ent. 1, 89
KEIDING, J. (1963) Bull. Wld Hlth Org. 29, 51
MILANI, R. (1961) Misc. Publs ent. Soc. Am. 2, 75
MULLA, M.S. (1962) J. econ. Ent. 55, 30
NEEDHAM, P.H. and DUNNING, R.A. (1965) Proc. 3rd Br. Insectic. Fungic.Conf. 46
QUARTERMAN, K.D. (1960) Misc. Publs ent. Soc. Am. 2, 95
REYNOLDS, H.T. (1960) Misc. Publs ent. Soc. Am. 2, 103
ROUSSEL, J.S. (1960) Misc. Publs ent. Soc. Am. 2, 45
SMITH, F.F. (1960) Misc. Publs ent. Soc. Am. 2, 5
TELFORD, J.N. (1964) Proc. Conf. Mirids. Ibadan, 4
WINTERINGHAM, F.P.W. and HEWLETT, P.S. (1964) Chem. & Ind., 1512
ZIV, M., BROWN, N.J. and BROWN, A.W.A. (1969) WHO/VBC/69.148

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The Economic Importance of Fungal Diseases of Soft Fruits.

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Introduction

This paper focuses attention on the effect of fungal diseases on soft fruit production. Three main aspects are dealt with. Firstly a few statistics will be given regarding acreages in order to give perspective to the soft fruit industry in this country. Secondly a description will be given of the uses made of soft fruits and the methods available for prolonging the shelf life of the fruit. Finally some of the more important fungal diseases of soft fruits will be discussed.

Soft Fruit Acreages

The total soft fruit acreage recorded for England and Wales in 1967 was approximately 34,000 acres. When this acreage is compared with 58,000 acres of dessert apples, or 2¼ million acres of wheat or 5¼ million acres of Barley, it is quite apparent that from an acreage point of view soft fruits are relatively unimportant.

This limited acreage of soft fruit has obviously influenced fungicide manufacturers, who are not going to spend time developing fungicides which will only specifically control fungal diseases of soft fruit when the potential market is so small. This results in soft fruit growers having to make do with fungicides that have been developed for fungal diseases of more important crops. This of course could mean that the available fungicides may have to be used at more frequent intervals with possibly less effect than if the development of a specific fungicide had been justified.

Of the soft fruit acreage strawberries was the largest in England and Wales in 1967 occupying some 15,930 acres. Blackcurrant acreage in that year was 11,054, gooseberries 4,415 acres, raspberries 1,286 acres, blackberries 828 acres, red and white currants 719 acres and loganberries 435 acres. Over the last ten years the yields, returns and acreages of the soft fruit crops have varied considerably. The yields have been adversely affected by frost and disease. A low crop will often command a high price but is off-set by high picking costs. The aim should be to produce large crops of high quality fruit which have a guaranteed market.

Soft Fruit Uses

There is a changing pattern of uses of soft fruit. The jam industry was the main outlet at one time but the public is not consuming as much as it used to. The fresh fruit market is still important. The trend is for growers to supply direct to local shops and supermarkets to minimise high transport costs and to avoid fruit deteriorating by travelling long distances. The market for frozen fruit has shown considerable increase in recent years.

Tonnages of soft fruit canned has varied considerably from year to year. Canned blackcurrants a year or so ago nearly disappeared from the market as a result of short crop and high prices.

Juice and essence manufacturers are also large users of soft fruit. Today there is only a demand for good quality fruit. Competition from Eastern Bloc countries, who are prepared to supply good quality fruit below English prices, is a serious threat to English producers.

There are various techniques which have been successfully used for prolonging the life of soft fruit. A cheap method for the control of mould growth, which has been successfully used on raspberries and blackcurrants is to fumigate with sulphur dioxide. It can be applied as a gas from a cylinder of compressed liquified sulphur dioxide, or sodium metabisulphite may be used. When applied from a cylinder, a single twenty minute fumigation with an atmosphere containing 0.25% of the gas is enough to maintain fruit in good condition virtually free from mould growth for about four days. However, it is absolutely essential that only good fruit is treated, as it is not possible to produce good quality fruit from poor quality.

It should be noted that the European Commission of the Common Market Countries has already agreed to the ban of sulphur dioxide as a means of fruit preservation, and it is only a matter of time before this is implemented. Sulphur dioxide is not permitted as a preservative in the United States. However, sulphur dioxide is still used widely in this country as a preservative especially with pulped fruit, even though it is reported to destroy flavour.

A new technique which has been successfully used on Scottish raspberries for prolonging the life of the fruit, is to use liquid nitrogen. This will cost about 3d. per lb., but has the advantage that the fruit can be treated in the field with portable equipment, which is not expensive.

The modern trend for preserving soft fruit is to deep freeze. Every year more and more tonnage is being preserved by this method. The cost for freezing is expensive and ranges from £6. per ton, with charges increasing by about £3. per ton per month, whilst the fruit is in store. However, fruit can be stored for a very prolonged period in deep freeze without deterioration.

Another technique for the temporary storage of blackcurrants which has been used on a large scale to keep fruit up to one month is to place the fruit in gas stores with a high concentration of carbon dioxide. The normal technique is to use an initial concentration of 40% carbon dioxide and to reduce the temperature as fast as possible to 34 degrees F. It has been found that provided the temperature is kept low the carbon dioxide can be reduced to 20% after about 7 days, provided the fruit has been put in the stores in good dry condition. This atmosphere controls yeast growth and the spread of Botrytis.

In Holland strawberries have been irradiated to control mould growth. This technique has considerably prolonged the shelf life of the fruit and only costs a few pence per lb. However, this process is not likely to catch on rapidly as the cost of atomic plant is extremely expensive and at the present time this technique is not permitted in this country.

All these techniques have increased the manufacturers opportunity of processing the fruit over a much longer period, but obviously results in an increase in price of the raw material, which must be off-set by the price paid by the housewife for the finished product.

Some Diseases of Soft Fruit

I will now deal with some of the more important diseases of soft fruit, and by means of slides I will refresh your memory of the effects of these diseases. These slides have been kindly lent to me by the N.A.A.S. and are from the Plant Pathology National Slide Collection.

Strawberry Mildew (Sphaerotheca macularis) is the most common fungus disease affecting strawberries. This disease flourishes in hot weather and can be kept in check by routine applications of sulphur or lime sulphur, but as these chemicals are not permitted on fruit for canning, quick freezing or jam making, dinocap is a very good alternative, although it is more expensive.

Up until recently fruit rot caused by Botrytis was a major problem of strawberries. It thrived under moist conditions, but with the development of dichlofluanid this disease has been more readily controlled. However, it is necessary to apply several applications and this can be a costly operation, but, when one considers that the quantity and quality of the crop can be so adversely affected if not controlled, and, provided the grower has a guaranteed market ensuring a reasonable return, the cost of the sprays should be fully justified.

In recent trials encouraging results have also been obtained with benomyl, which is reported to have partial systemic properties. Captan or thiram may be used if the fruit is not for processing.

The fungus disease Red Core (Phytophthora fragariae) of strawberries is becoming a major problem. It usually occurs in patches in the field, frequently where drainage is poor. Affected plants become dwarfed and may wither and die, particularly in dry weather. If the roots of the plant are cut lengthwise a characteristic red dis-colouration of the central tissue may be seen. Even resistant varieties are becoming susceptible and it is quite apparent that further research work is required on the basic biology of this disease.

One of the most important diseases of blackcurrants is leaf spot (Pseudopeziza ribis) . In severe attacks premature defoliation of the bushes may occur before harvesting, which often results in fruit shrivelling and becoming unsaleable. Experiments have shown that this disease not only affects the crop in the year of attack, but also in the subsequent years as it reduces the vigour of the bush. The spores of leaf spot are produced on the under surface of the leaf, and therefore the fungicide must be applied so as to reach these lower surfaces unless it is systemic. Zinc preparations have proved cheap and effective. Copper based sprays are not permitted pre-harvesting by the largest processor of blackcurrants for juice manufacture, as it effects the vitamin 'C' content of the fruit.

It is interesting to note that growers have tried to reduce the number of applications of fungicides for leaf spot control, or have cut out spraying completely, and it can therefore be seen that this disease is now again on the increase.

Blackcurrants are sometimes attacked by the Honey Fungus (Armillaria mellea) especially where the bushes have been planted near old trees. A characteristic fan of cream coloured mycelium can be found on dead and dying bushes. Infected bushes should be dug up and the source of infection, usually on old tree roots, should be removed and burnt. In young plantations it is well worth while filling the gaps with new bushes.

With the introduction of destructive mechanical harvesting of blackcurrants, the incidence of powdery mildew (Sphaerotheca mors-uvae) has increased. It has been found that if not controlled the crop can be seriously effected in the following year. Dinocap, quinomethionate or drazoxolon will control this disease and may also be used where the fruit is intended for processing. Very encouraging results have also been obtained with benomyl and elanco EL 273.

Some growers are increasing bush populations to 20,000 bushes or more per acre with the object of increasing yield in the early life of the plantation. This makes spraying more difficult as a result of the dense foliation.

American Gooseberry Mildew (Sphaerotheca mors-uvae) which affects both leaves, stem and fruit of gooseberry, will retard the growth of the fruits if they are infected early in their development. The fruit will become enveloped in fungal mycelium and the large infections produce unsightly areas, which although only superficial, render the fruit unmarketable. Shoots will become stunted and deformed with consequent reduction in crop the following year.

Dinocap and dichofluanid are the recognised treatments. Sulphur can be used except on the varieties Careless, Leveller and Golden Drop. However, if the crop is intended for canning, fungicides containing sulphur should not be used, as residues on the fruit may cause corrosion and blowing of the can.

Cane Spot (Elsinoe veneta) is often serious on raspberries, loganberries and other hybrid berries, but less common on blackberries. In severe cases cane die-back may occur. The fungus can affect the berries causing severe distortion. If the fruit is to be used for processing, a proprietary copper fungicide instead of the normal thiram treatment should be applied pre-blossom.

Lime sulphur should not be used on Loganberries.

Horticultural techniques can also help to reduce fungal infection. For instance, by training young loganberry canes above the fruiting canes the chances of infection from fungal diseases is reduced. Hygiene in the plantations is also to be recommended.

Grey mould frequently causes severe loss of fruit of blackcurrants, loganberries and raspberries, but less frequently on blackberries. Grey masses of spores rapidly colonise ripening fruit in moist conditions. Most of the primary infection takes place during the flowering period and fungicides applied then will give the best control of the disease.

Taint

Manufacturers of fungicides are naturally keen to see a return on the vast sums of money spent on developing a new material, but it is absolutely essential to carry out tests carefully to ensure, not only that the fungicide is effective, but will not have side effects, such as damaging the crop, or imparting an off flavour or taint to the fruit. The damage that can be done by allowing a crop to become contaminated with an off flavour could be enormous. The reputation of a processor could be destroyed if products were found to be tainted.

Most processors operate a strict control on what chemicals they permit. The time intervals between last application and harvest and the number of applications and concentrations are very clearly stipulated.

Most manufacturers of fungicides co-operate very closely with processors to ensure the necessary tests are carried out. However, any experiments planned should ensure that the main commercial soft fruit varieties are included. This may appear obvious, but from experience it is often found that some hardly known variety is selected for test, which obviously will detract from the value of the experiment. Varieties certainly do vary in their tolerance to chemicals. This is especially marked with the French varieties of blackcurrants, which are known to be susceptible to damage from certain fungicides, such as quinomethionate.

Conclusion

All the facts are pointing to a crisis in the soft fruit industry. New and inproved fungicides have been produced; selective herbicides introduced; new machinery has been designed; use of irrigation for frost protection has been successfully demonstrated; increased bush populations are being used; which should all contribute to increased yields. It has already been stated that returns to growers fluctuate considerably from year to year. However, cultivation, picking, transport and marketing costs do not appear to fluctuate, they just increase rapidly. Pickers are becoming a "rare race". Spray programmes are becoming more complicated. The farmer needs to be a highly skilled chemist, mechanic, economist and optimist to survive.

The processor is faced with fantastic increases in production costs, which makes it all the more difficult to market the finished product. Competition from high quality foreign produce is always evident. It is therefore obvious that it is in the growers interest to obtain a guaranteed market for fruit before planting. It is then essential to produce the best quality fruit possible and the judicious use of fungicides will help to achieve this. It must be stressed that these fungicides must be marketed at realistic prices.

The crisis in the soft fruit industry can be avoided if production is limited so that the supply does not exceed demand by obtaining guaranteed markets.

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References

M.A.F.F.	Estimates of Area and Gross Production of Fruit in United Kingdom 1967.
M.A.F.F.	Bulletin 156 Cane Fruits Bulletin 95 Strawberries Bulletin 4 Blackcurrants
N.A.A.S.	Plant Pathology National Slide Collection
Scottish Hort. Res. Inst.	Jarvis, W.R., Soft Fruit Preservation private communication.

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INTEGRATED CONTROL OF THE POTATO CYST NEMATODE

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For many years the potato cyst-nematode, Heterodera rostochiensis Woll. has been controlled by suitable crop rotation, sometimes combined with soil sampling to ensure that numbers are not damaging when potatoes are planted. Now, however, the situation is changing because commercially acceptable potato varieties resistant to the nematode have been bred. These are effective against H. rostochiensis sensu stricto (previously called Pathotype A and known as the golden nematode in the U.S.A.). The females of this species soon turn golden yellow and remain so until the female dies and its cuticle tans dark brown (Guile, 1967). The current resistant varieties are ineffective against the related species or sub-species of round-cyst nematode called Pathotypes B and E, which may eventually be redescribed under a name or names other than H. rostochiensis (Parrott, 1968). Attempts to breed varieties resistant to all the round-cyst nematodes that attack potatoes in the U.K. are continuing and, meanwhile, renewed efforts are being made to find ways of controlling them with nematicides and of integrating crop rotation, resistant varieties and nematicides.

Because so much emphasis was placed on crop rotation for so long, little was known about the effects on yield and nematode numbers when susceptible potato are grown continuously. Information on these effects and on the effects of growing resistant varieties continuously was also needed to compare with the effects of rotations. It was also necessary to grow potatoes continuously because experiments that include rotation take so many years to complete. Moreover, in the U.K. advisers already have much information on population decreases and yield improvements after rotations of different lengths.

When resistant potatoes are grown frequently, there is evidence that either genotypes within a population are selected that can circumvent resistance or related round-cyst nematodes, the so-called pathotypes, are increased and resistance lost (e.g. Cole & Howard, 1962). Theoretical studies also suggested that long rotations, frequent planting of resistant varieties, using nematicides or doing anything that diminished pre-planting numbers would favour genetic change within a population or colonisation by a foreign one (Jones, Parrott, and Ross, 1967).

Growing resistant and susceptible varieties continuously

The results of an experiment in microplots started at Woburn Experimental Farm Bedfordshire in 1960, in which seven susceptible potato varieties were grown continuously for 6 years, showed that nematode populations oscillated about an equilibrium and that the oscillations tended to decrease with time (Jones & Parrott, 1969). Randomised within the same experiment were some plots in which the susceptible variety Majestic and a resistant variety NY24/7, bred from Solanum tuberosum ssp. andigena by Dr. H. W. Howard, were grown continuously and others in which the resistant and susceptible varieties were grown alternately or in a rotation of one susceptible to two resistant (Jones, Parrott & Williams, 1967).

Yields and population trends are in Fig. 1 and Table 1.

Over the 10 years studied, the yield trends of the susceptible variety bore little relationship to the population trends. This is not surprising because numbers are related to and influence root size during May and early June, whereas yield of tubers is determined not only by the size of the root system but also by climatic and other factors during June, July and August. Except in 1960, when the experiment began and in 1967 when some influence, possibly the exceptionally wet May, depressed multiplication of the nematode, numbers oscillated narrowly about an equilibrium level of about 85 eggs/g soil. The decrease in 1967 seems to have started another series of oscillations, which may be similar to those when the experiment began. In the plots where the resistant variety grew continuously, numbers decreased slowly, the average being about 15% per annum, less than expected perhaps partly because the soil contains much clay (39%) and partly because the nematode reproduces slightly on the resistant variety (Fig. 2).

Yields of resistant and susceptible varieties were greatly influenced by season. 1961 and 1968 were unfavourable, 1960, 1965, 1967 and 1969 favourable and the rest intermediate. Yields of the susceptible variety never again reached that of the first year, 1960, although the trend was upwards after 1961. As the nematode population decreased, the yield of the resistant variety trended upwards and in three years (1965, 1967 and 1969) greatly exceeded that of the first year.

Table 1 gives the total tuber production for the 10 years from 1960 to 1969.

Table 1

Total tuber production per plot over 10 years in an experiment in microplots at Woburn Experimental Farm.

lbs/plot

Sequences

Yield of:	Continuous (one phase each)	Alternating (two phases)	Two resistant one susceptible (three phases)
Susceptible	174.9	283.9	330.3
Resistant	334.6	234.5	213.4
Resistant	-	-	271.4
Mean	-	259.2	271.7

The best total yield (more than 330 lbs/plot) was obtained from growing the resistant variety continuously. Production from the susceptible variety was nearly as good when grown in rotations with two resistant ones. Evidently two crops of the resistant varieties were equivalent to resting the land from potatoes for about 5 years (see Table 3). Growing resistant and susceptible varieties alternately in a three or four course rotation with other crops would probably also have given near maximum tuber production but would have lengthened the experiment to 30 or 40 years.

Integration of a resistant variety with a nematicide

A second experiment with large plots was begun at Woburn in 1966 to see how irrigation, fumigation and growing a nematode-resistant variety affected the yield

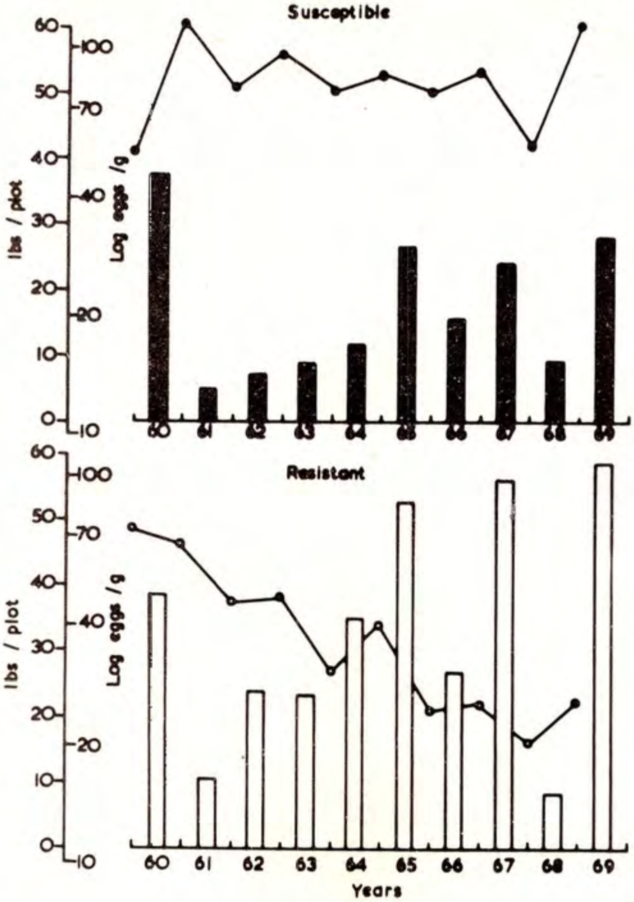

Fig. 1. Yield and population trends in microplots at Woburn Experimental Farm when eelworm resistant or susceptible potato varieties were grown continuously. Susceptible variety, Majestic in all years. Resistant variety, NY24/7 in all years except the last when Maris Piper was grown. In 1968, seed stocks became virus infected in store.

Table 2. Yield of tubers and changes in nematode numbers in the experiment on large plots at Woburn, Beds.

	Previously potatoes every 3 years				No potatoes for 15 years previously			
	Pentland Dell Susceptible		Maris Piper Resistant		Pentland Dell Susceptible		Maris Piper Resistant	
	Unfumigated	Fumigated	Unfumigated	Fumigated	Unfumigated	Fumigated	Unfumigated	Fumigated
				Ware tubers, tons/acre				
	-	DD	-	DD	-	DD	-	DD
1966	5.8	12.3	10.6	14.6	13.1	15.5	16.4	18.3
1967 Same	0.6	3.6	4.5	11.3	5.0	11.5	10.0	12.7
•Alternating	3.2	8.6	4.5	12.3	9.7	14.9	8.2	12.5
1968 Same	1.6	6.6	11.6	13.9	1.2	5.2	14.1	15.9
•Alternating	3.6	11.4	9.7	13.6	9.9	13.3	12.8	14.3
	-	Dazomet	-	Dazomet	-	Dazomet	-	Dazomet
1969 Same	1.2	13.2	11.0	16.9	1.3	13.3	11.0	16.9
•Alternating	3.0	14.7	6.7	18.4	6.6	16.2	7.5	18.1
				Nematode eggs/g soil after harvest				
	-	DD		DD	-	DD	-	DD
1965	10	8	7	6	2	1	1	2
1966	83	136	12	12	38	19	4	4
1967 Same	50	109	4	4	38	48	3	1
•Alternating	27	29	48	29	6	10	4	3
1968 Same	68	149	5	4	90	177	5	6
•Alternating	94	96	38	41	78	46	20	21

•i.e. Susceptible preceded by resistant and vice versa of ware tubers and the numbers of H. rostochiensis in the soil. One half of the experiment, now in its fourth year, was on land that had grown only lucerne and grass since the last potato crop 15 years previously. On average these plots contained fewer than 1 egg/g soil and on some the infestation was patchy. The other half was on land that previously grew potatoes every 3 years, usually early varieties. Plots on this half had infestations ranging from 1 to 42 eggs/g soil and averaged 7.5. Results are in Table 2. The effects of irrigation were slight and are omitted.

Initially in 1966 the susceptible variety yielded more than twice as much on the site without potatoes for 15 years as on the site that previously grew potatoes every 3 years; 13.1 compared with 5.8 tons/acre. Subsequently, its yield decreased on both sites and was sometimes less than 1½ ton/acre. The resistant variety yielded more on both sites and its yield fluctuated with the season. Injecting 400 lb DD/acre in autumn, increased the yield of the resistant variety only slightly on the lightly infested site but appreciably on the heavily infested site. Except in the first year on the lightly infested site, fumigation also increased the yield of the susceptible variety appreciably on both sites. Large yield increases from fumigation with DD were obtained only where nematodes were very numerous before planting. The average increase from DD was 4.3 tons/acre. Other pathogens and the small amounts of nitrogen released by DD had only small effects on yield. Dazomet killed more nematodes than DD and large yield increases averaging 10 tons/acre followed its use before the 1969 crop, far too large to be from the nitrogen in its molecule or from the small amount of nitrogen mineralised after three previous fumigations with DD.

A previous crop of resistant potatoes increased the yield of the susceptible variety on average by 4.9 tons/acre, rather more than the average increase from fumigation with DD, and both together increased yield by 9.9 tons/acre. A previous crop of susceptible potatoes decreased the yield of the resistant variety on average by less than a ton an acre.

Multiplication, kill and control

Fig. 2 shows the relationship between nematode numbers before and after growing the susceptible and the resistant potato variety in the second experiment with large plots. The points plotted were obtained by grouping results and the curves are similar to ones discussed by Seinhorst (1968). To show multiplication rates, the scales are logarithmic. Population changes of cyst-nematodes are complicated because part of the population does not hatch when potatoes are grown but persists to the next year. The fraction thus carried over seems characteristic of the field and varies little with population density or season (Jones, 1966). On average (derived from 389 fields) a third of the eggs hatch when land is fallowed or grows other crops and two thirds when susceptible or resistant potatoes are grown. Presumably the additional third is stimulated to hatch by the hatching factor given out by potato roots, and cysts containing the remaining third are not reached by roots or are occluded in soil aggregates.

In the first experiment, in microplots where the soil contained 39% of clay, at least four fifths (0.40) of the population persisted to the next year (Fig. 1), whereas in the second experiment in large plots where the soil contained only 7 to 10% of clay, only about one fifth (Fig. 3, 0.20) of the population persisted.

Under the susceptible variety, Pentland Dell, the maximum multiplication rate (more than 50 times) was when nematodes were fewest at planting time. As populations at planting increased, the multiplication rate decreased, was unity at the equilibrium density (about 50 eggs/g soil) and less than unity thereafter, and became assymptotic to the fraction persisting (the X 0.20 line) from 200 eggs/g/soil onwards. The multiplication rate decreases as preplanting numbers increase because

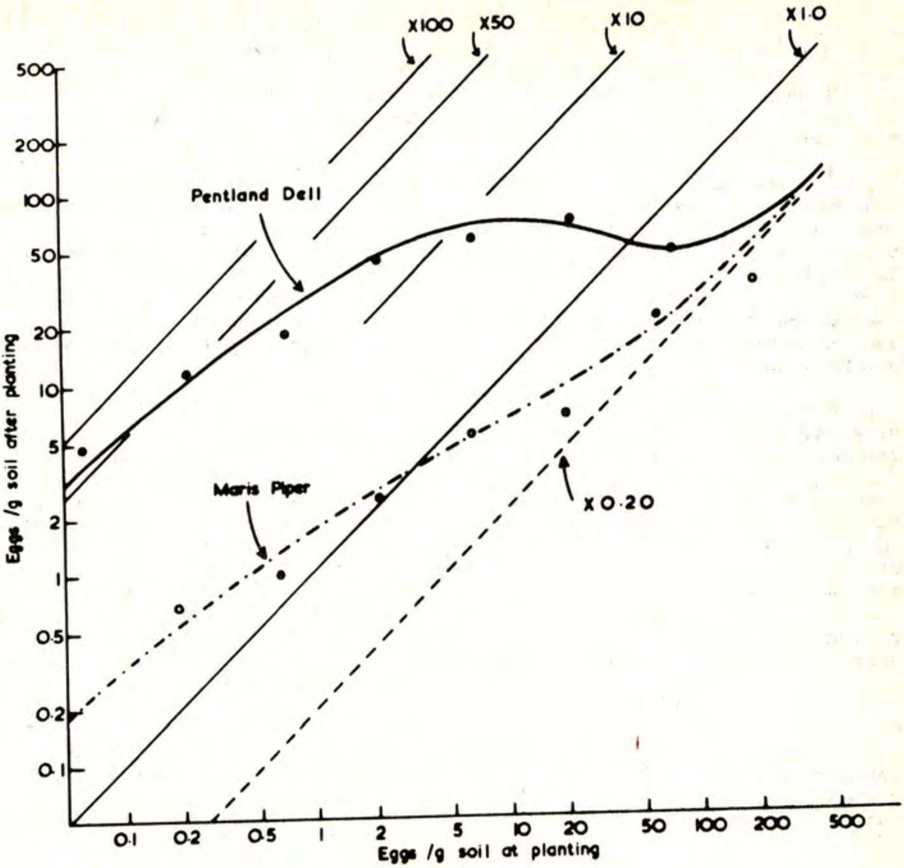

Fig. 2. Curves relating eelworm numbers before planting to those after harvest. Pentland Dell, eelworm susceptible; Maris Piper, eelworm resistant. The X1 line indicates no change in numbers between planting and harvest X10, etc, indicates multiplication and X0.20 a decrease of 80%. Curves derived from the experiment in large plots at Woburn Experimental Farm.

larvae compete for space and food in the potato rootlets but, near the curve's peak and afterwards, the decrease quickens as invading larvae stunt root growth and diminish their supply of space and food. When susceptible varieties are grown continuously, the oscillations in population density and their tendency towards an equilibrium arise from the shape of the multiplication curve and would be greater if they were not damped by that part of the population persisting to the next year.

Very few larvae that enter roots of the resistant variety, Maris Piper, become females; most become males. When numbers at planting are great, they decrease to about two fifths after harvest, but when they are small, initially they increase slightly (Fig. 3). Assuming that this increase is real and does not arise from the lack of precision in estimating small populations, the resistant variety behaves as a poor host rather than as a non-host. It seems to decrease large populations by 80% (X 0.20 times), maintain populations of a few eggs/g of soil, and increase smaller populations by two to three times, so its effect varies with the number of nematodes in the soil at planting.

Percentage kill with a nematicide (Fig. 3) can be related to the rate at which survivors must multiply to restore the original population (Jones, 1969). For example, starting with 100 nematodes, an 80% kill leaves 20 survivors, which must multiply five times to replace the original 100. The decrease by growing other crops or a resistant variety can also be regarded as a "kill" and related to the balancing multiplication rate required to reinstate the population. Fig. 3 shows that, for populations of potato cyst nematodes that can multiply at a maximum rate of about fifty times, killing fewer than 98% leaves enough survivors to reinstate the population. Moreover, in heavily or moderately infested sites, "kills" of 70-80% merely remove larvae surplus to the carrying capacity of potato roots, prevent root stunting and so produce populations at harvest exceeding the average for susceptible potatoes grown continuously (Table 2). "Kills" of this order, however, obtained, often increase yields of the first potato crop grown but leave very large populations that are difficult to deal with.

Using the average rate at which populations decrease when crops other than potatoes are grown (1/3 per annum), Table 3 gives the percentage surviving, the average yield loss and the equivalent kill. A 70% kill from DD is equivalent to a three-year rest and a single crop of a resistant variety, on land with 10-200

Table 3

Crop rotation, survival, yield loss and equivalent kill

Years from potatoes	Remaining population	†Yield loss/ acre approx.	Equivalent kill
1	67%	11 1/4 tons	
2	44%	8 3/4 tons	
3	30%	6 1/4 tons	70% DD, 400 galls/acre
4	20%	3 3/4 tons	80% Resistant variety
5	13%	1/4 ton	
6	9%	Loss negligible	
7	6%		94% Dazomet, 150 lbs/acre
8	4%		96%
11	1%		99%
17	0.1%		99.9%

†Partly after Empson and James (1966).

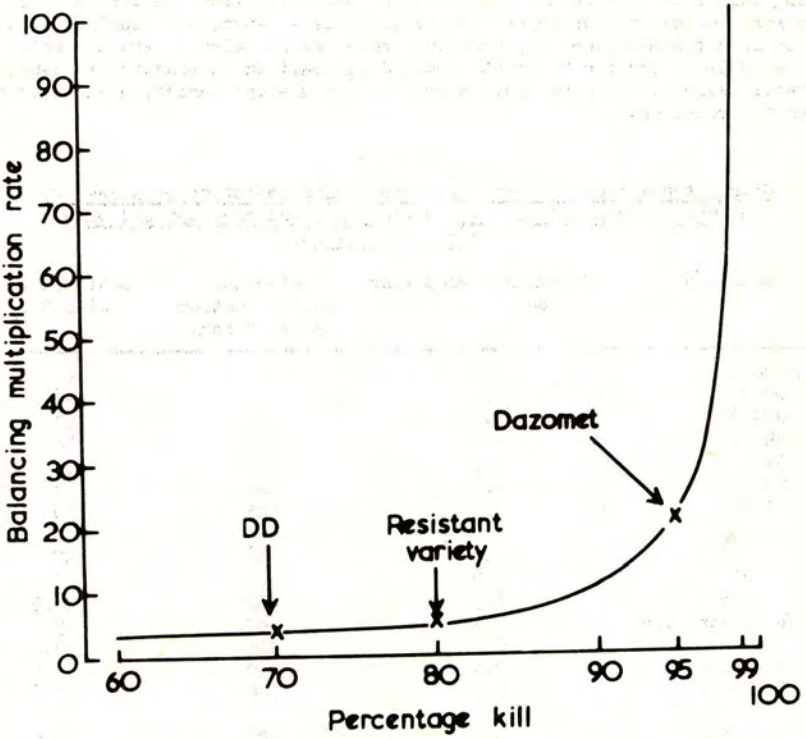

Fig. 3. The relationship between percentage kill after a nematicide or the decrease after a resistant variety or a rotation, and the balancing reproductive rate required to reinstate the population, i.e. to make numbers after harvest equal to those initially, before the treatment was applied. It is assumed that a resistant variety decreases numbers by 80% but the decrease is less or may even become an increase when the population is sparse (see text).

eggs/g soil, to a four-year rest, whereas a rest of five or more years is needed to make yield loss acceptable or negligible.

The effects of trying to integrate control by combining crop rotation, a resistant variety and a nematicide can be calculated by multiplying together the fractions (or the percentages) of the population that survive and considering the balancing multiplication rate in the light of the multiplication curves in Fig. 3. Calculations for seven crop rotations are in Table 4, where the benefits of applying an efficient nematicide only once in a rotation are clear. Whether kills exceeding 99.9% at the end of rotation would be realised in practice is debatable for several reasons. To give maximum benefit a resistant variety would have to come early in the rotation.

Table 4

Calculated effects of rotations containing resistant potatoes (R) and other crops (O) with and without a nematicide applied once during the rotation

Rotation	Percentage surviving at end of rotation	Balancing multiplication rate approx.	Equivalent kill %
ORO	8.8	11	91
OOROO	3.9	26	96
OOOROO	1.8	56	98
RR	4.0	25	96
ORR	2.7	37	97
OORRO	1.2	83	98
OOOROO	0.8	125	99.2
As above	2.6	38	97
but	1.2	83	99
with	0.5	200	99.5
400 lb DD/acre once	1.2	83	99
in	0.8	125	99.2
rotation	0.4	250	99.6
70% kill	0.2	500	99.8
As above	0.4	227	99.6
but	0.2	513	99.8
with	0.1	1,111	99.9
150 lb/acre	0.2	500	99.8
Dazomet	0.14	741	99.9
once			
in rotation	0.06	1,667	99.9
95% kill	0.04	2,500	99.9

It is assumed that a nematicide is equally as efficient at any point in the rotation whereas in practice kill is influenced by the time of year when it is done and the state of the soil following the previous crop. It is also assumed that ground keepers are eliminated by cultivations or by the nematicide and that kill below plough level is the same as above which is unlikely, especially with Dazomet which is rotavated into the surface. Nevertheless calculations of a theoretical kind are valuable because they clarify thinking, improve understanding and show where essential information is inadequate or lacking.

A computer programme could be written to print tables of survival, balancing multiplication rate and equivalent kill appropriate to different kills from the nematicide and different rates of decrease when other crops are grown. Using a relationship like that in Fig. 3, the effect of a resistant variety could also be varied according to its position in the rotation i.e. according to the pre-planting population density. It would also be possible to print the population increase expected when a susceptible variety was grown again. This could be done using the relationship plotted for Pentland Dell in Fig. 2 and it would be convenient if population density were expressed in terms of the equilibrium density or the peak density. This procedure would eliminate the units in which nematode numbers are measured (larvae/g root, hatchable eggs/g soil, eggs/g soil, or "full" cysts/g soil). Such tables would be useful as guide-lines for advisers but unsuitable for most farmers. Advisers in the U.K. already have notions of rates of population decrease under crops other than potatoes and of peak numbers for particular susceptible varieties, soil types and regions.

About 80% of fields in the Eastern Region, many in Scotland but fewer elsewhere, contain mainly the so-called pathotype A of H. rostochiensis and are therefore suitable for planting with the current resistant varieties. The crop rotations suitable for such fields are sequences of crops such as those in Table 4 preceding a susceptible variety. Where land is moderately or heavily infested, it would benefit from fumigation once in the crop sequence preferably with Dazomet or some equally efficient nematicide. On light sandy soils at current prices applying 150 lb/acre costs about £50 an acre equivalent to an extra 2½ tons of potatoes at current prices but the less effective treatment with 400 lb DD/acre costs nearly £40 an acre equivalent to 2 tons and requires specialised injection machinery. On heavy soils or those with much peat DD is not very effective and more Dazomet is needed (300 lb/acre) to give as good a kill. In peat soils its break-down products sometimes persist long enough to damage the growing of potato plants and large or repeated applications of DD sometimes taint the tubers.

The population dynamics of H. rostochiensis have been more thoroughly studied than those of any other plant nematode. The principles here discussed apply equally to other species but for most of them essential information is lacking. We do not know what fraction if any of the population persists from year to year and although the multiplication curves relating their initial to final numbers when a susceptible crop is grown may be generally similar to those of H. rostochiensis and other cyst nematodes, they differ in details, especially in the maximum multiplication rate, which is so important in relation kill by nematicides.

Integrated control usually includes competitors and enemies. There is no evidence that effective enemies of the potato cyst nematodes exist in the U.K. Population decline seems independent of population density whereas it would probably be faster when populations are dense if there were effective egg parasites or predators. Predaceous fungi seem quite unable to limit migration of larvae to root systems and the multiplication curves (Fig. 2) suggest that numbers are limited only by the space and food supplied by the roots. Nematicides are required that operate in a different way from the fumigants now available. These kill eggs or larvae, the residues of previous susceptible crops, whereas therapeutic chemicals are needed to prevent the stages in the roots from developing and the females from producing eggs. Perhaps also enemies should be sought from the Andes plateau of South America where round-cyst nematodes and potatoes seem to have originated. Other harmful nematodes may have important enemies or competitors (e.g. H. avenae; Williams, 1969) that must be considered in integrating nematicides with other control measures.

References

COLE, C. S. and HOWARD, H. W. (1962) Nematologica. 7, 57.

EMPSON, D. W. and JAMES, P. J. (1966) N.A.A.S. Quarterly Review No. 73, 22.

GUILE, C. T. (1967) Ann. appl. Biol. 60, 411.

JONES, F. G. W. (1966) Rep. Rothamsted Exp. Stn. for 1965.

JONES, F. G. W. (1969) In: Nematodes of tropical crops. Ed. J. E. Peachey. Tech. Commonw. Bur. Helminth. No. 40 (in the press).

JONES, F. G. W. and PARROTT, D. M. (1969) Ann. appl. Biol. 63, 175.

JONES, F. G. W., PARROTT, D. M. and ROSS, G. J. S. (1967) Ann. appl. Biol. 60, 151.

JONES, F. G. W., PARROTT, D. M. and WILLIAMS, T. D. (1967) Nematologica 13, 301.

PARROTT, D. M. (1968) Nematology Department. Rep. Rothamsted exp. Stn. for 1967, 147.

SEINHORST, J. W. (1968) Nematologica 13, 481.

WILLIAMS, T. D. (1969) Ann. appl. Biol. 64, 325.

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INSECTICIDE USAGE ON VEGETABLE CROPS

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Summary The results of a survey of the extent of use of insecticides applied to vegetable crops grown for human consumption in 1966 are presented. Some 300 holdings were visited over five counties: Bedfordshire, Lancashire, Lincoln (Holland), Norfolk and Worcestershire. Details of crops grown are given, with usage of insecticides, method of application and reasons for use. Emphasis is given to the use of organophosphorus insecticides as alternatives to the persistant organochlorine group.

INTRODUCTION

In 1966, the Plant Pathology Laboratory of the Ministry of Agriculture, Fisheries and Food started a series of surveys on the usage of pesticides on crops grown for human consumption. The surveys were made in the autumn or winter following the season in which the crops were harvested and have covered the usage on vegetables, orchard and small fruit and in glasshouses. The first survey was on vegetables and was made in the autumn of 1966, covering the crops grown for harvest in 1966. The information was obtained from the growers by personal visits and about 60 holdings were visited in each of the five counties: Bedfordshire, Lancashire, Lincoln (Holland), Norfolk, Worcestershire. These counties were chosen as being representative of the more important areas of vegetable production and holdings were selected from each county to give a range of sizes of vegetable enterprises.

The diversity of cropping varied somewhat in each county, the average number of crops being:

Worcestershire	8.6	crops per holding
Bedfordshire	7.6	" " "
Lincs. (Holland)	6.5	" " "
Lancashire	5.4	" " "
Norfolk	2.4	" " "

The cropping varied from smaller areas of most vegetables being grown in Worcestershire and Bedfordshire to the specialised, large-scale cropping of peas, beans and carrots in Norfolk.

During the visit to each grower, questions were asked on each vegetable crop grown including the varieties, soil type, planting and harvesting dates. Information obtained on usage of pesticides covered insecticides, fungicides and herbicides including methods of application, area treated, reasons for application, frequency of application and success of the treatment.

The results of this and the other surveys will be published by the M.A.F.F. in the form of reports covering all the data obtained during the survey, but this paper will confine itself to the use of insecticides on vegetable crops. The crops will be dealt with in their natural groups.

Brassicae and root cruciferae

Apart from the root cruciferae (turnips, swedes and radishes) these crops were well represented in the survey. Table 1 shows the numbers of crops surveyed, their acreage raised to be representative of the county in which they were grown and the percentage the crops in these sample counties represent of the acreage of vegetables in England and Wales in 1966.

Table 1

Acreages of brassicae etc.

Crop	Crops surveyed No.	Crops surveyed raised acreage	Proportion of national acreage %
Cabbage - spring	99	7,421	29
- summer	100	3,521	40
- others	182	10,519	42
Brussels sprouts	165	25,878	71
Cauliflower/broccoli	246	18,620	45
Roots	39	1,623	17

The cabbage crops were grown fairly evenly through the five counties; "other cabbages" included autumn/winter cabbages, savoys and kale. Bedfordshire grew about half of the sprouts with Worcestershire growing a further quarter. The bulk of the cauliflowers and broccoli were grown in Holland (Lincs.). Insecticides were used only infrequently on root cruciferae.

The use of insecticides on these crops is given in Table 2, and the reasons for their use given in Table 3.

Table 2

Percentage of acreage of brassica crops treated

Crop	demeton-S-methyl	other O.P.'s	aldrin, dieldrin ± fungicides	BHC ± fungicides	DDT ± fungicides
Cabbage - spring	13	10	(4)	36	(3)
- summer	30	12	35	25	(13)
- others	42	30	24	24	10
Brussels sprouts	48	79	46	8	18
Cauliflower/broccoli	36	14	51	5	14

Note

Figures with () come from data with less than 30 counts

Table 3

Reasons for use of insecticides on brassicae

Percentage of acreage treated

Crop	aphids ± other pests	cabbage root fly ± other pests	caterpillars	flea beetles ± other pests	damping off ± pests
Cabbage - spring	23	5	3	20	13
- summer	37	45	11	11	12
- others	70	25	8	22	4
Brussels sprouts	106	71	18	5	3
Cauliflower/broccoli	48	54	13	3	3

Aphids were the principal pests of all these crops, especially on the autumn/winter cabbages and on Brussels sprouts. The latter received more than one insecticide to control aphids. Demeton-S-methyl was the most used aphicide, but about 25 per cent of the sprouts and autumn/winter cabbages were sprayed with other organo-phosphorus insecticides, mostly dimethoate. Granular aphicides were only important on sprouts: disulfoton or phorate were applied to 38 per cent of the acreage. Aphicides were sprayed on average of 1.4 times to the late brassicae and were frequently followed by a second application of a different insecticide. The granular formulations were generally only applied once.

Insecticides were used extensively to control cabbage root fly, principally on the transplanted brassicae, i.e. on all except spring cabbages which were normally drilled, and about 10 per cent of the sprouts which were sown directly into the field. Cabbage root fly was controlled by the use of aldrin and dieldrin dips or drenches except on sprouts, where 20 per cent of the crop received diazinon or chlorfenvinphos granules. About 95 per cent of the use of aldrin and dieldrin to control cabbage root fly was in the form of dips at transplanting, the rest was applied as a drench: in each case, only one application was made.

Flea beetles and damping off were controlled by seed dressings, mostly BHC with thiram or captan. In the case of transplanted crops, the area of seedbed was not always known so it was assumed to be 1/20th of the field area. In these crops, the area planted with dressed seed refers to the seedbed area rather than the area in the field. The proportion of crops which had been treated against flea beetles/damping off was:

spring cabbage	61%
summer cabbage	33%
other cabbage	43%
Brussels sprouts	45%
cauliflower/broccoli	31%

Peas and Beans

Only dwarf (French) beans and peas for harvesting dry were not well represented numerically in this survey but as they were generally grown in fairly large fields, they represented a reasonable proportion of this acreage grown (Table 4).

Table 4

Acreages of peas and beans

Crop	Crops surveyed No.	 raised acreage	Proportion of national acreage %
Beans - dwarf	32	5,737	60
- runner	106	3,190	37
- broad	58	4,123	53
Peas - fresh	103	31,340	32
- dry	29	12,311	35

Most of the dwarf beans were grown in Norfolk: runner beans, either grown on sticks or as bushes were grown in Bedfordshire, Norfolk and Worcestershire, while broad beans were grown in all counties, but mostly in Norfolk. Fresh peas included peas for marketing fresh as well as peas for dehydrating, canning or freezing, 66 per cent of which were grown in Norfolk and 22 per cent in Holland (Lincs.); virtually all of the peas for harvesting dry were grown in Holland (Lincs.).

Table 5

Percentage of acreage of peas and beans treated

Crop	O/P insecticides	Other insecticides ± fungicides
Beans - dwarf	(22)	(44)
- runner	26	(21)
- broad	67	(22)
Peas - fresh	35	12
- dry	(6)	(44)

The usage of insecticides on peas and beans is given in Table 5. All types of peas and beans were treated to some extent with organophosphorus insecticides against aphids, demeton-S-methyl accounting for all the use except on runner beans and fresh peas where half of the applications were other organophosphorus insecticides, principally dimethoate. Dimethoate was used on average 1.3 times on broad beans to control aphids, especially black fly. Treatment against pea moth was not extensive although DDT sprays were used in each case: only one crop was treated against pea midge, jointly with pea moth. Other pea and bean pests included bean seed fly in which case the seeds were dressed with aldrin or dieldrin plus a fungicide to control damping off.

Table 6

Reasons for use of insecticides on peas and beans

Percentage of acreage planted

Crop	aphids ± other pests	pea moth ± pea midge	other insects	damping off ± pests
Beans - dwarf	22	0	13	31
- runner	26	0	2	19
- broad	68	0	15	7
Peas - fresh	35	9	3	0
- dry	6	38	6	0

Onions and root vegetables

Onions and leeks were well represented while about one third of the national acreage of carrots, parsnips and beetroot were represented in the survey (Table 7).

Table 7

Acreage of onions and root vegetables

Crop	Crops surveyed No.	Crops surveyed raised acreage	Proportion of national acreage %
Onions - dry	36	2,969	61
- salad	65	2,165	65
Leeks	33	944	45
Carrots	48	9,304	35
Parsnips	34	1,524	33
Beetroot	67	2,152	32

Most of the onions for harvesting dry were grown in Holland (Lincs.) while 60 per cent of the onions for salad were grown in Worcestershire with a further 25 per cent in Bedfordshire. 60 per cent of the leeks were also grown in Worcestershire with a further 35 per cent divided between Norfolk and Bedfordshire. Maincrop carrots were confined largely to Norfolk (70 per cent) and Lancashire (25 per cent). Lancashire grew very few parsnips while half of the beetroot were grown in Bedfordshire.

The usage of insecticides on these crops is given in Table 8 and the reasons for their use given in Table 9. Aphids were important pests on carrots and parsnips, much less so on beetroot while treatment against them on the onion crops was rare. Organophosphorus insecticide sprays were used to control aphids, with demeton-S-methyl accounting for 90 per cent of the usage in single applications.

Table 8

Percentage of acreage of onions and roots treated

Crop	O/P insecticides	O/C insecticides
Onions - dry	(3)	(5)
- salad	(1)	20
Leeks	(3)	0
Carrots	102	81
Parsnips	94	16
Beetroot	23	0

Table 9

Reasons for use of insecticides on onions and roots
Percentage of acreage planted

Crop	aphids ± other pests	carrot fly ± other pests	onion fly
Onions - dry	3	0	5
- salad	0	0	23
Leeks	2	0	1
Carrots	63	113	0
Parsnips	56	54	0
Beetroot	19	0	0

Carrots, and to a lesser extent, parsnips were treated extensively against carrot fly. About 40 per cent of the two crops were treated once with granular formulations of disulfoton or phorate. Organochlorine insecticides were also used on carrots and parsnips to control carrot fly as 25 per cent of the carrots received aldrin or dieldrin, 15 per cent received BHC and 40 per cent received DDT with a further 13 per cent of the parsnips treated with DDT; an average of 2-3 applications of DDT were usually made to both carrots and parsnips. Onion fly was the most serious pest of onions being controlled by aldrin or dieldrin seed dressings. Some 4 per cent of the beetroot acreage was sprayed with organophosphorus insecticides to control various pests such as leaf miners, mangold fly and flea beetles.

Other vegetable crops

Of the other vegetables which were detected in the survey, only lettuce grown in the open were well represented. The national acreage of marrows was not available and first-early potatoes represented only 16 per cent of the national acreage. The tomatoes were always grown under glass and the other vegetables included rhubarb, celery and asparagus with spinach, cucumber, parsley, thyme and sage also recorded (Table 10).

Table 10

Acreages of other vegetables

Crop	Crops surveyed No.	 raised acreage	Proportion of national acreage %
Lettuce	96	6,660	40
Marrow	32	343	
Potatoes (first early)	84	11,330	16
Tomato (glass)	32	662	33
Others	72	4,035	31

Lettuces were widely grown in all counties except Holland (Lincs.), vegetable marrows were almost exclusive to Bedfordshire and first early potatoes were well represented in all counties except Worcestershire. Tomatoes and other vegetables were evenly distributed.

The usage of insecticides on these crops is given in Table 11 and the reasons for use given in Table 12.

Table 11

Percentage of acreage of other vegetables treated

Crop	O/P insecticides	O/C insecticides
Lettuce	50	(8)
Marrow	(18)	0
Potatoes (first early)	13	(3)
Tomatoes (glass)	(7)	(20)
Others	52	(33)

Aphids were the most important pests on lettuce: the relative importance of root aphids was not recorded. Organophosphorus insecticides were used to control lettuce aphids and on average were applied 1.3 times with demeton-S-methyl accounting for about half of the usage. Of the other vegetables, the most important pest was carrot fly on celery, about 50 per cent of which received organophosphorus insecticide for control.

Table 12

Reasons for use of insecticides on other vegetables
Percentage of acreage planted

Crop	aphids + other pests	other pests
Lettuce	53	(7)
Marrow	(18)	0
Potatoes (first early)	14	(3)
Tomatoes	(5)	(37)
Others	22	64

DISCUSSION

Although the original questionnaire asked for details of rates of application of pesticides, these were generally not forthcoming or the grower stated that they were applied at the "recommended rate". The most recent estimate of rates of usage are given by Strickland (1966). Strickland also gives the acreages of vegetables which were treated with insecticides in 1960-64, but as the data are not separated into specific vegetable crops, they are not strictly comparable.

A repeat survey is being made on vegetables during the autumn of 1969 and it is hoped that trends in usage of insecticides will then become apparent.

Reference

STRICKLAND, A. H. (1966) J. appl. Ecol., 3 (Suppl.), 3.

Proc. 5th Br. Insectic. Fungic. Conf. (1969)

DEVELOPMENTS IN VEGETABLE PRODUCTION AND MARKETING: THEIR INFLUENCE ON INSECTICIDE REQUIREMENTS AND USAGE

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Summary In response to economic pressures and commercial opportunities marked trends in the size of enterprise and the areas of production of field grown vegetables are developing. A rising standard of living and increasing demand for convenience foods is having a profound effect on the grower. Quality standards imposed by processors are demanding exceptional levels of pest control and bulk purchasers of produce for fresh sale, who are rapidly increasing their share of the market at the expense of traditional outlets, will require similar standards of quality.

The influence of these parallel developments on the incidence of pest infestation and the problems of control is discussed and possible solutions indicated.

During the last few years the vegetable industry has been undergoing a metamorphosis in structure and technique which has affected all aspects of production and marketing. It is by no means complete, but the industry is today more closely adapted and in a position to conform even more closely, to the changing demands of the economic and social climate in which it must exist.

Vegetable production in the open occupies some 450,000 acres and has a gross annual value of about £80 million. Despite seasonal variations the total vegetable acreage shows a downward trend but it is highly significant that the acreage of certain crops has increased and over the last decade yields per acre of every important crop have risen. Returns per acre have not risen commensurately, although vegetable production as a whole has increased in value by 20 per cent over the past four years. This reflects the changing make-up of the industry, in that higher value crops are increasing at the expense of lower priced ones. It is changes of this type that are likely to bring new requirements in pesticides.

There are a dozen crops which are of sufficient importance to form the economic base of the industry. All have been the subjects of intensive agronomic investigation. Varieties have been improved and much information on nutrition, plant spacing and irrigation has been obtained. Effective chemical weed control has become a reality and is the key to full exploitation of many other developments, in particular mechanisation of production and harvesting, with resulting increases in scale of operation and economy of effort.

Scale of Production

The changing scale of production is a prominent feature of developments in vegetable growing. A comparison of June Returns for 1963 and 1968 shows that during the period numbers of holdings with 100 acres or more of vegetables have increased by 12 per cent, while those on which they comprise less than 20 acres have declined by 27 per cent. This trend towards increase in scale is likely to persist as further advances in mechanisation continue to raise vegetable growing from its traditional labour intensive status to a highly capitalised farm scale operation. Increasingly vegetables are becoming a farm crop; as a break crop for cereals or as an alternative to sugar beet and potatoes.

Areas of Production

Concurrent with increasing scale is the trend towards well defined areas of production. Proximity to processing plants has shaped the areas in which crops for canning, freezing and drying are grown, and it is fortunate that many of these factories should be within easy reach of areas where the soils and topography are suitable for large scale production of the type of vegetables required by the processor.

Though the processing industry has been instrumental in stimulating interest in farm scale vegetable growing in these areas, the conditions are suitable for other crops and East Anglia is now the centre of the U.K. vegetable industry. This is illustrated by the fact that during the last 10 years the acreage of carrots grown in Norfolk has risen by 16 per cent, and that of beetroot in Lindsey, Lincs. by 10 per cent (MAFF 1967). During this period Norfolk and Suffolk have together recorded an increase of 21 per cent in the acreage of dwarf beans. The revival of onion production has taken place primarily in Holland, Lincs. and Norfolk, while cauliflower acreage has increased by 23 per cent in Holland and Lindsey, and more Brussels sprouts are being grown in Bedfordshire, Lincolnshire and Norfolk. Similar trends are apparent for other important crops.

These trends indicate that the industry is rationalising itself in response to economic pressures and commercial opportunities. Production and productivity is rising as growers take increasing advantage of the many technical developments offered to them but it is an open question as to how far output can rise before over-production has a depressing effect on profitability.

Expansion or Contraction?

Hinton (1968) has suggested that the demand for fresh and processed vegetables may be expected to increase during the next decade as a result of positive income elasticity of demand consequent upon a continuing growth in the national economy. He has suggested increases in demand of over 50 per cent for salads and leguminous crops, 16 per cent for onions and 11 per cent for brassicas. If this forecast proves correct then from past experience it seems likely that it could be met by further increases in output per acre, while for certain crops such as peas, green beans and onions there could be an expansion in the acreage.

Increasing output per acre pre-supposes a high level of cultivation and management expertise with the aim of growing quality produce. A simple expansion in acreage may not have this result, for it is an unfortunate fact that the market is often adversely affected by supplies of poor quality produce from farms where vegetables are only one of the enterprises. Yet quality, above all, is the keyword for success in modern marketing, and in the context of this paper this means freedom from pests and from the evidence of their earlier attack.

Consumer Demand

The British housewife is the most important person to every vegetable grower for she spends 17 per cent of her weekly food budget on fruit and vegetables. In the shop she sees the end products of the quality control imposed by grower or processor and tests them regularly and experimentally. If Brussels sprouts are full of aphids, or slugs appear in frozen peas the product is condemned and confidence is lost. On the other hand clean, well grown, well presented produce creates an impression of efficiency in production, and of satisfaction - and this is a highly subjective response, in the purchaser.

A rising standard of living pre-supposes an increase in disposable income but it also comprehends many intangibles included under the term 'improved standards' which are difficult to isolate and quantify. Suffice it to say that so far as vegetables are concerned it is manifested by an ever increasing demand for convenience foods together with willingness to pay for high quality well presented fresh produce. These two developments in produce sales present a challenge to the industry to meet the standards imposed upon it by the large buying organisations.

In his paper on the "Significance of Pest and Disease Damage in the Production and Marketing of Processed Vegetables" given at the last Conference (Bundy 1967) pointed out that processed crops will ultimately be made available to the consumer under a brand name and though the consumer is well aware that market bought produce often contains aphis and caterpillars which must be removed during preparation, pre-packaged food is expected to be completely clear of insects and other pests as well as any trace of their depredations on the crop. He pointed out that every complaint was of great concern to the processor. It was also an offence against the Food Hygiene Regulations and that one complaint in every 10,000 packets was a seriously high level. On the assumption that only one in ten of all purchasers complained this could mean the presence of five slugs or caterpillars per acre, or if 99 per cent were removed in the factory, field infestation would be 500 per acre. There were therefore tremendous shortcomings in any control procedure that only eliminated 60-76 per cent of the pest or damage.

These are the standards required by the processors but surely they are standards that should apply to the sale of fresh produce also. The purchaser should not need to be aware that it often contains insects or evidence of their attack, but should expect and obtain completely clean vegetables. It is a matter of time before this is the accepted standard, for no lower one will be tolerated by bulk buyers who are leading the way in retailing methods.

Changes in Retailing

The latest figures indicate that 73 per cent of fresh vegetable and fruit sales are made through specialist greengrocers and fruiterers which are predominantly small one-shop businesses. (Ellis et al 1967). Only 20 per cent is sold through the big retail grocery chains but the trend is upwards and the potential enormous. Ten years ago there were only 175 supermarkets in Britain. Today there are over 3,000. The British housewife has a marked preference for one-stop shopping and it has been forecast that in a few years time 60-70 per cent of all grocery sales will be made through supermarkets. More and more housewives will be visiting supermarket produce departments and an increasing percentage of sales will be made through these outlets, and a dwindling amount by the wholesale markets and traditional greengrocers. (Haslam 1968). The vast majority of self-service stores and supermarkets are served by 1,200 or so buying points controlled by multiple organisations and because of this concentration of buying power they are able to insist on the standards of quality that they know the consumer expects. It is these standards to which the vegetable growing industry must be geared if it is to have a viable and profitable future.

These are some of the more obvious changes that are taking place in production and marketing and together they are raising new pest problems and demanding higher standards of control.

The problems that pest infestation and control present to the processor have been discussed by Bundy (1967) and Carden (1967) in papers at the last Conference. I would now like to look at the way in which the agronomic developments already outlined may be affecting the incidence of pest attack or raising new difficulties for the grower.

Changes in Production

One trend already mentioned is that towards growing vegetables as a cereal break crop. Brussels sprouts are well suited to this treatment and there is considerable farmer interest in this crop. Land carrying cereals is frequently infested with leatherjackets and in some areas this pest has been extremely troublesome. Organochlorine insecticides before drilling cereals whilst not completely effective give good control but damage to sprouts results in individual plant losses that must be made good by gapping up, with the inevitable consequences of an uneven crop. Variation in time of buttoning may be an advantage in crops for market picking, but it is most undesirable in a once-over harvest system which though only accounting for about 5 per cent of the present acreage seems likely to be the production method of the future. The solution to this problem would appear to be increased grower-awareness of the extent of infestation so that the cereal crop can be treated with DDT or BHC before the vegetable break or alternatively more efficient chemical baits than those currently advocated.

A second problem arising from the extension of vegetables onto arable farms is the intensity of attack by birds due to the isolation of the crop from other acceptable food sources. Bird damage is especially serious on space-sown crops where opportunities for subsequent gapping up do not exist.

One of the most striking developments of recent years has been the revival of bulb onion production - a development stimulated by work at Kirton E.H.S. on weed control, varieties and problems associated with handling and storage. The extension of the acreage however has revealed the widespread incidence of stem and bulb eelworms in soils where its alternative hosts have been grown. Eelworm attack may be encouraged by the very efficiency of chemical weed control, for in the absence of weed hosts the crop bears the full attack. So wide is the range of alternative hosts and so extensive the infestation that it is doubtful whether it is possible on many farms to adopt a rotation that offers any hope of a reduction in eelworm population.

Closely related to this problem are those which are beginning to arise from the concentration of crops into certain localities where soil and climate are suitable. There is evidence that pea moth and pea root eelworm are building up and becoming increasingly important where peas are intensively grown. The same may be said of pea midge which though cyclical in frequency can persist in diapause for some years in the soil until conditions are suitable for emergence and attack. In the absence of effective chemical treatments for these pests, which must be regarded as priority requirements, the only solution would seem to be a reversal of this trend towards localisation of production on to suitable soils of other areas. This may however destroy the economic base upon which the successful production of these crops is founded.

The build-up of pests in well defined areas of production increases the risk of inducing resistance to insecticides through selective pressure, as occurred in the case of cabbage root fly, and there is need for a close check to be kept on pest populations so that alternative control measures can be used. On the other hand one wonders how long it will be before cheap and effective soil sterilants will be available that could eliminate the need for rotation by dealing at one time with 'soil sickness' problems and pests that spend at least part of their life cycle in the soil. A cost of £60 per acre may be acceptable if treatment was required no more than once in three years and if it could be offset by savings in other chemical costs such as those involved in weed control. The potential use would be enormous, though there would need to be detailed investigation into the effects on the soil fauna if such a treatment ever became feasible on a large scale.

Improved spatial arrangement is one of the developments which has contributed to the rising output of vegetable crops. Frequently this means closer plant spacing, but the dense cover provided by close-spaced crops encourages certain pests. Slugs for example have been particularly troublesome in sprouts for processing and to a lesser extent in dwarf beans. It is of course in these crops that slugs cannot be tolerated, but until recently it was difficult to control them because metaldehyde - the only available chemical, relied for its effectiveness on dehydration of the animal and close planted crops provide moist conditions in which recovery could take place. The introduction of methiocarb has been most timely in view of the increasing interest in closer spacing as an aid to yield control and mechanical harvesting, though in some quarters concern is expressed as to the wider effects of this chemical on other soil fauna.

Close spacing of sprouts is also known to increase cabbage root fly attack on the buttons. Damage is especially severe in early crops spaced at less than 24 inches apart. As much of the processing crop, which accounts for about 5 per cent of the total acreage, is both early and spaced at 18 inches to 20 inches apart it is in this crop the main problem has arisen. Trichlorphon is an effective remedy but there is often difficulty in gaining access to the crop without causing damage, since the last application must be applied only one month before harvest. Perhaps there is scope here for a more persistent granular systemic insecticide which can be applied well before the crop grows together.

Another problem of access arises through the need to control late attacks of carrot fly in crops which are to be left in the ground throughout the autumn. Existing chemical treatments give good control of first generation larvae but not those appearing later. In the absence of more persistent materials, or those that work through foliar application, the only solution appears to be deep placement of liquid or granules beside the growing crop. This is difficult, if not impossible to achieve without injury to the roots, especially in close-row growing systems. Consequently, however desirable multi-row or mini-beds may be on other grounds, the inability to control carrot fly may require the crop spacing to be arranged to suit the limitations of application equipment. The main requirement however is for a more persistent and specific chemical that can be applied at drilling to give season-long protection.

From time to time isolated problems associated with particular growing techniques arise. Where bamboo canes are used to support runner beans red spider may be a problem - the initial attack arising from adults over-wintering in the canes. Red spider has been severe this season, and since following spacing and costing studies canes have become widely used there is a real risk of early attack next season unless steps are taken to disinfect the canes before use.

Finally, it should not be forgotten that with increasing international trade in vegetables there is a risk of introducing alien pests into this country. We are aware of the threat from such insects as Colorado beetle and cherry fruit fly. We must be alert to the possibility of other unwelcome importations.

Developments in production and marketing of vegetables are introducing new requirements in both the methods and levels of pest control required. Changes in production techniques invariably involve greater inputs, whether at the level of the specialist vegetable producer or the farmer looking for diversification in cropping. Apart from the standards being set by the markets the need to service the capital investment associated with intensive production, and the competition that a situation bordering on over-supply forces upon producers, makes the efficient use of pesticides to optimise yield a dominant factor governing economic survival. In contracted crops the prices paid take account of the costs of pest control. If, through the changes which have been outlined, these costs increase then prices too must rise. As the volume of produce disposed of through processors and central buyers increases it must affect the general level of market values. This is to the advantage of everyone concerned - to the grower who through chemical expertise can improve his gross margins; to the bulk buyer who can insist on the highest standards, knowing that fair allowance has been made for proper measures of control, and to the housewife, whom the changing pattern of marketing has shown is willing to pay for vegetables well grown and well presented.

References

BUNDY, J. W. The significance of pest and disease damage in the production and marketing of processed vegetables. Proc. 4th Br. Insectic. Fungic. Conf. (1967) 2 534

CARDEN, P. W. Pest control in relation to processing and pre-packaging. Proc. 4th Br. Insectic. Fungic. Conf. 1 221 (1967)

ELLIS, P. G. et al The distribution of fresh fruit and vegetables from markets to shops. Wye College Marketing Series No. 3 July 1967

HASLAM, H. Producing for the consumer. Agriculture 76 4 165

HINTON, W. L. Outlook for horticulture. Occasional paper No. 12. Univ. Camb. School of Agric. (1968)

M.A.F.F. London. June Census (1963) Distribution of holdings and vegetables for human consumption; acreage by farm and crop size groups.

M.A.F.F. London. Examination of the horticultural industry (1967)

M.A.F.F. London. June Census (1968) Distribution of holdings and vegetables for human consumption; acreage by farm and crop size groups.

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A PRACTICAL METHOD FOR ECONOMIC CONTROL OF POTATO CYST NEMATODE (HETERODERA ROSTOCHIENSIS)

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Summary. Two hundred and fifty l D-D/ha injected into sandy soils in N.E. Netherlands killed at least 80% of *Heterodera rostochiensis*, if fumigation was carried out carefully and soil conditions were favourable. A preventive control scheme, embodying crop rotation, resistant varieties and soil fumigation has been drawn up, enabling farmers to grow potatoes every other year on fields infested with pathotype A, or on uninfested fields.

INTRODUCTION

Potatoes are an important crop in Dutch agriculture. About 150,000 ha of potatoes are grown each year, of which a third are starch potatoes grown in the North East, where the processing plants are located. In this part of the Netherlands starch potatoes are the cornerstone of agriculture. But farmers are not allowed to grow potatoes as frequently as they would like because they would probably run into difficulties, especially with respect to potato cyst nematode (PCN) (*Heterodera rostochiensis*). Some 20 years ago regulations were introduced to control PCN by crop rotation. It was assumed that growing a non-host plant decreased the nematode population by 30% per annum. Farmers were allowed to grow one potato crop every three years on uninfested fields and the crop was banned on infested fields until varieties resistant to pathotype A became available in 1958. These varieties reduced pathotype A populations by 80%. Then a crop of resistant potatoes was allowed every three years on pathotype A infested fields. On fields with other pathotypes potatoes were restricted to one crop in six years. By these means the build up and spread of the nematode was no doubt substantially retarded, but not totally prevented. It was recognised that, in the long run, potato growing in this particular area could be threatened, particularly as plant breeders failed to produce quickly a series of varieties resistant to all pathotypes that could match the yield and quality of existing susceptible varieties.

METHOD AND RESULTS

In 1963 research was started to find a preventive control system that fitted phytosanitary requirements and was acceptable economically. It was realised that soil fumigation could be the answer.

Eradication of the nematode population by large doses of chemicals was economically unacceptable, so trials were made with small doses of D-D mixture, the cheapest of the existing nematicides, which is usually effective and relatively non-toxic. From 1965 large scale field experiments were done in the autumn with 100 to 400 lD-D/ha applied about 15 cm deep by tractor-mounted equipment, on sites with soils representative of the region. They are mainly of two types: sands with 2-8% organic matter, and more peaty soils with 10-20% organic matter.

When small doses of D-D are used it is extremely important to apply them properly. A first and fundamental part is a proper soil preparation prior to fumigation. Fields were carefully cultivated, using normal farm practice to get a loose top soil of about 12 cm deep without clods and coarse materials.

Soil moisture content is very important. In our experience moisture content should be about equivalent to planting time, i.e. about 40 - 60% of field capacity. Soil temperature should be in the range 7 to 12°C, but there are indications that fumigation can be successful when soil moisture and temperature are larger or smaller than this, provided they are not too extreme. In our climatological situation, however, a high soil temperature often coincides with a low soil moisture content and vice versa. In practice soil fumigation is therefore best done in September or October. In table 1 results are given of a number of experiments, carried out under favourable soil conditions; in table 2 results obtained when conditions were unfavourable. From these experiments it can be concluded that, provided soil moisture content and soil temperature are favourable, 250 l D-D/ha killed at least 80% of potato cyst nematode eggs and larvae.

Table 1. Percentage killed eggs and larvae of PCN after soil fumigation with D-D. Results of 10 field experiments, carried out in the autumn of 1965, 1966, and 1967 at normal soil conditions. D-D injected by plough system.

Experiment No.	1	2	3	4	5	6	7	8	9	10
Dosage rate D-D:										
(l/ha) 100	85	58	21	75	60	47	76	51	60	50
200	89	87	78	85	84	77	96	94	81	80
300					90	83	98	97	84	91
400						87	98	97	98	91
Observations/ object:	18	36	36	18	36	32	24	16	16	32
Soil moist. content %:	20	21	18	19	19	29	22	32	25	26
Soil temperature (°C):	13	14	7	10	13	14	13	11	12	12

Table 2. Percentage killed eggs and larvae of PCN after soil fumigation with D-D. Results of four field experiments, carried out in the autumn of 1967 under unfavourable soil conditions.

Experiment number	1	2	3	4
Dosage rate D-D (l/ha):				
100	18			
200	20			
250		24	36	61
Observations/ object:	18	12	12	15
Soil moist content (%):	45	60	56	14
Soil temperature (°C):	5	5	10	18

Note: In experiments 1, 2, and 3 the soil was saturated with water at injection time.

To ensure proper fumigation, the soil is crumbled during the application of D-D by a single or a double pulveriser and then compacted with a smooth roller to seal the surface of the soil and thus prevent escape of the fumigant. It is generally accepted that due to rapid escape at the surface the concentration of fumigant in the soil two to four cm deep is insufficient to kill the nematodes. So the soil was reploughed crumbled and compacted again about 10 to 14 days after injection when it was assumed that some fumigant would be left at injection level, which could kill these nematodes. But in two recent experiments, (Table 3) there was no difference in the percentage of nematodes killed between plots where the soil was turned, crumbled and compacted again 12 days after fumigation, and plots without this cultivation. In one experiment the nematicidal effect was even lowered 8% when the soil was turned without crumbling and compacting 12 days after fumigation. From these experiments it can be concluded that some fumigant is still active some two weeks after injection. The ultimate result of fumigation is not improved by soil management after injection.

Table 3. Influence of soil cultivation after fumigation on the percentage of killed eggs and larvae of PCN (means of 12 observations).

Experiment number:	1				2			
Dosage rate D-D (l/ha):	100	200	300	400	100	200	300	400
No cultivation	77	82	91	93	74	82	87	91
Turning + crumbling + rolling	79	82	92	94	73	81	88	81
Turning only					66	77	74	84
Soil moisture content (%):	17				31			
Soil temperature (°C):	12				10			

All experiments to measure the effect of different dosage rates of D-D were carried out with a plough injector. In course of time two other types of application equipment became available, one being a modified liquid fertiliser applicator, the other a goose-foot tine injector with nozzles underneath the tines. In an experiment the effectiveness of these machines was compared with different dosages of D-D (Table 4).

Table 4. Percentage of killed larvae and eggs of PCN after fumigation with different doses of D-D, applied with three machines. P: plough; C: cultivator; G: goose-foot tine injector. (Means of 20 observations).

D-D dosage	% killed nematodes		
(l/ha): Equipment:	P	C	G
100	50	40	40
200	74	56	44
300	77	65	37
400	79	78	55

Note: results at each dosage level are somewhat low, due to unfavourable soil conditions at injection time. Soil moisture content: 35%; soil temperature: 5°C.

The plough system gave the best result, the goose foot tine injector the worst. This can be ascribed to unequal and irregular depth of injection. The plough injected at 14-16 cm depth, the cultivator mainly at 7-12 cm, and the goose foot tine injector at 5-12 cm depth. One may assume that each type can give equally good results when properly used, but in practice the plough system is more reliable than the others.

DISCUSSION

Summarising the practical control possibilities a theoretical control scheme can be drawn up, embodying the following principles:

- cultivating a non-host plant reduces the PCN population by 30% of a year;
- a resistant potato variety decreases pathotype A populations by 80%.
- soil fumigation (250 l/ha) decreases the population by 80%:
- cultivation of a susceptible potato variety multiplies the population 30 times.

Control scheme:

Year:	Crop:	Changes in nematode population: (pathotype A)
1	susceptible potatoes	100 (starting point)
	soil fumigation	20
2	non-host plant	14
3	resistant potatoes	3
4	non-host plant	2
5	susceptible potatoes	60

This scheme leads to a steady decline of pathotype A populations, and one may expect free soils to remain free for a long time. Therefore phytosanitary requirements are satisfied. Important to the growers is that in this system potatoes can be grown every year instead of once in three years. And this, together with some beneficial side effects such as killing other nematodes, increased yields of all crops, a saving of nitrogen and some weed control, makes soil fumigation, which costs about 400 guilders per ha, economically attractive. The attractiveness of soil fumigation can perhaps best be demonstrated by recording the acreage of fumigated agricultural land in N.E. Netherlands. These figures are: in 1966; 400 ha; in 1967; 12,000 ha; in 1968; 17,000 ha, and in 1969; 28,000 ha.

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SYSTEMIC FUNGICIDES, INCLUDING RECENT DEVELOPMENTS IN THE AGRICULTURAL SPHERE

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Summary The particular advantages of systemic fungicides lie in their ability to protect new growth and to offset imperfections in spray application, and the promise which they show in combating deep-seated infections. To act as a systemic fungicide (using the term in its broadest sense), a compound must be readily translocated in the host's vascular system, non-phytotoxic (even within the plant), and relatively persistent. The requisite physicochemical characteristics for optimal translocation are not those for high fungitoxicity, but 'systemics' may also act following conversion within the host or even by inducing the formation of host metabolites toxic to the invader. Several fungicides, predominantly heterocyclic compounds, which are systemic to varying degrees are now used in agriculture: their spectrum of biological action will be described in detail. Possible future developments will be considered.

INTRODUCTION

The limitations of conventional fungicides, acting at the plant surface, have long been recognised (Horsfall, 1945). Thus, poor disease control can follow imperfect coverage by protectant fungicides, or from erosion of deposits by rain and wind. During periods of rapid growth new, and often highly-susceptible, foliage and shoots are produced which lack any fungicide deposit until the next application. Fungicides of the 'eradicant' type are often not persistent and tend to be phytotoxic. Also, conventional fungicides cannot make contact with pathogens causing deep-seated infections, such as the vascular wilts. Systemic fungicides, which are translocated and act within the plant, offer new possibilities in disease control. In this paper the term is used in its broadest sense, to include compounds which are themselves not toxic to the fungus *in vitro*, but which nevertheless control the disease on the host. Early work in the U.K., the Netherlands and the U.S.A. has formed the basis for recent major advances which have resulted in systemic fungicides being used on a commercial scale to great effect. The whole subject has been admirably reviewed by Wain and Carter (1957) and by Bent (1969), and important developments of individual fungicides are described elsewhere in these Proceedings.

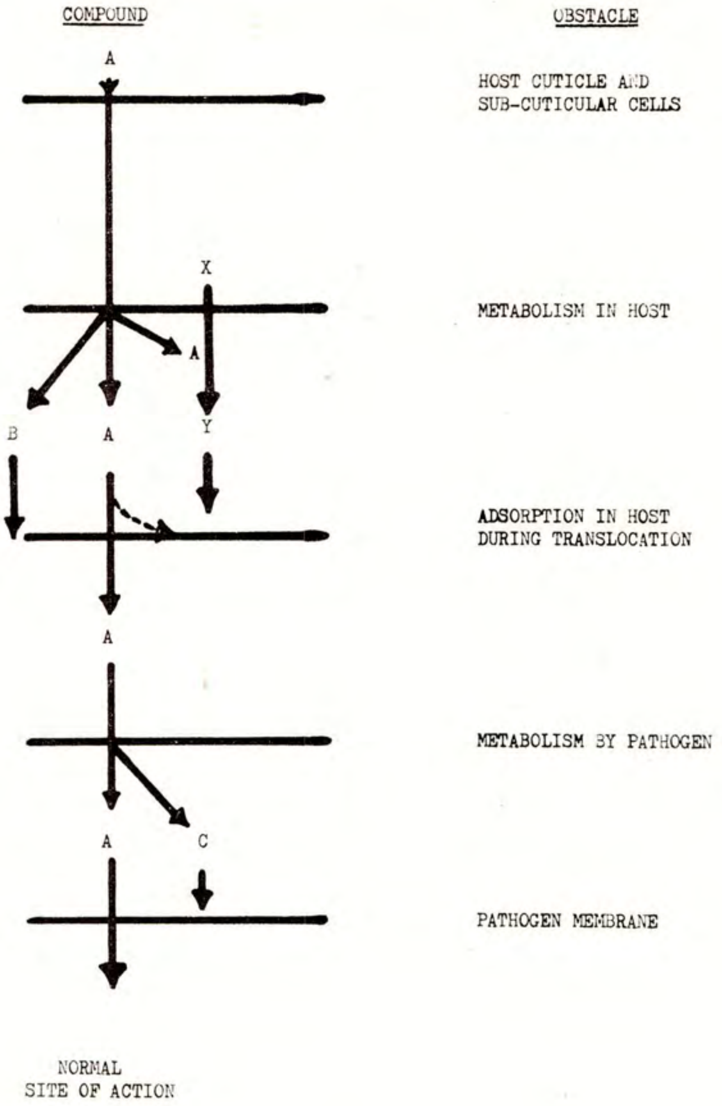
PROPERTIES FOR SYSTEMIC ACTION

Many organic fungicides have been developed since the introduction of the dithiocarbamates in 1934. Yet, until very recently, few have been really effective as systemic fungicides in agriculture. This may well have arisen largely because commercial fungicide testing was originally based on toxicity *in vitro* and on foliar protectant action. However, as Bent (1969) has pointed out, the whole emphasis has now shifted to specific tests for systemic action, of which excellent examples have been described by Erwin (1969).

The lack of correlation between toxicity *in vitro* and performance as a systemic compound is soon apparent when the complex host/parasite/systemic fungicide interaction is examined. Fig. 1 presents a simplified model of the system, with particular reference to the obstacles which a fungicide must normally surmount in order to act systemically. Firstly, it must penetrate the host and reach the vascular tissue. Once within the host in aqueous solution, the compound may break

Fig. 1

Model for systemic action



B and C are breakdown products of A
X and Y are host metabolites unrelated to A

down spontaneously or be metabolised to a compound (B in Fig. 1) which may well be less toxic than the applied compound, A. Some breakdown is in fact desirable in edible crops to avoid the presence of residues at harvest. The compound must also be non-toxic to the plant with which it is in intimate contact.

Even when the fungicide is stable within the host, it may be strongly adsorbed to host xylem tissue, as shown by Edgington and Dimond (1964). When the compound finally encounters the pathogen, it is normally necessary for it to penetrate the fungal membrane in order to act (though these considerations clearly do not apply to compounds acting against extracellular fungal products). The compound may also be metabolized by the fungus.

On the other hand, dissociation in water or metabolism by host do not necessarily result in reduced activity. For example, benomyl breaks down in aqueous solution to benzimidazole carbamic acid methyl ester, which is equally as toxic as benomyl to some fungi and relatively stable within the plant (Clemons and Sisler, 1969; Peterson and Edgington, 1969).

It is now clear that the physico-chemical requirements for optimal performance at each of these obstacles are different and indeed contradictory. As Crowdy and Rudd Jones (1956) convincingly demonstrated by partition chromatography, a degree of lipid solubility is required for movement across the cortical tissues as also for the penetration of a pathogen membrane (Hansch and Fujita, 1964). On the other hand, the presence of 'polar' groups makes for easier translocation, and water solubility is often a limiting factor in systemic activity (Wain and Carter, 1967). The possibility of deriving an optimum partition value for such conflicting requirements, as has been done for the fungal cell or a fungus/leaf cuticle situation (Clifford, Deacon and Holgate, 1969) is thus remote.

For a given chemical, rapid translocation is aided by a high transpiration rate and occurs more readily in herbaceous than in woody plants (Bent, 1969). For compounds taken up by the roots, soil properties are also important, with a need for a balance between adsorption and leaching. Some systemic fungicides are readily translocated upwards in the plant xylem, e.g. from roots to shoots, and even from seeds through the developing plant. The latter offers a particularly economical method of disease control of great importance in agriculture. The movement of others seems to be more restricted and the term 'local systemic activity' is often used.

From the above considerations, optimal conditions for use of systemics are likely to occur in the greenhouse, while treatment of a quick-growing annual crop in a sandy or silty soil is likely to be more effective than of an established tree growing in grass in a heavy soil.

Movement from the foliage down to the roots in the phloem has not been achieved, but the fact that assimilated carbohydrates, and also viruses, are capable of such movement encourages the hope that systemic fungicides with these properties may be developed.

SPECTRUM OF BIOLOGICAL ACTIVITY

Systemic fungicides introduced in the late 1960's are sufficiently effective and cheap to be used commercially. Table 1 lists the principal compounds in use or in a late stage of development but does not include antibiotics and nickel salts which found limited earlier use.

Table 1

Action spectrum of systemic fungicides

Compound	Diseases controlled	Diseases not controlled	Reference*
Benzimidazoles			
Benomyl ('Benlate')	Most	Phycomycetes, '*Helminthosporium*', *Alternaria*	Delp and Klopping (1968)
Thiabendazole ('TBZ')	Many, especially fruit storage rots	Ditto	Staron and Allard (1964)
Oxathiins			
Carboxin ('Vitavax')	Basidiomycetes, especially Smuts, Rhizoctonia	Many	von Schmeling and Kulka (1966)
Oxycarboxin ('Plantvax')	Basidiomycetes, especially Rusts	Many	Rowell (1967)
Pyrimidines			
Dimethirimol ('PP.675')	Powdery mildews of cucurbits and other plants	Most	Elias *et al.* (1968)
Ethirimol ('PP.149')	Powdery mildews of cereals	Most	Bent (1969)

* See also Hickey (1969)

All these new fungicides are heterocyclic compounds, a group offering great versatility of structure. It is a matter for speculation as to whether these compounds are in fact more effective than aromatic compounds or whether the introduction of more relevant testing methods happened to coincide with a predominance of such compounds.

There is a wide variation in action spectrum, ranging from the effective control by dimethirimol and ethirimol of powdery mildew diseases on specific hosts to benomyl's wide spectrum. The nature of such specificity remains to be elucidated, though Richmond and Pring (1969) present a working hypothesis for the inactivity of benomyl towards the Phycomycetes.

Several of the systemic fungicides listed in Table 1 are highly active *in vitro* and therefore are likely to act as conventional protectant fungicides in addition to their effects as systemics.

The chief group of diseases against which the newer systemic fungicides are not effective is those due to Phycomycetes, which include potato blight.

FUTURE DEVELOPMENTS

As stressed by Bent (1969), large-scale screening programmes will long remain the chief basis of fungicide development. However, there is a hope of being able to exploit 'natural' chemicals involved in host resistance for disease control (Wain and Carter, 1967). In particular, compounds which 'trigger' such responses may be worthy of study, since these would not have to penetrate the fungal membrane. Cruickshank (1968) has demonstrated that induction of the formation of one phytoalexin may be achieved by very low concentrations (ED.50 = 8 x 10^{-9}M) of the water-soluble peptide monilicolin A (molecular weight about 8,000). The possibility exists that the active group may constitute only a small part of the molecule.

An even more long-term approach is due to McNew (1968), involving the modification of plant nucleic acids by synthetic nucleotides in a form of 'genetic engineering' and thus keeping pace with mutation of pathogens to fungicide-resistant strains, which may well be a problem with highly specific fungicides.

By whatever routes systemic fungicides may be developed, two facts are already clear: a basic knowledge of their mechanism of action will be required in a detail hitherto not attained. Also, they will be eagerly and effectively used to give control of diseases where hitherto none has existed, to give better control of others, and so to bring food to some of the world's empty stomachs.

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References

BENT, K. J. (1969) Endeavour 28, 129.
CLEMONS, G. P. and SISLER, H. D. (1969) Phytopathology 59, 705.
CLIFFORD, D. R., DEACON, A. C. and HOLGATE, M. (1969). Ann. appl. Biol. 64, 131.
CROWDY, S. H. and RUDD JONES, D. (1956) Nature, Lond. 178, 1165.
CRUICKSHANK, I. A. M. (1968) Life Sci. 7, 449.
DELP, C. J. and KLOPPING, H. L. (1968) Pl. Dis. Reptr 52, 95.
EDGINGTON, L. V. and DIMOND, A. E. (1964) Phytopathology 54, 1193.
ELIAS, R. S., SHEPHARD, M. C., SNELL, B. K. and STUBBS, J. (1968) Nature, Lond. 219, 1160.
ERWIN, D. C. (1969) World Rev. Pest Control 8, 6.
HANSCH, C. and FUJITA, T. (1964) J. Am. chem. Soc. 86, 1616.
HICKEY, K. D. (1969) (ed.) Fungicide and Nematocide Tests 24, 153.
HORSFALL, J. G. (1945) Fungicides and their action. Chronica Botanica.
McNEW, G. L. (1968) Abstr. 1st Int. Cong. Plant Path., London, 120.
PETERSON, C. A. and EDGINGTON, L. V. (1969) J. agric. Fd Chem. 17, 898.
RICHMOND, D. V. and PRING, R. J. (1969) Proc. 5th Br. Insectic. Fungic. Conf., 1969, 488
ROWELL, J. B. (1967) Pl. Dis. Reptr 51, 336.
von SCHMELING, B. and KULKA, M. (1966) Science 152, 659.
STARON, T. and ALLARD, A. (1964) Phytiat.-Phytopharm. 13, 163.
WAIN, R. L. and CARTER, C. A. (1967) in (ed.) TORGESON, D. C. Fungicides Vol. I, 561. Academic Press.

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CURRENT TRENDS IN TOXICOLOGICAL REQUIREMENTS

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This is the so-called "space age", as virtually anyone who has witnessed the fantastic explorations and acrobatics of 1969 will probably agree. In an expanding universe, science and technology are burgeoning as well. What, you may ask, has this to do with the essentially terrestial business of toxicity testing for insecticides, fungicides and the like? Have no fear; I am not embarking on an imaginative discourse devoted to the noxious features of the lunar environment, less still to the possibilities of selective weed control in the Sea of Tranquility. There is nevertheless - I suspect - an analogy between these achievements in space on the one hand and progress in toxicology on the other. Men have reached the moon, walked upon its surface and returned safely. Mars has been photographed and televised at close quarters. Yet what exactly does this offer to the welfare of mankind? Similarly, in our laboratories today we can calculate LD_{50}s with mathematical precision, reveal previously unsuspected changes in cellular and intro-cellular structure by electron microscopy, demonstrate apparent carcinogenicity in very new-born mice and dilate upon the most elaborate enzyme changes in the liver - exciting stuff and the very life's blood of Ph.D. theses. But what does this really do to protect that splendid fellow - the man on the Clapham 'bus? That is what ultimately concerns us.

Regulatory Methods

In the process of government, statutory law has its undoubted attractions, not least in terms of logic and pragmatism. Authority declares from the start what shall and what shall not be. The community is left in no doubt about its obligations to conform - and, incidentally, opportunity is at once created for those skilful and enterprising operators (and their financial advisers) to contrive advantageously how to observe the letter of the law, without necessarily abandoning themselves to its spirit. By contrast, the realm of case law is relatively uncharted. No one clearly sees the way - sometimes not even the lawyers, and they make a bonanza out of this as they take us by the hand and we grope ahead together.

These considerations become relevant in the world of toxicology, just as soon as authority assumes some responsibility in this respect on behalf of society generally. Everything, it is argued, would be so much simpler if, centrally, an edict could be issued setting out categorically the tests required and the standards to be attained. Then the sponsor of each agricultural chemical (or, for that matter, drug, food additive, cosmetic and so on) would know just what to do from the beginning and how, scientifically and commercially, to plan development and strategy over the ensuing years. In practice, though, our central agencies have, adopted, instead, the Christian-Mosaic philosophy. However deeply and permanently engraved upon the tablets of stone the commandments may have been they remain - as the playwright Bridie pointed out - only telling people what <u>not</u> to do! Little wonder, then, that so many of our enterprising firms tend to suffer from a sense of frustration.

Ironically enough it is in the still developing countries with a dearth of scientific expertise that the more positive, didactic attitude of government continues to survive. The more advanced countries - among which I venture to name the U.S.A., the United Kingdom and a number of other European States - play it more cautiously. Here, under the auspices of the Crop Protection Council of Britain, I may perhaps be permitted to confine my comments to the scene in this country.

The Pesticides Safety Precautions Scheme

For the moment, at any rate, the arrangements made under the Pesticides Safety Precautions Scheme between government departments and industry have been entirely voluntary - as you know - and the extent to which they have been adopted and observed on all sides has been exemplary. Official guidance has been confined to a small, loose-leaf booklet with which, I expect, all of you are familiar. This is the "guide", as it is called, not without good reason. It sets out to point the way, without being precise. At least, unlike the Commandments to which I have previously referred, it takes a positive, though not unequivocal attitude. Section B is devoted to "Toxicity Data". This includes a "General Plan of Studies", comprising, inter alia, acute toxicity, cumulative toxicity, chronic toxicity, metabolic studies and so on, but only in the most general of terms. Experimental details are relegated to "Working Documents". These are limited in their scope and are by no means binding. So, with any new chemical intended as an insecticide, fungicide, herbicide, etc., no rigid or universal routine for toxicological testing has to be followed. For each substance the procedure must be, as it were, specifically "tailored" and the advantages of a discussion, at an early stage, between the firms' scientists and the technical officials are repeatedly emphasised.

Review of the Safety Arrangements

It will not have escaped your notice that the departmental Review of the Safety Arrangements for the Use of Toxic Chemicals in Agriculture and Food Storage has come out in favour of a mandatory scheme in place of the voluntary arrangements that we have enjoyed for some years (to my astonishment, largely at the insistence of the agricultural and commercial interests and not by any means at the behest of government departments). So, shortly I suppose, there will be a formal Act of Parliament, together with accompanying Regulations and Orders, just to control the use of chemicals employed in agriculture and food storage - all of which sounds ominous and constrictive. Are we to look forward, then, to a series of directives on toxicity testing that must be implicitly followed, or else suffer the consequences? Some consolation may, however, be derived from the official prounouncement that "It is essential to preserve the flexibility of the present scheme in respect of information required before a licence can be granted". Dare we hope, therefore, that what on the toxicology side has been very much a constructive exchange of views between the scientists on the two sides, commercial and official, will be allowed to continue?

The Independent Scientific Adviser

Mind you, I realise only too well how the delicacy of balance that has obtained until now between notifier and departments can so easily become distorted as soon as one side becomes armed with legal powers. So much then depends on administrative wisdom and common sense. Lacking this, each application for a licence can degenerate into a "copper-and-robber" war of attrition in which no one is prepared to concede a point and a decision is never reached. Against this, I fear, our only defence is faith in the officialdom of this country and that includes, today, not the established civil service alone but also the scientists variously enlisted to provide expert opinion. If in this session I am permitted a personal admission it is in reference to those of us who, as so-called specialists, have to perform in this capacity. When you badger us with your pleas and arguments, and complain that we are inordinately insistent and obdurate, do you ever pause to put yourself in our position?

The community, expressing itself perhaps in somewhat exaggerated form through the politicians, demands absolute safety - which like all Utopias is an unattainable objective. The chemical industry, whilst not at all unmindful of its obligations to mankind, seeks for obvious economic reasons to establish practical safety as simply and cheaply as possible. In between, we on a committee must adjudicate.

Whenever doubt presents itself the instinctive reaction is to hesitate, to stall and, in justifying ourselves, to demand further tests. After all, there is so much at stake. How do you think we should be regarded and manhandled if another thalidomide-like disaster, equally unforseeable, should ever overtake us? As it is, you and we will never have enough evidence to make a conclusive pronouncement. All we can do is to "play the sedulous ape" to our noble judges in the civil courts and pronounce on reasonable probabilities with the facts at our disposal. Which brings me back to the theme with which I opened this talk to you; in the face of such rapid advances in the techniques of toxicological testing, what is meaningful in the end? But before I return to this topic I would like to turn my gaze outward from Britain and across the Channel to Europe, with which, it appears, we shall inevitably become more involved.

The Council of Europe

Let me say at once that I am not about to disclose the secrets of the "Six" as far as toxicity testing is concerned. They remain a mystery to me, more so probably than they do to you. I refer, though, to the Council of Europe (Partial Agreement) - this latter qualification in brackets indicating, let me assure you, no divergence of opinion but simply that the negotiations are confined to certain states, viz. Belgium, Denmark, France, the Federal German Republic, Italy, Luxembourg, the Netherlands, Switzerland and the United Kingdom and not to Europe as a whole. You are no doubt aware that this organisation, with its headquarters in Strasbourg, has a whole series of expert committees, one of which is designated as that examining "Poisonous Substances in Agriculture". The members are all official nominees of their own Governments. Each is responsible, to a greater or lesser extent, for what goes on by way of regulating pesticide sales and usage in his own territory. As you are acutely aware, each country has its own distinctive way of dealing with these affairs - which makes the life of you who are working for international pesticides companies all that much more perplexing and onerous. Clearly this is a subject in which, although there must be allowance for obvious and sincere divergence of scientific opinion and interpretation, there is good reason to co-operate, co-ordinate and converge. One way, possibly the only way at present so to advance, is through the Council of Europe. What is agreed there is not necessarily adopted by all member states, but through this medium the grosser differences tend to be eliminated.

"Agricultural Pesticides" - The Council of Europe Booklet

In 1962 a small booklet was published from Strasbourg. This embodied guidance on toxicity testing - the first of its kind from a group of sovereign nations. From all sides it was criticised as being insufficiently explicit. At least it was a first step in a promising direction. That booklet has now been revised and is about to be issued as a new edition. I think you will find it more to the point and informative than its predecessor. Still, though, it is nothing like a set of instructions, largely for the reasons to which I have already referred. It nevertheless expresses a philosophy for toxicity testing common to all its signatories, which itself is an advance over independent and often conflicting ideas. In part, it might bear a little closer examination at this juncture.

(i) To begin with it is stressed that "The toxicological studies ..... vary for different substances," and "it is strongly suggested that manufacturers should discuss their programme of investigation at an early stage with the responsible authorities". I trust you will not contest either of these principles. I hope too that you will be rewarded by gaining the audience of enlightened personnel representative of these authorities who will be able and willing to scrutinise your proposals and offer you constructive reactions.

(ii) On acute toxicity, mention is made of "approximate LD_{50}" values - not elaborate calculations. The emphasis falls on a range of animal species, the features of the poisoning and its mechanism of action - not just a column of figures, no matter how impressive the standard deviations may be. Parenteral and dermal routes are also stressed, with values by the respiratory route as well for substances which, in practice, might be inhaled. What is more, reference is made not only to the active ingredient, but also to the technical material, formulated product, effect of storage, nature of solvent, potentiation with the chemicals and so on. Herein lies, you may suspect - as I do, an invitation to multiply the acute studies well-nigh indefinitely.

(iii) On short-term toxicity and dermal and percutaneous toxicity the Council of Europe document offers nothing substantially new. What it avoids is any detailed instructions about the percutaneous technique, which is something of a toxicological Sargasso Sea. Perhaps the joint study conducted by the toxicologists under the sponsorship of the British Joint Medical Panel will, now it is published, point the way to a more standard procedure. However arbitrary this may be it will at any rate afford comparable results.

(iv) Degradation products, metabolites etc. - while the chemicals with which the worker or operator comes into contact are those of the formulated product, the residues which the consumer ingests may be quite different, substantial changes having been undergone on the growing plant, or in the process of storage or processing. Conceivably these derivatives could be less, or more, toxic than their progenitors. This opens up tremendous elaborations in terms of toxicity testing. How far should we thus proceed? Sooner or later we must make up our minds about this.

(v) Long-term toxicity studies. With these, of course, are interwoven the tests for carcinogenicity. Should they be universally applied to all pesticide chemicals? What are acceptable species and methods? What really is significant by way of findings and how does one extrapolate to man? All these questions are left unanswered. If - in "As You Like It" the Duke could " .... find good in everything" it is terrifying that so many of the cancer specialists seem to entertain carcinogens everywhere. Someday, somehow, we shall have to come to terms with this too. Meanwhile the most illustrious of expert committees skate round and round in ever wider circles without finding the answer.

(vi) Reproduction, Teratology, etc. These are truly emotive aspects. Anything likely to affect woman's or more so man's procreative prowess stirs up morally (sic!) righteous indignation, while any suggestion that the newborn may be deformed by chemicals gives rise to an outburst of wailing and gnashing of teeth. But short of experiments on human "volunteers" what can we do by way of precautions? Animal tests may be conducted as a ritual and the findings may serve as soul-washing to those in regulatory control. Yet what they yield scientifically is still anyone's guess.

(viii) Potentiation. Why is it always assumed that, if two chemicals interact toxicologically at all it will be in the direction of potentiation? Granted there are a few examples which so subscribe, e.g. when two organophosphorus anticholinesterases are present together. But, as we are currently discovering from liver microsomal studies, the very reverse may occur. The previous exposure to one chemical, e.g. dicophane, may impressively augment the metabolism and thus reduce the toxicity of the second, e.g. phenobarbitone. It is all very confusing.

The Council of Europe booklet, I still submit, has brought together what were otherwise often grossly divergent ideas on the past of the European regulatory authorities and their scientific advisers. Nevertheless we remain overall in that state of uncertainty that led to my opening remarks today. There is no finality to the toxicological testing in which we could indulge if we were so minded - and had the requisite time, personnel and money. Our objective, however, is not to raise a

Memorial to toxicity, but to provide criteria by which we can ascertain the conditions under which this, that or the other pesticide chemical can be deployed without causing harm. To this end it is an admission of defeat just to dodge the issue and ask for more and more experiments to be carried out. Rather do we need men (and women) of purpose and courage. They just do not emerge from committees. Perhaps we should seek the omniscient individual to make up his mind - the toxicological Solomon. He could hardly do less for us than this succession of bodies that, over the years, have framed us with their superficially impressive and attractively-bound reports, from W.H.O. onwards that promise so much and yet yield so little.

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CURRENT TRENDS IN RESIDUES REQUIREMENTS

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I am in full agreement with the statement that "there exists only one possible justification for the use of poisonous substances such as pesticides in connection with food production: that justification is control".
Being engaged in a pesticide residues control activity I feel obliged to amplify this to a two-way control, aiming both at the control of use and the control of the consequences of use.

The requirements for information, know-how and insight in connection with the use of pesticides have increased considerably in the last decade and it is not surprising that the manufacturers and the users of pesticides often regard these requirements as a burden. They must, however, be weighed against the mounting evidence on residues in food which has accumulated in the same decade. This evidence shows that unwanted residues may be left on most food and feed crops from direct and indirect applications and that residues can be transferred from one link to another in complicated food chains. It also shows that chemical, biochemical and physical reactions are converting the original pesticide chemical into series of metabolic products all of which may have to be taken into account in the final evaluation.

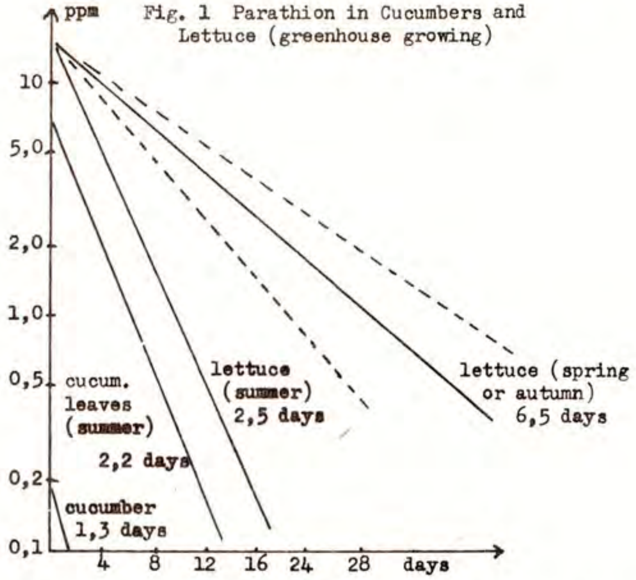
The establishment of this evidence is in my opinion one of the most important parts of any pesticide control scheme, being fundamental to the safe use of any pesticide. In the Council of Europe booklet "Agricultural Pesticides", which is available here and which I hope will be welcomed by Industry, we have endeavoured to set up guidelines on relevant residues data.

The ultimate purpose of the enforcement of these requirements is to get a thorough knowledge of the residues levels under all practical circumstances and the risks connected with them at the time of consumption. To achieve this, however, it is often necessary to set up experiments of a much broader scope. A full disappearance curve for a pesticide on a given crop, based on four samplings up to and including the actual harvest, tells us much more than merely four times the information from a single harvest-time sampling. Properly designed, such an experiment or a combination of such experiments may give us information about the rate and mechanism of disappearance. It may give us ideas about the variability and the significance of the residue levels and it may open up an understanding of a multitude of external factors influencing their disappearance. These factors may be quite uncontrollable as, for example, the day-to-day fluctuating weather conditions. In many cases, however, they are still easy to define as inherent in the crop, as for example, the age or the form and shape of the crop or the overall agricultural and geographical conditions connected with a region or a location.

Before reaching any conclusions I will try to illustrate some of these points with the following examples:

In a series of experiments in the years 1963-68 (1) we compared the disappearance of five insecticides from vegetables grown in greenhouses and on open land. From these data have been selected and presented here as calculated straightline disappearance curves in a semi-logarithmic system. Each curve is based on a sampling programme with from 5-7 duplicate samplings per experimental lot. All the curves have been found statistically to represent first order reactions and the calculated half-lives (RL_{50}-values) are shown for each curve. One case is further illustrated with the corresponding safety limits (dotted line in fig. 1).

Fig. 1 Parathion in Cucumbers and Lettuce (greenhouse growing)



From the curves it will be seen that there is a considerable difference between residues characteristics on two different crops such as cucumber and lettuce, in respect of both initial deposits and rates of disappearance. On the other hand it will be seen that leaves of the cucumber plants show more or less the same pattern as the lettuce, both being leafy plants with large surface areas and moderate growth rates when compared with the cucumber fruit. From the graphs it is possible to estimate residues levels for given times and, with a reasonable degree of safety, it is possible to make sound and balanced regulations taking into account both the initial amount of chemical required and the growth rate.

On the other hand it should be remembered that these curves and the half-lives, waiting periods, etc., which they represent are not physical constants. They should be evaluated by considering the conditions under which they are produced. The two lettuce curves in fig. 1 clearly demonstrate this. They represent experiments with parathion on lettuce carried out under identical circumstances except for the season of the year. They were carried out in the same greenhouse, one in the month of June and the other in March-April (it could also apply to October) and at least some of the climatic differences between summer and spring (or autumn) will have been eliminated by the greenhouse conditions. The seasonal difference is, nevertheless, the only difference and thus it is necessarily the one which has given this dramatic change in the disappearance curve. Factors such as growth rate and temperature may have some small influence, but probably the most significant factor is the difference in light intensity which is rather marked in the change of seasons in Denmark.

This brings us to the question of the chemical and physical characteristics of the individual pesticides. We all know that the insecticide mevinphos (or 'Phosdrin') is rapidly degraded and this is shown in fig. 2 indicating a half-life of 1.5 days for mevinphos as compared to 6.5 days for parathion in parallel experiments on lettuce. This is true, however, only if the chemical analysis measures the active and probably genuine insecticidal compounds, whereas measurements including metabolites (here as total organic phosphorus) gives a completely difference picture.

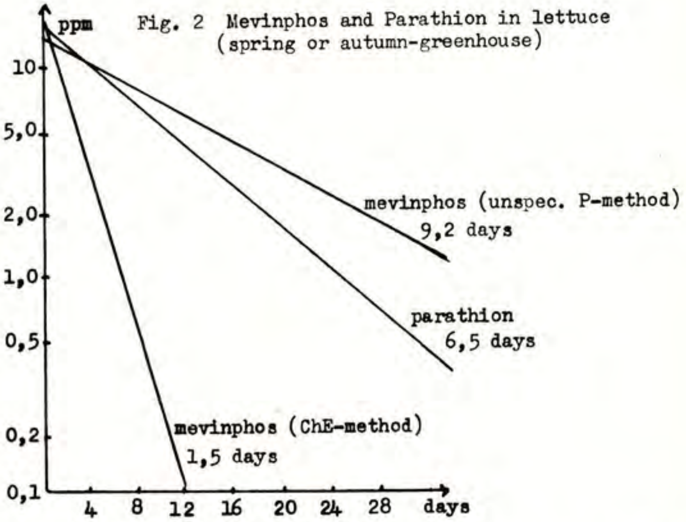


Fig. 2 Mevinphos and Parathion in lettuce (spring or autumn-greenhouse)

The curves in fig. 2 are all connected directly with edible crops and illustrate some of the problems there. Another, and in some respects more disturbing, problem connected with the use of pesticides, is the problem of persistence in our environment which may ultimately bring the stable and still toxic compounds back to the sphere of human and animal life.

One of the particular areas where this problem has been demonstrated is in connection with the great efforts in all countries to get a better control of soil pests. The use of chlorinated, almost chemically inert, pesticides and the introduction of granular formulations has increased this problem and resulted in treatments which can sometimes be traced in food crops for several years after a single application.

To recover the situation it is now deemed necessary to use less stable compounds, particularly organophosphorus pesticides. The increasing use, however, of granular formulations produces a need for a better quantitative evaluation of the soil residues levels and for a means of evaluating the degree of persistence. Many efforts in this direction have been made, both here and on the other side of the Atlantic and I would like to discuss some of our attempts to standardise a screening test under laboratory conditions and eventually to set up a coarse scale for the quantitative characterisation of persistence. It was first necessary to have some indication of which parameters or external factors could be involved in the disappearance of a pesticide from soil. A preliminary test using diazinon and two different soil types was attempted to sort this out in a statistically designed multi-factor experiment (2). Based on 32 individual experimental units, each of them followed through a period of 96 days, the half-lives and their variations were determined under different laboratory conditions. A summarised picture of the results is shown in fig. 3. The bars indicate RL50 values found in individual experiments, each experiment representing a certain combination of soil characteristics as shown. The meaning of a factor combination, for example, a b c d, is that the experiment has been performed using a) a non-sterilised soil, b) with a low

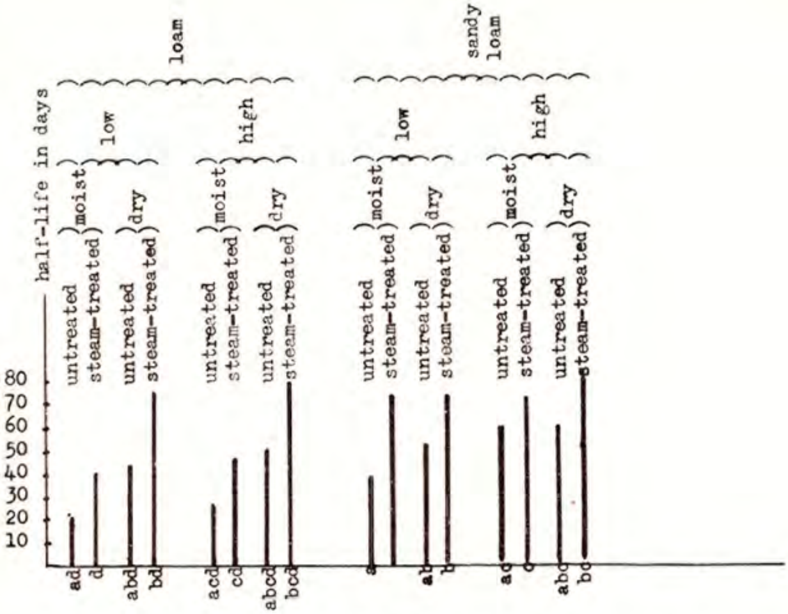


Fig. 3 Diazinon disappearance from soils. Laboratory exp. (RL_{50}-values)

humidity (25% of capacity), c) treated with a high diazinon concentration (corresponding to 10 p.p.m.) and finally d) that the soil is characterised as a loam.

From a comparison of the bars representing untreated soils and steam-treated soil it is obvious that the micro-organisms of the soils play an important role in the disappearance of diazinon. In addition there is a highly significant effect from the changing of the humidity of the soils and there is a significant difference between the rates of disappearance in the two soils, the loam type soil giving a faster degradation of diazinon than the sandy soil. And, finally, there is some indication that an increase in the concentration of diazinon results in a decrease in the rate of disappearance.

From the practical point of view the most important of these factors is the effect of soil type. This is, of course, not a single parameter, but is a combination of many individual factors, among which we, at present, rate the pH and the humus content the most important. The findings so far clearly indicate the need, as in any standardised test, to standardise the soil types which should be used.

The results from a standard test using a loam soil typical of many Danish agricultural areas are shown in fig. 4. The details of this experiment are to be published but I can mention here that the degradation of eight insecticides were followed under identical laboratory conditions for a period of 80 days. As a result it was found that the compounds could be grouped as follows: the three chlorine-containing thiophosphates, dichlofenthion, trichloronate and chlorfenvinphos, were classified as relatively persistent with RL_{50}-values above 100 days. Dimethoate, 'Aphidan' and diazinon were relatively non-persistent with RL_{50}-values below 40 days, and the two compounds mecarbam and bromophos were intermediate with RL_{50}-values between 40 and 100 days.

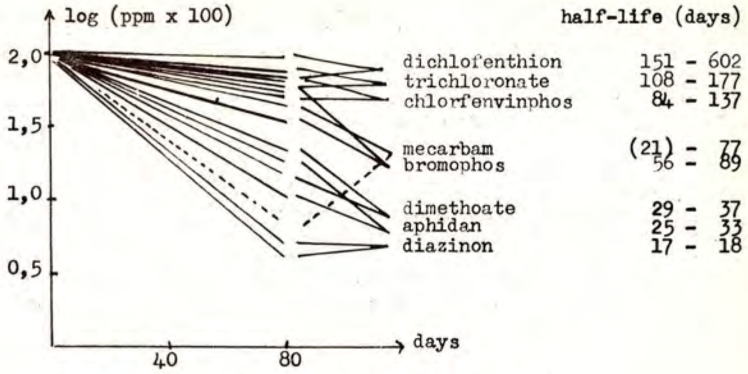


Fig. 4 Degradation of 8 Insecticides in Soil. Laboratory exp.

This grouping is, of course, arbitrary and the numerical values for the disappearances have no direct practical significance as they are based on laboratory conditions. However, they do give a most important relative scale of the degree of persistence and, in as far as they are reproducible, they give a forecast of what might be expected in practice. This is illustrated in fig. 5, which represents the results from a parallel field experiment. It was started at the same time as the laboratory study testing the same eight insecticides in the same soil. In this outdoor experiment the residues were followed for one year and we found that the very marked influence of climatic factors was shown by the fact that the disappearance curves were no longer straight lines. It is interesting to note that the picture of degradation is nearly identical with the laboratory experiment during the first two to three months, i.e. in the summer with reasonably high temperatures. At the end of the experiment, i.e. the following spring, the grouping of insecticides is qualitatively the same as in the laboratory.

Quantitatively, we could not use the half-lives in this case, as we have broken curves. Instead we express the residue level at the beginning of the next growing season as a percentage of the originally applied amount. By definition it could be claimed that a residue of 30% or more is a substantial residue and should indicate a high persistence of the compound. From 30-10% should be connected with a moderate

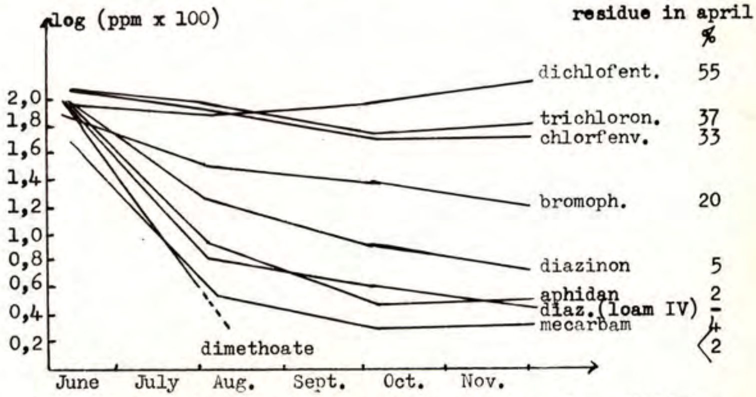


Fig. 5 Degradation of 8 Insecticides in loam I. Field exp.

persistence, whereas pesticides leaving only 10% or less accordingly are nonpersistent. Using these figures as the basis for the grouping and going back to the laboratory experiment it is found that the two series of experiments agree well with each other. The results from the laboratory experiment then have a practical meaning and it is our feeling that such correlation could justify the use of laboratory experiments for the routine testing of persistence of pesticides in soil.

I am sure that you will recognise that these attempts to measure persistence are somewhat imprecise and much work still needs to be done before we have a finalised reliable technique for this measurement. But I do feel, and this is what I would like to emphasise, that persistence and the problems connected with it are of such importance that there is an urgent need to try to achieve a sound basis for the evaluation of this property which is inherent in many pesticides. National authorities concerned with pesticide registration will, I am sure, increasingly require data on persistence of pesticides to be included in registration submissions.

References:

(1) F. Bro-Rasmussen, K. Orbaek and M. Dahl (1969). Dansk Tidsskrift for Planteavl. Under publication.

(2) F. Bro-Rasmussen, E. Nøddegaard and K. Voldum-Clausen (1968) J. Sci. Fd. Agric. 19, 278.

Trends in Requirements for Residues Data in Wildlife and the Environment

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Introduction

This paper reviews the trend over the years for requiring more data for assessing possible risks to wildlife arising from the introduction of new pesticides, or, new uses of existing pesticides.

In the immediate post-war period a number of incidents of deaths to birds and small mammals suggested the need to provide an appraisal of possible hazards to wildlife before the general introduction of a chemical. In Great Britain, the consequences of the increased use of pesticides were first comprehensively studied by the Zuckerman Working Party which reported to Ministers in 1951, 1953 and 1955. The latter report on risks to wildlife dealt with the following terms of reference:

> "To investigate the possible risks to the natural flora and fauna of the countryside from the use in agriculture of toxic substances, including the possible harmful effects for agriculture and fisheries, and to make recommendations."

The Pesticides Safety Precautions Scheme

As a result of the first two Zuckerman Working Party reports, discussions had already commenced between industry and government departments which led to the inception of the present Pesticides Safety Precautions Scheme (earlier called the Notification of Pesticides Scheme until 1966). This voluntary scheme came into formal effect early in 1957 but informal consideration had been given to notifications as early as 1954. At that time, the notification arrangements emphasised studies on mammalian and avian toxicity designed to provide information, which when suitably applied, would prevent injury to domestic animals and wildlife. There was a preoccupation, however, with the known and possible risks to game birds, bees and fish, rather than a study of risks to all flora and fauna. It will be recalled that for many years certain wild mammals, birds or fish have been protected in some way by legislation (Papworth, 1965).

From its inception the Pesticides Safety Precautions Scheme did not overlook the need for notifiers to supply information on the possible risks to wildlife caused by the introduction of new chemicals. Information on toxicity to at least one avian species and to fish has nearly always been included in the preliminary data. When bees were likely to be exposed to risks (e.g. as a result of spraying insecticides on crops in flower), some knowledge of the toxicity of the chemical to bees was also requested. Because they were backlog chemicals extant prior to 1957, no formal data of a similar kind was considered for gamma-BHC, DDT and a number of other organochlorine compounds.

The cereal seed dressing incidents

In 1956 and following years (Turtle et al., 1963), increasingly large numbers of seed-eating birds were found dead in cereal growing areas in the spring. In 1960, and again in 1961, there was considerable public concern about the poisoning of birds (mainly wood-pigeons and other wild seed-eating birds but also a certain number of game birds) from cereal seed treated with aldrin, dieldrin or heptachlor insecticidal dressing as a protection against wire-worm and wheat bulb fly. These dressings had been introduced some years previously and although it was known they would be toxic to birds, it was thought no great risk would arise in practice provided the seed bed was reasonably well covered. However, as the use of such cereal seed dressings increased, there were bird casualties on quite a large scale. Following surveys and analyses organised by the Infestation Control Laboratory, arrangements were agreed with the manufacturers and others, in 1961, in which the use of these particular cereal seed dressings was for the future confined to the dressing of winter wheat and barley for protection against the wheat bulb fly. Few, if any, bird casualties had arisen in the autumn from the use of these seed dressings, largely no doubt because of the abundance of other foodstuffs at that time of the year, and under certain conditions at any rate these seed dressings were the most effective means of protecting winter sown cereals.

Following the successful voluntary ban on the seed dressings for spring sown cereals, this Laboratory presented a second report on pesticides and wildlife to government departments and other interested organisations in 1962. This report described (a) an investigation of any unusual deaths of birds or mammals likely to have been caused by insecticidal seed dressings or other toxic chemicals, (b) a planned survey of roosts in cereal growing districts designed to obtain an unbiased picture of the use of seed dressings and any deaths of wildlife that might be linked with their use and (c) investigational work on feeding gamma-BHC to feral pigeons and examining apparently healthy birds shot before the spring sowing period. This and other relevant work has been reported in more detail in the Infestation Control Laboratory's reports for 1962-64, (1965), 1965-67(1969), and other published papers.

The arrangements for investigating incidents reported in the field have continued from that time and indeed the continuation of this arrangement by the headquarters and regional pests offices of the Ministry of Agriculture, Fisheries and Food is a useful safeguard against any hazardous product passing the initial screening. In the main, the voluntary agreement has been honoured and no mass deaths of wild birds on the scale which occurred in earlier years has been reported. There have been occasional incidents of the deaths of birds due to very late sowing of winter dressed seed in January or early February.

Arising from the seed-dressing incidents was the knowledge that collecting residues data from wildlife specimens was of limited value. There was an urgent need to be able to interpret the significance of such data. Much work has been done by colleagues in my laboratory in recent years to acquire further evidence.

Known quantities of both DDT and DDD have been fed to pigeons and residues of the compound and its metabolites measured at intervals after cessation of feeding by Bailey, Bunyan, Rennison and Taylor (1969). A study has also been made by Bunyan, Page and Taylor (1966) of the 'in vitro' metabolism of DDT in pigeon liver slices and homogenates under both aerobic and anaerobic conditions. Enzymatic changes following DDT stress in Japanese quail have been investigated. A substantial amount of work has also been done to facilitate diagnosis on organophosphorus poisoning in birds by Bunyan and Taylor (1966) and Bunyan, Jennings & Taylor (1967 and 1968). Workers in other laboratories (e.g. Robinson, 1969) have also contributed much additional knowledge to help elucidate some of the many problems posed by the earlier incidents involving seed dressings.

The Joint Panel on Wildlife

The co-operative spirit that has been an essential element of the Pesticides Safety Precautions Scheme was not lacking when the seed dressing incidents began to attract attention. A small joint panel representing industry, relevant government departments and interested organisations drafted a document giving general guidance to a notifier on the amount and type of data which should be provided to assess possible risks to wildlife. This joint panel was wound up by voluntary agreement when Appendix D to the Safety Scheme was first published in 1959.

The Wildlife Panel

It was appreciated by the earlier joint panel that there would need to be some permanent specialist body capable of considering wildlife data contained in confidential notifications from industry. In 1959 the Scientific Subcommittee on Poisonous Substances used in Agriculture and Food Storage set up its Wildlife Panel which has since been in continuous operation. It consists of scientists with expertise or an interest in wildlife and most of them are also members of the Scientific Subcommittee. Additional specialist members may be co-opted when necessary.

Laboratory appraisal of potential risks to wildlife

Reference has already been made to the usefulness of preliminary chemical and toxicological data in assessing possible hazards to wildlife. A knowledge of residue levels in soil samples, effects of the chemical on beneficial insects and other invertebrates derived from early efficacy trials also assists in building up knowledge on possible effects to some species. The only initial indication of risks to birds may be derived from toxicity data on the domestic hen. Phytotoxic effects may be an early indicator of possible risks to flora. The persistence of the chemical and its metabolites on control plants in the laboratory may also give a clue to possible persistence when used outdoors under field conditions.

The desirability for common agreement on laboratory test procedures has been recognised for a long time. The Safety Scheme does not normally impose a standard technique if the notifier can satisfactorily demonstrate the relative risks of a new substance compared with similar chemicals or chemicals used for the same control purposes.

The kind of laboratory test which can be adopted may depend upon a number of factors, not least of which is the class of animals on which the experiments are being conducted. When fish toxicity tests are required, many notifiers find it convenient to use the Fish Testing Service provided by the Salmon and Freshwater Fisheries Laboratory of the Ministry of Agriculture, Fisheries and Food. Firms wishing to test pesticide products for toxicity to fish themselves may follow the recommended technique published as Working Document No. 6 to the Safety Scheme in 1966. Some firms use alternative methods and these are acceptable provided a product of known toxicity is used as a positive control.

Risks to bees have in the past been initially evaluated on laboratory data based on acute toxicity data. Two kinds of test may normally be done, namely topical application to the bee and direct feeding trials. Both types of test are required because in the field, contact as well as oral route of entry may be important. A Working Document outlining standard techniques for contact and oral toxicity testing of chemicals to honey bees has recently been drafted and will be issued as soon as industry and the Scientific Subcommittee have approved the final draft.

Risks to birds cannot easily be determined by limited trial feeding or exposure tests to caged birds. At the moment notifiers tend to submit acute and some chronic toxicity data for common birds easily kept under laboratory conditions. The evaluation of such information is often extremely difficult when trying to relate the results to potential risks in the field.

Studies of invertebrates can give a useful indication of both short-term and long-term effects on the different species. Laboratory studies of this kind are carried out on a very small scale but may need to be increased and be specially indicated when testing chemicals known to be persistent in the soil.

Field Appraisal of potential risks to wildlife

When the Safety Scheme was first introduced the main method of assessing risks to wildlife under field conditions consisted of examining limited laboratory data and making general field observations of a superficial nature. Farmers or users of the pesticide would be asked to observe wildlife, particularly any birds and large mammals seen in the treated area, and report evidence of dead bodies or affected animals. Refinements of this empirical method included the completion of written questionnaires, or the occasional visit of a trained biologist to make more detailed observations. Such methods were of very limited value even if organised before application of the chemical. Any insidious delayed effects passed unnoticed. The seed dressing incidents then highlighted the problems caused by relatively persistent chemicals accumulating in the environment. This led to the review of persistent organochlorine compounds (1964) and the realisation that subtle long-term effects on wildlife populations need to be detected at an early stage of development of a new pesticide. Incidentally, attention has recently been drawn to a similar problem involving prolonged phytotoxicity due to the presence of low levels of persistent herbicides in the soil.

In 1961 the first notifications for the use of some dinitro compounds as potato haulm killers were considered. The Advisory Committee on Pesticides and other Toxic Chemicals mindful of the earlier wildlife incidents involving these substances (as reported in the third Zuckerman Report) insisted on a specific set of field trials before it would agree to any provisional commercial clearance.

The result of this request was the drafting by the Wildlife Panel of Working Document No. 4 to the Safety Scheme. It was agreed with industry and published in 1966. The methods described therein were first used with the dinitro compounds on three or four suitable sites. The formulations were sprayed from conventional machinery on commercial crops. Contrary to what had been predicted, the trials produced no evidence that wildlife hazards had been created. Subsequently these compounds have been used on a very large commercial scale throughout the U.K. and there are no positive signs that wildlife has been adversely affected.

This working document has since been used by a number of firms as a basis for field testing other chemicals whenever initial notification data indicated such products might be harmful to wildlife when used in commercial practice. Modifications to the techniques have been necessary on occasions due to the nature of the formulation or method of use. The Infestation Control Laboratory has provided advice and guidance to many notifiers involved for the first time in using the working document, as have the Ministry's Regional Pests Officers and their staffs and our colleagues in the Nature Conservancy. The results of such field trials, when well executed, have enabled clearances to be given with more confidence as to the possible effects of commercial use on wildlife.

No specialist who has participated in a field trial based on the working document or read a well-written report of such a trial can feel confident that this appraisal method is entirely adequate or reliable. One of the primary reasons for doubt was pinpointed by the 'Review of the Present Safety Arrangements for the use of Toxic Chemicals in Agriculture and Food Storage' (1967). In paragraph 78 of the report appears the statement:-

> 'although the survey for assessing risks to wildlife described in one of these documents, has been used a number of times, it has not been tested for scientific validity in a control survey using one of the more toxic active ingredients. We recommend that at least one such official trial should be carried out and, if no bird deaths or other effects on wildlife occur, the document should be reconsidered.'

An attempt was subsequently made to check the validity of the document. but a combination of unforeseen events led to indefinite conclusions. The document has still to be adequately tested as recommended in 1967.

The difficulties arising in interpretation of such relatively large-scale field trials has led to demands for more data on the effects of chemicals on invertebrates in the soil and more extensive field trials using a wider range of indicator species.

The work of Edwards, Thompson and Lofty (1967) and of Newman (1967), provide examples of how direct and indirect effects of chemicals to plants and animals in the field can be evaluated with more precision.

Despite these major drawbacks no chemical, which has been recommended for commercial clearance following reports of field trials based on the working document, has subsequently been shown to be hazardous to wildlife. Even when such studies suggest little or no hazard to wildlife, a careful watch is kept for possible effects in the early stages of commercial use of some of the more toxic pesticides and I consider this an essential follow-up procedure. More detailed observations in the early years of commercial application would seem to be highly desirable but present many difficulties. It is during these early years in use that any unforeseen hazards of persistency, or, increasing soil residues and effects on food chains may be first detected. The present arrangements for investigating alleged incidents in the field are likely to detect any acute effects unexpectedly arising in commercial use.

Discussion

The flexibility of a voluntary scheme has enabled government departments, industry and conservation interests to introduce new or better evaluation techniques over the years. Such techniques used individually, or in comprehensive laboratory and field programmes, can still be questioned however, when an appraisal has to be made of likely effects to wildlife during the commercial life of a pesticide. How can the present methods be improved so that a comprehensive screening programme provides a more confident assessment?

Table 1 summarises the extent to which present methods may be employed under the Safety Scheme for the more common groups of indicator species. (See end of paper).

Studies on soil flora and fauna have been restricted to occasional laboratory studies and field observations by skilled or unskilled workers. This is largely the position with beneficial insects, especially predators of pest species.

Laboratory studies on bees and general observations in the vicinity of treated crops have enabled reasonable assessments to be made of the likely toxicity of new pesticides to the honey bee. The bee-warning scheme agreed between the department, industry and beekeepers has also proved to be helpful. It is hoped a working document will soon be agreed for carrying out a standardised procedure for checking effects on honey bees in the field.

The laboratory fish testing methods appear to have provided reasonable appraisals of pesticide effects. It would seem prudent however, to consider whether more positive field studies ought to be made. This could be done by having fish caged under suitable conditions in treated areas, or, studying limited stretches of waterway systems. The practical difficulties likely to be encountered are considerable.

The position of aquatic organisms other than fish has received less attention than other groups of indicator species. This may partly be explained by the practical difficulties to be overcome, but more attention to these organisms may be required in future when one considers the commercial clearances given under the Safety Scheme for aquatic herbicides.

Birds have been more widely studied than other indicators, primarily because they tend to be more easily seen and a wider knowledge of their biology and behaviour is available. Observations on mammals, particularly wild mammals, is less comprehensive than indicated by the above table. Much data is available on the common laboratory species and it may be justifiable in most cases to extrapolate laboratory observations to wildlife species. Field observations of effects of a chemical on mammal populations have been limited to trapping, recording of occasional dead bodies and sometimes the chemical analysis of certain tissues from such bodies.

In general, the methods for assessing possible risks to wildlife before a chemical is introduced commercially seem to be satisfactory in that incidents have not occurred from correct use of cleared chemicals.

The current methods are sometimes criticised because the size of suitable trial sites is limited. For example, when a trial is done on 10 to 20 acres, the range and population of bird or mammal species at risk may be very small. Other chemicals used in the vicinity could also be exerting an unknown influence. Because of these drawbacks those who criticise the present methods suggest hazards to wildlife may be more accurately assessed by studies on whole populations in larger areas after the chemical has entered commercial use.

However, a population decline (even if established rather than alleged) where a new chemical is being predominantly used is not adequate proof of cause and effect.

Even if this type of wider study was introduced instead of the present techniques, one could argue that the discovery of serious effects on wildlife at such a late stage is unacceptable. Furthermore, a hue and cry resulting from such incidents could unnecessarily hinder or prevent the use of an effective pesticide. The whole idea of the Safety Scheme is to prevent a chemical hazardous to wildlife reaching the market. This means the final answer will be a combination of both kinds of field evaluation permitting conclusions based on sound scientific principles rather than emotion and supposition.

The cost of enlarging the scope of evaluation methods must be borne in mind. Firms already spend very large sums of money in scientific research and development before a chemical can become a commercial success. There are already indications that the gap between research and development expenditure and likely profits from a new pesticide is narrowing. Farmers and other users of pesticides are rightly conscious of any added expenditure when only marginal improvements in the quality or quantity of food produced can be achieved. At the moment however, expenditure on wildlife trials is a very small percentage of total development costs. It was calculated that each of the earlier field trials for assessing risks from the dinitro compounds involved about 150 man hours. In such circumstances it would seem justifiable, when preliminary data so indicate, for government departments to request more sophisticated field trials.

The interests of government departments, industry, conservationists and the public will increasingly demand that chemicals are not released for commercial use until the possibilities of risk to any forms of wildlife have been accurately evaluated.

Council of Europe

The second edition of the Council of Europe's booklet 'Agricultural Pesticides' has just been published and a new feature of this edition is the chapter on guidance on wildlife data to be supplied by manufacturers to national authorities when registering pesticides. In general the Council of Europe guide covers a wider range of possible tests than the United Kingdom Pesticides Safety Precautions Scheme. This guide represents a general agreement by countries participating in the Partial Agreement on the amount of information that may be required to support a registration.

Studies relating to risks to wildlife are the province of the European Committee for the Conservation of Nature and Natural resources, which is also a Council of Europe body. Close liaison between this European wildlife committee and the Council of Europe's sub-committee on Poisonous Substances in Agriculture, which was responsible for the booklet, has been established and the wildlife committee fully supports the guidance on wildlife data requirements.

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References

'Toxic Chemicals in Agriculture: Report of the Working Party', H.M.S.O., 1951, London.

'Toxic Chemicals in Agriculture: Residues in Food - Report of the Working Party', H.M.S.O., 1953, London.

'Toxic Chemicals in Agriculture: Risks to Wildlife - Report of the Working Party', H.M.S.O., 1955, London.

'Pesticides Safety Precautions Scheme', Ministry of Agriculture, Fisheries and Food, Pesticides Branch, Great Westminster House, Horseferry Road, London, S.W.1.

Papworth, D.S. J. forens. Sci. Soc., 1965, 5, 66-72

Turtle, E.E., et al J. Sci. Fd Agric., 1963, 14, 567-577

Infestation Control: A report on the work of the Infestation Control Laboratory, 1962-1964, H.M.S.O., 1965, London.

Infestation Control: Report of the Director of the Infestation Control Laboratory, 1965-1967, H.M.S.O., 1969, London.

Bailey, S., et al Toxic. appl. Pharmac., 1969, 14, 13-22

Bunyan, P.J., Page, Jane M., and Taylor, A. Nature, 1966, 210, 1048-9

Bunyan, P.J., and Taylor, A. J. agric. Fd Chem., 1966, 14, 132-7

Bunyan, P.J., Jennings, D.M., and Taylor, A. J. agric. Fd Chem., 1967, 17, 1027

Bunyan, P.J., Jennings, D.M., and Taylor, A. J. agric. Fd Chem., 1968, 16, 332-9

Robinson, J., Chemical Fallout 1969, Chapter 7, 113-69. Charles C. Thomas, Springfield, Illinois, U.S.A.

'Review of the Persistent Organochlorine Pesticides', Parts I and II, H.M.S.O., 1964, London.

'Review of the Present Safety Arrangements for the Use of Toxic Chemicals in Agriculture and Food Storage', H.M.S.O., 1967, London.

Edwards, C.A., Thompson, A.R., and Lofty, J.R. Proc. 4th Brit. Insecticide and Fungicide Conf., 1967, 48-55.

Newman, J.F. Proc. 4th Brit. Insecticide and Fungicide Conf., 1967, 45-7

'Agricultural Pesticides' - Council of Europe, Strasbourg 1969, 52 pps., 2nd Edition.

TABLE 1

The extent to which techniques currently available are used under the Pesticides Safety Precautions Scheme to assess hazards to wildlife

	Laboratory Studies on Toxicity, Metabolism, Persistence etc.	Laboratory Studies on Toxicity by Standard or agreed techniques	Field Observations by skilled or unskilled workers	Field Trials (e.g. by Working Document No. 4.	Field Trials using sophisticated techniques
Soil flora and fauna	——		————		
Beneficial insects	————		——		
Bees	————	————	——		
Fish	————	————	——		
Other aquatic organisms	——				
Birds	————	- - - -	————	————	
Mammals	————	- - - -	————	——	

The continuous line indicates methods are available and used under the Pesticides Safety Precautions Scheme. A half-line indicates a partial use of available methods. A broken line represents acceptable methods not designed for assessing wildlife hazards.

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CAN HAZARDS TO WILDLIFE BE ASSESSED BY FIELD TRIALS BEFORE REGISTRATION?

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CONSERVATION AIMS

Pesticides are always toxic to some organisms, otherwise they would not be used; and since none are specific to pests they are bound to affect other species as well. The British Pesticides Safety Precaution Scheme, like other registration schemes in other countries, is designed to reduce hazards to non-target species. The main concern is for Man, especially for operators and for those who consume the treated crop. Secondly, there is concern for domestic animals and honey bees, which may feed in the treated area. Thirdly, there is concern for wild animals which may feed or shelter in the sprayed area or may come in contact with pesticides outside it. Obviously there is much more concern for Man than for wildlife; in the case of Man, the aim is to prevent harm to each and every individual, whereas for many wild animals hazard to individuals is often acceptable and the principal concern is for populations. The requirements for wildlife are not self-evident; before we can discuss procedures for predicting the effects of pesticides on wildlife and so reduce the hazards, it is essential to clarify the underlying purposes. Why should we conserve wildlife at all, and what priorities should be adopted?

Wildlife is a renewable natural resource which is valued by society for a number of different reasons. Some species provide food or clothing, whose economic value can be assessed like crops and domestic animals; in some countries wild animals provide the principal source of protein for Man, for example paddyfield fish in parts of tropical Asia, and antelope in parts of Africa. In Britain, game birds, wildfowl, deer, hares, freshwater and marine fish are relatively less important as a source of food than domestic animals, but their contribution to our diet is not negligible and their sporting value in some cases is very great; in many districts of Britain income derived from fishing, shooting and deer stalking far exceeds that which can be obtained from agriculture or rearing stock.

For those who are concerned with crop protection, outbreaks of pests may seem to be the rule rather than the exception, but in fact, potential pest species are frequently, and in many cases, are usually controlled by natural predators and parasites. The economic value of these beneficial species and of pollinating insects must be immense, but since it is very difficult to quantify, it is often overlooked or taken for granted. In addition, many species are of great aesthetic, educational and scientific value to the community; with increasing leisure in an increasing population their economic value will steadily grow; but it is, of course, impossible to make adequate financial estimates of the cultural value of wildlife.

Conservation of wildlife is a national aim in an increasing number of countries. Conditions vary, but the underlying intention of all conservation authorities is to maintain biological diversity for future generations (Moore 1969). There is special concern for species in the following groups:-

1. Species which are essential to the maintenance of the ecosystems to which they belong (e.g. nitrifying bacteria in the soil, common planktonic organisms in coastal waters)

2. Species of known economic value (e.g. commercial fish, whales and game birds)

3. Species of special aesthetic, educational and scientific value (e.g. many flowering plants, butterflies, birds and mammals)

The vast majority of species do not fall into these categories. Wildlife is best protected by protecting habitats - in Britain this is partly achieved by a series of National Nature Reserves which are selected as representing all the main habitats found in this country. Pesticides, like other pollutants, tend to reduce biological diversity, therefore special measures have to be taken to reduce this effect. In practice the control measures taken are mainly concerned with species in the last two categories mentioned above.

PESTICIDE EFFECTS

When a pesticide is used it always has complex and interacting direct and indirect effects. Theoretically only one type of effect - acute toxicity - can be predicted reliably by laboratory studies. Many species will be affected every time a pesticide is applied, yet in practice, toxicological data, on which assessments have to be made, will always be restricted to a very few species. Since it is well known that there is great interspecific variation in response to the same chemical, toxicity data on indicator species can only give a very general idea of toxic effects in the field. Some insecticides, notably those which are not metabolised rapidly, can cause delayed toxicity: predators can die as a result of eating prey containing the pesticide. Many of the most important effects of pesticides on organisms are due indirectly and not directly to toxicity: owing to differential effects on food, predator and competitor species, the application of an insecticide can have considerable indirect ecological effects, and these cannot be studied in the laboratory. Yet, field experiments in which the fauna of sprayed plots is compared with that in unsprayed controls will usually only provide information about the net results and not about the detailed causes of those results.

Consideration of two theoretical cases will show the difficulties inherent in ordinary pre-registration testing.

1. The use of a completely specific pesticide. Toxicological tests would show that this compound was "harmless to wildlife"; a short term field trial would confirm this, yet if the pest species was an important one in the crop ecosystem, its total destruction might have important indirect ecological repercussions. A good example of the complexity of the effects which result from the elimination of a single species is well shown by the effects of myxomatosis on the rabbit (Oryctolagus cuniculus) in Britain. The Myxoma virus is harmless to animals other than rabbits, yet the destruction of rabbits by this disease has caused complex changes in vegetation throughout the country and striking declines in a number of plant and animal species in a wide variety of habitats.

2. The use of a total insecticide which kills all animals in the treated crop. Toxicity tests and field trials would show that this compound was "hazardous to wildlife". Yet if the areas treated were small and reservoirs of wildlife existed nearby, the treated areas would be quickly recolonised with little or no harmful effect on the species concerned.

From the wildlife point of view, the crucial question is this - does a significant amount of the pesticide come in contact with a significant proportion of the population of the species under consideration? The answer to this question will depend on:-

1. The scale of use.
2. The ability of the pesticide to disperse from areas of application - this will largely depend on its persistence.
3. The extent to which animals are attracted from outside the area to the treated area.
4. The amounts consumed by individual animals.

During recent years none of the new pesticides cleared under the Pesticide Safety Precaution Scheme appear to have caused serious damage to wildlife (Moore 1968). Was this due to the effectiveness of toxicological testing and field trials in predicting hazards, or was it due to the pattern of use of most of the pesticides?

In Britain, crop patterns are so diverse and the average field size is so small that the territories of very few birds are entirely covered by any one spray application. Therefore, very few chemicals, even if highly toxic to birds, will kill enough individuals to have a significant effect on the populations. I suggest that the fine grain of the pattern of most British crop systems has provided an important safety factor in protecting wildlife from serious damage by the more toxic pesticides which we use in Britain. If the crop patterns were different, and some of the more toxic compounds were used over large contiguous areas, they might cause serious damage to wildlife. In other words, such chemicals are only acceptable from the conservation point of view so long as their use is localised. The main wildlife problems have been caused by the use of moderately to highly toxic pesticides which were not only used extensively, but were also sufficiently persistent to affect environments outside the sprayed areas. One special case is worth considering for the light it throws on pre-registration testing.

A TEST CASE

It is generally accepted that the use of aldrin, dieldrin and heptachlor as cereal seed dressings killed more birds and seriously affected more populations than any other pesticides which have been used in Britain to date, (Moore 1968). This is extraordinary when one considers that in this particular form of use very small amounts of insecticide were used in each acre (about 2 oz). Further, it was applied only where it was needed (on the seed corn) and appeared to be out of reach of animals above the soil. This particular use was withdrawn in Britain in 1962 by voluntary agreement between Government Departments and Industry. Aldrin, dieldrin and heptachlor were introduced into Britain before the Pesticide Safety Precaution Scheme was in operation. It is pertinent to ask whether the particular hazard resulting from their use as seed dressings would have been predicted by the scheme as it exists today. Acute toxicity tests would have shown that these compounds were highly toxic to birds and mammals. If a field trial of the type outlined in Working Document No. 4 had been done on heavy land after a wet spell, and if a large number of birds had been present in the area under observation, heavy casualties might have been spotted. However, it is much more likely that the field trial would have been done under different conditions and the crucial information would not have been obtained. The crucial information was the fact that under certain circumstances enough corn was left on the surface after ordinary ploughing, to attract seed-eating birds. These then fed on the corn to such an extent as to cause their deaths, and the deaths of bird and mammal predators which fed upon them. Work at Monks Wood (Jefferies and Prestt 1966 and Jefferies personal communication) has shown that a Peregrine (Falco peregrinus) need only eat three contaminated pigeons, and a Kestrel (Falco tinnunculus) only seven contaminated mice in order to be killed. Incidentally, this sort of information would not have been obtained under existing requirements! It is unlikely that the normal procedure of the Pesticide Safety Precaution Scheme would have shown up the peculiar hazards to wildlife provided by the spring use of aldrin, dieldrin and heptachlor as cereal seed dressings.

Consideration of the seed dressing case suggests that toxicological testing backed by field trials of the kind recommended in Working Document No. 4, will not provide an infallible basis for the prediction of pesticide effects on wildlife. Already we have seen that it is theoretically unlikely that they would. Refinements of existing techniques are obviously possible and desirable and will be discussed later today, but I think we have to accept that no one can produce a foolproof pre-registration scheme for assessing risks to wildlife. The only way to obtain a scientific basis for predicting wildlife risks is to study the effects of a pesticide under a wide range of conditions in the field; in practice this can only be done when the compound has come into widespread commercial use, that is after its initial registration.

ASSESSMENT OF HAZARDS AFTER REGISTRATION

Up till now causes of serious damage to wildlife due to pesticides have come to light haphazardly; game-keepers and naturalists have reported incidents e.g. (Cramp and Conder 1961) and some of these have been investigated by officials of the Ministry of Agriculture, Fisheries and Food. At present no attempt is made to make objective scientific studies of effects of new compounds on wildlife during their first few years of use. Yet, since toxicological studies and limited field trials cannot give adequate information, it is obvious that post-registration studies are necessary at least when new chemicals are likely to be used on a large scale.

The scientific requirements for post-registration studies are relatively simple. In the first instance a trained biologist should study what actually happens after the application of a new spray in a wide range of circumstances in the field. He could do this partly by sending a questionnaire to farmers who were willing to make observations, but he would have to make as many observations as possible himself. It is obvious that the report 'no damage observed' has practically no significance if it merely means that a farmer has not noticed anything unusual in the course of his work, but it means much more if a farmer, and very much more if a trained observer, has looked for specific effects and not observed any. If the preliminary study revealed wildlife casualties under certain circumstances, these should then be investigated by further observations and by field experiments.

In this paper I have done no more than show that there are good theoretical and practical reasons for believing that the answer to the question posed by the title of my talk is 'no', and that the inevitable corollary is this - for every new pesticide which is likely to be used extensively, objective studies should be made on its possible effects on wildlife during its first years of use. Post-registration studies pose difficult administrative problems both for Industry and the authorities responsible for the registration of pesticides. This Conference provides us with an excellent opportunity to discuss them.

References

CRAMP, S. and CONDER, P.J. (1961) Report No. 1 of the B.T.O. - R.S.P.B. Committee on Toxic Chemicals.

JEFFERIES, D. J. and PRESTT, I. (1966) Brit. Birds, 59, 49.

MOORE, N.W. (1968) in Some Safety Aspects of Pesticides in the Countryside. London, 73 (reprinted in Internat. Pest Control 11, 27).

MOORE, N.W. (1969) Biol. Conserv. 1, 201.

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NEW APPROACHES TO CABBAGE ROOT FLY CONTROL

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Summary Control measures for the cabbage root fly have undergone considerable changes during the past 100 years. These range from the application of materials that repel or prevent the flies from attacking brassica plants to synthetic insecticides. Until resistance developed to the organochlorines few direct problems occurred from the use of these insecticides, but indirectly their persistence produced undesirable effects on the natural enemies of the pest. This has been avoided with the alternative organophosphorus insecticides (O-P's). The integration of natural mortality of the root fly, plant tolerance to larval damage and insecticide control could lead to less insecticide being used if accuracy of application could be made reliable.

With the possibility of resistance arising to the O-P's other concepts for cabbage root fly control are being investigated. Studies on the ecology and behaviour of the adult flies have indicated several lines of approach. These include chemosterilisation from food-based lures, pest management from the restriction of natural food sources and oviposition decoys that induce the female to lay away from the host plant. Knowledge of the stimuli needed to elicit host plant recognition and oviposition may also be useful in the selection of resistant plant material.

EVOLUTION OF CONTROL MEASURES

Early methods for protecting brassica crops from cabbage root fly (Erioischia brassicae) attack were aimed principally at deterring or preventing the flies from laying their eggs around the plants. Deterrence was sought by treating the roots of plants, or the soil around them, with substances such as ashes, lime, sulphur, tar-gas water, carbolic or napthalene, to mention but a few, but none of these substances were reliable without frequent retreatment which was impractical on a large scale (Curtis, 1860). Prevention from attack was more successfully achieved by covering the seed beds with cheese cloth or the soil around the base of the plants with tarred felt discs (Slingerland, 1894). It was not until the beginning of this century that the first really effective insecticide-corrosive sublimate (mercuric bichloride) - was used (Glasgow, 1925) but because of its high toxicity to both plants and animals it was replaced by calomel (mercurous chloride) which is less toxic. Calomel remained insecticidally active for several months when used as a 4% dust applied along the row, to the soil at the base of the plants or as a root dip, provided that the protective barrier of dust was not broken. Even so, two or three applications were often necessary to guarantee effective control (Wright, 1952). Calomel acts as an ovicide and, like all subsequent insecticides, it had to be applied before egg laying started. In addition to chemical methods, some control was obtained from crop rotation and also cultural practices such as the destruction of infested plants, the avoidance of growing succulent host crops in the autumn, such as swedes and turnips which carry large overwintering populations, and growing seed crops away from main brassica areas (Schoene, 1916). Again, the control by these methods was not reliable and it was not until the development of the organochlorine insecticides (O-C's) with their considerable insecticidal potency and persistence in the soil that a reliable control was achieved (Wright, 1954). Unfortunately, the persistence of these insecticides, although helpful for cabbage root fly control, was too great and left residues in the soil. After several years' application these residues accumulated to levels that were toxic to the natural enemies as well as the eggs and larvae of the cabbage root fly. Not unexpectedly, after about 15 generations of root flies had been exposed to continuous selection by these insecticides, resistance to the most commonly used chemicals, aldrin and dieldrin, and cross resistance to gamma BHC, developed in several parts of the country (Coaker, T.H. et al 1963; Gostick and Baker, 1964). Very severe damage occurred on some crops where resistance developed. This arose partly from the failure of the insecticide to control the resistant strains and partly from the destruction of natural enemies which normally impose a high level of root fly control (Mowat and Coaker, 1968). The principal natural enemies of the cabbage root fly are carabid and staphylinid beetles that prey on its immature stages and hymenoptera and staphylinids that parasitise its pupae (Hughes and Salter, 1959; Coaker and Williams,1963). Under normal conditions, predation accounts for about two-thirds of the 90% natural mortality of the immature stages (Hughes, 1959), and consequently any reduction in natural enemies permits a greater survival of the pest. Dieldrin residues of about 0.1 p.p.m. in the soil have reduced the numbers of beetle predators present in brassica crops and increased survival of root fly eggs and larvae leading to augmented damage on a variety of brassicas. This resulted in reductions in yield of up to 70% when compared with crops grown on untreated soil (Coaker, 1966).

Alternative insecticides were found amongst the organophosphorous compounds (O-P's) (M.A.F.F., 1965). When compared with the O-C's the persistence of O-P's is only fractional and so to achieve the best results accurate application is essential. Throughout the history of cabbage root fly control, application procedures have always been given serious attention. Because the O-C's gave an almost complete control and rarely any serious phytotoxicity problems, however, casualness in their use was not uncommon and broadcast treatments were frequently employed on widely spaced brassica crops. These features together with the broad spectrum toxicity of O-C's tended to move insecticidal control of cabbage root fly away from more rational methods. The shorter persisting O-P's, however, are costlier, are not efficient unless accurately applied and can be phytotoxic if carelessly applied. These chemicals are likely, therefore, to be used more rationally, i.e. applied to the site where minimum doses only are needed to give the required level of control (Dunn and Coaker, 1965). In addition, the shorter persistence of O-P insecticides should not produce long-term effects on the populations of natural enemies. Chlorfenvinphos, the O-P now widely used for cabbage root fly control, is selective and at the recommended rates of application it is not toxic to predatory beetles in the soil (Mowat and Coaker, 1967). This insecticide, therefore, possesses some necessary properties for use in an integrated control system.

Organophosphorus insecticides rarely give a complete control of larval damage but recent experiments have shown that a high level of control is needed only during the first few weeks after transplanting (Coaker and Finch, 1965). Once the plants are established and passed their early growth, they are then able to withstand injury without serious reductions in yield (Coaker, 1968). This means that with accurate placement, compounds with even shorter persistence than those currently recommended could be used. As a consequence, this should reduce insecticidal selection of root fly populations where brassicas are grown intensively and delay the development of resistance. The likelihood of resistance arising to the present groups of insecticides is, however, still possible and the current research programme at the N.V.R.S. is orientated towards the development of alternative methods.

NEW CONCEPTS OF CONTROL

The cabbage root fly has a high natural mortality (Hughes and Mitchell, 1960), has little innate dispersal tendency (Mowat and Coaker, 1968) and can be chemosterilised (Swailes, 1966). It has also been shown that flies recognise the host plants by chemical stimuli characteristic of cruciferae (Traynier, 1965 and 1967a) and that plants are able to tolerate some larval damage. With this knowledge it was decided to study the behaviour of the adult fly and to assess the possibilities of attracting of flies to baited lures. This approach to the sterilisation of the field population seemed more feasible than the release of sterile insects because, although cabbage root flies can be reared in the laboratory in large numbers (Finch and Coaker, 1969a), to rear the numbers required to compete with field populations of 50,000 flies/acre would be an enormous and unnecessarily expensive task. Also eradication of the species, which is the usual objective of a sterile release technique, is not necessary with the cabbage root fly since the host plant can withstand some damage.

This study has concentrated on the movement of the flies in the field and the factors governing their movement such as feeding and ovipositional requirements. It has now progressed from experiments designed to elucidate adult behaviour to preliminary experiments involving chemosterilisation.

FIELD BEHAVIOUR

In the field most flies were found to be confined to the hedgerow during the morning, and to move to the crop to lay their eggs during the afternoon and return to the hedgerow in the late afternoon. This pattern of activity was determined by trapping flies in 6 in diameter yellow water-traps which were highly attractive to the flies. The capture data also showed that there was a distribution gradient out from the hedge (or barrier) that was independent of wind direction and shelter effects, suggesting that the flies aggregate at these sites by visual attraction. The decline in the density of flies from hedge outwards was sharper for males than for females indicating that males stayed at the hedges longer than females probably because this was the site where mating occurred. Since more flies were caught at the hedge than at a comparable shelter made of wooden lathes, the presence of hedgerow flowers from which they feed probably arrested more of the flies at the hedge (Hawkes, 1968). In addition, more immature females stayed at the hedge than mature females, a behavioural difference possibly linked with feeding requirements. Flies marked with ^{32}P were released at different sites in relationship to brassica crops and the rates of dispersal were estimated from the numbers of flies recaptured in yellow water-traps placed at different distances from the release points. When released away from a crop, most immature flies dispersed towards the hedgerows at an average rate of 250 ft/day. On reaching maturation at the hedgerow the females moved at a rate of 400 ft/day when they orientated their movement upwind towards a brassica crop. Once in the crop their movement became more random and slowed to a rate of 60 ft/day. Having reached a crop; therefore, mature flies are unlikely to disperse away from it more rapidly than this and, consequently, they would not mix with a population half-a-mile away in a 30-day life span. The information so far obtained on the activity of the adult cabbage root fly suggests that female flies find the host crop probably from odour stimuli derived from the crop and that their movement is relatively slow once they have found a host crop/hedgerow complex suitable for feeding and oviposition. Diurnal movements between the crop and the food sources in the hedgerow affect the numbers of the flies in the crop at any period of the day.

Thus the behaviour of this species makes it amenable for the application of a sterilisation technique and since the flies aggregate at hedgerows and barriers these are likely to be the best sites for lures. One important question remains unanswered, however, and that is at what stage of maturity do the female flies reach the host crop? If the majority of flies feed, mature and mate at the hedgerows in the vicinity of the new host crop, sterilisation would be more effective than in the situation where the flies reach the crop mature and mated (Hawkes, 1969).

FEEDING BEHAVIOUR

Before the cabbage root fly lays its eggs it must feed on carbohydrates which it obtains in the field principally from the nectar of umbellifers and the pollen and anthers of grasses (Finch, 1968). The fly does not have to feed on protein to lay the first batch of eggs (about 60 eggs/female) but protein is essential for the maturation of subsequent batches (Finch and Coaker, 1969a).

The effects of nutrition on the fecundity of the flies in the field has been assessed in two ways. Firstly, flies were caged in large tents (50' x 10' x 6') which enclosed a section of hedgerow containing natural food sources and a plot of brassica plants, and the eggs were counted. Secondly, abdomens from females caught in the field were analysed chemically to determine whether they contained the free amino acids necessary for maturation of the second batch of eggs. The stage of egg development in the flies analysed and also the number of egg batches laid as indicated by the presence or absence of corpora lutea in the ovarioles were determined and compared with the free amino acid contents of the flies. In the field the main sources of food for the flies were hedge parsley (Anthriscus sylvestris) and white dead nettle (Lamium album) during May and hogweed (Heracleum sphondylium) and cocksfoot (Dactylis glomerata) during July, the times of the first and second generation of flies, respectively (Finch and Coaker, 1969b). On no occasion during these experiments did the average fecundity of the flies in the tents exceed 60 eggs/female, the size of a single batch of eggs, indicating that the majority of flies fed only on carbohydrates and laid only the first batch of eggs. This was confirmed from the examination of field flies since the tests showed that none of the first and only 13% of the second generation had fed on protein and of these only 6% had matured a second batch of eggs. The diet of flies in the field is, therefore, rich in carbohydrate and low in protein. Only a few plant species are sources of highly nutritive carbohydrate for the first generation flies so that the management of these may lead to other means of limiting infestations of the pest. The lack of protein feeding in the field is attributable to the low concentrations of essential amino acids present in the feeding sites because, at higher concentrations certain of these amino acids, e.g. leucine, are good feeding stimulants. When they are in mixture with sucrose they cause the flies to imbibe more solution than they do when it contains only sucrose. Food baits containing sucrose and a feeding stimulant should, therefore, enhance the effectiveness of a chemosterilising or toxic bait by causing the fly to imbibe excessively (Finch, 1969).

CHEMOSTERILISATION

In laboratory tests, over 90% of the eggs laid by flies fed during the 2nd and 3rd days after emergence on a 0.1% of the chemosterilant Tepa in a sugar solution, were sterile whether laid by normal females mated with treated males or treated females mated with normal males. Mated female flies which fed on the chemosterilant prior to oviposition also laid a similar percentage of sterile eggs. Females mated with sterile males produced sterile eggs throughout their lives, even when the sterile males were replaced with normal males after mating.

In a preliminary experiment, flies were sterilised under field conditions in a tent enclosing part of a hedgerow and a brassica crop. Four yellow traps containing a mixture of Tepa, sucrose and leucine absorbed in cotton wool were placed on the ground 2 ft apart and 2 ft away from the hedge. Two hundred male and 200 female newly emerged flies were released into the tent and the food lures were maintained in the tent for a week. Of the eggs laid around the crop over 70% were sterile compared with 6% when Tepa was not included in the lures. In both tents, an average of 30 eggs/female was laid. Although the high level of sterilisation was achieved with flies confined in a tent, the principles derived from the behavioural studies have proven to be applicable to the siting and composition of the lures. Experiments in open field situations will test these principles further and will evaluate the addition to the lures of chemicals which have been shown in laboratory tests to stimulate the flies into greater activity and to increase the number of flies attracted to traps.

INSECT/HOST PLANT RELATIONSHIP

Observations on adult flies in the laboratory and field suggest that oviposition behaviour can be interpreted as essentially a chain of fixed action patterns, triggered off by specific stimuli and culminating in egg laying. These stimuli enable the fly to find and identify its host plant or elicit oviposition in the soil around the base of the plant, and they can be visual or chemical.

It has been shown that the orientation of flies upwind towards a brassica crop is possibly stimulated by the odour of the crop. In the laboratory, traps baited with juice extracted from cruciferous plants attracted four times as many female flies and twice as many male flies as those containing water. Attraction may not have been the only stimulus that caused more flies to enter the baited traps since host plant odour has also been shown to stimulate the flies into greater activity (Traynier, 1967a). The degree of attractiveness depended on condition and sex of the flies. Mated gravid female flies were the most responsive, whereas immature flies and flies that had laid their eggs were the least responsive (Coaker and Smith, 1968). These results are analogous with field observations which showed that only mature female flies moved towards the crop. Activity as a response to odour is not sufficient to distinguish between excitatory (attractant) or inhibitory (repellent) odours and so other techniques have been developed to identify a stimulatory odour. Behavioural tests indicated that flies detected the odour by sense organs in their antennae and so the response of these sense organs to odour was examined electrophysiologically. This was done by an electroantennogram (EAG) method which measures the change in electrical potential resulting from the stimulation of the sense organs when odour is blown over them (Schnieder, 1966). Several chemicals present in brassica odour (MacLeod and MacLeod, 1968) elicited responses similar to those given by cabbage juice but the magnitude of the responses was different and indicated the relative stimulatory level of the constituent odours. The character of each odour was then assessed on flies in an olfactometer and this enabled different types of response to be recognised. Odours entering the olfactometer through an illuminated port evoked a different response in the flies depending on whether the odour was an attractant or a repellent. Attractant odours caused more flies to settle on the port than were attracted to it by light alone and repellent odours reduced the numbers settling. Increased catches of flies in traps baited with chemicals shown to have attractant characteristics have been obtained in the laboratory but these attractants have not yet been tested in field lures.

On arrival at the crop the flies alight on the host plant and receive a contact chemical stimulus that encourages the flies to move down the plant to the soil. The irregular surface of the soil then stimulates the fly to extend its ovipositor and to search for a suitable crack in which to lay its eggs. The contact-chemical oviposition stimulus can be obtained with the mustard-oil glucosides and their derivatives that occur naturally in cruciferous plants (Traynier, 1965). The response to oviposition stimulants is also correlated with their concentration since there is an optimum concentration eliciting maximum egg laying (Traynier, 1967b). In a recent field experiment, the ovipositional preference of cabbage root fly was assessed on several varieties of rape containing different amounts of thioglucosides. The numbers of eggs laid around these varieties was found to be positively correlated with the thioglucoside content of the plants, increasing by 50% for a four-fold increase in total thioglucosides.

CONCLUSIONS

At present, satisfactory insecticidal control of cabbage root fly can be obtained on most crops attacked by the pest. Most recommended methods aim at rational control and this implies the minimal practical use of insecticides. This does not mean, however, that improvements cannot be made. The selection of compounds with a low toxicity to beetle predators would allow natural control to proceed unhindered and permit its full contribution towards the control of this pest. In addition, the presence of predators helps to suppress violent fluctuations of root fly populations (Hughes and Mitchell, 1960). Improvements in methods of insecticide application may encourage a reduction in the amount of insecticide applied, since it may only be necessary to control damage during the early stage of growth and not over several months as was once practiced.

Alternative methods of control to conventional insecticides will be needed should resistance arise to the types of insecticides being used for cabbage root fly control. The alternatives being considered are chemosterilisation, pest management and plant resistance. To develop any of these methods will be necessarily a long term task demanding a thorough knowledge of the various ecological and behavioural aspects appropriate to each project. The approach adopted for developing a chemosterilisation method at Wellesbourne should soon reveal its practical feasibility. Should this method prove to be impractical, the information obtained from the study of the adult fly will be useful for other methods. For instance, the dependence of the fly on specific hedgerow plants as sources of carbohydrates, particularly limited in variety during the first generation, may offer an opportunity of pest management since these plants could be eliminated. Although this suggestion may immediately appear to conflict with the principles of conservationists, only a limited area may need to be cleared in order to reduce the number of flies in the vicinity of the crop. A successful reduction of first generation flies, from either chemosterilisation or the elimination of the food sources may also have benefits to confer by limiting the size of the following generations.

The identification of the chemical stimuli that elicit the flies to oviposit may have several uses. The volatiles present may add to the attractiveness of lures, or a contact chemical oviposition stimulant may provide the basis for an oviposition decoy. Also quantitative analyses of these stimulants in plants may be useful for the selection and breeding of resistant varieties.

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References

COAKER, T. H. and WILLIAMS, D. A. (1963) Ent. exp. et appl. 6, 156.
COAKER, T. H., MOWAT, D. J. and WHEATLEY, G. A. (1963) Nature, Lond. 200, 664.
COAKER, T. H. and FINCH, S. (1965) Pl. Path. 14, 1.
COAKER, T. H. (1966) Ann. appl. Biol. 57, 397.
COAKER, T. H. (1968) Ann. Rep. Nat. Veg. Res. Stn. for 1967, 73.
COAKER, T. H. and SMITH, J. (1969) Ann. Rep. Nat. Veg. Res. Stn. for 1968, 73.
CURTIS, J. (1860) Farm Insects, 141.
DUNN, J. A. and COAKER, T. H. (1965) Ann. appl. Biol. 56, 342.
FINCH, S. and COAKER, T. H. (1969a) Bull. ent. Res. 58, 619.
FINCH, S. and COAKER, T. H. (1969b) Ent. exp. et appl. (in press).
FINCH, S. (1968) Ann. Rep. Nat. Veg. Res. Stn. for 1967, 74.
FINCH, S. (1969) Ph.D. Thesis, Univ. of Birmingham.
GLASGOW, H. (1925) Bull. N.Y. Agric. Exp. Stn. No. 512.
GOSTICK, K. G. and BAKER, D. M. (1968) Ann. appl. Biol. 61, 447.
HAWKES, C. (1968) Ann. Rep. Nat. Veg. Res. Stn. for 1967, 74.
HAWKES, C. (1969) Ph.D. Thesis, Univ. of Birmingham.
HUGHES, R. D. (1959). J. anim. Ecol. 28, 343.
HUGHES, R. D. and SALTER, D. D. (1959) J. anim. Ecol. 28, 231.
HUGHES, R. D. and MITCHELL, B. (1960) J. anim. Ecol. 29, 359.
MACLEOD, A. J. and MACLEOD, G. (1968) J. Sci. Fd. Agric. 19, 273.
M.A.F.F. (1965) Pl. Path. 14, Suppl.
MOWAT, D. J. and COAKER, T. H. (1967) Ann. appl. Biol. 59, 349.
MOWAT, D. J. and COAKER, T. H. (1968) J. appl. Ecol. 5, 591.
SCHNEIDER, D. (1963) Proc. 1st Int. Symp. Olfaction and Taste Stockholm, 1962, 85.
SCHOENE, W. J. (1916) Bull. N.Y. Agric. Exp. Stn. No. 419.
SLINGERLAND, M. V. (1894) Cornell Univ. Agric. Exp. Stn. Bull. 78, 572.
SWAILES, G. E. (1966) J. econ. Ent. 59, 596.
TRAYNIER, R. M. M. (1965) Nature 207, 218.
TRAYNIER, R. M. M. (1967a) Ent. exp. et appl. 10, 321.
TRAYNIER, R. M. M. (1967b) Ent. exp. et appl. 10, 401.

WRIGHT, D. W. (1952) Rep. 13th Int. Hort. Congr., 1.
WRIGHT, D. W. (1954) The Grower <u>41</u>, 293.

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THE DEVELOPMENT OF DISEASE ASSESSMENT METHODS

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Summary For the development of disease assessment methods for use in the field in England and Wales some basic principles have proved particularly useful. The three main types of method involve a) counts of affected plants b) description keys or c) diagrammatic keys. For the keys representations of the percentage area diseased are used and the most suitable visually distinguishable categories are usually 1, 5, 10, 25, 50, 75, and 100 per cent. For individual diseases and for specific purposes additional aids such as growth stage keys are also essential if uniformity of recording is to be obtained.

INTRODUCTION

In this country interest in disease assessment was first stimulated by the Plant Pathology Committee of the British Mycological Society at a symposium it organised in 1933 on the measurement of plant diseases. Nearly ten years later, the Committee set up a sub-Committee to develop assessment methods for recording the incidence of diseases in the field. Plant pathologists at research stations and at the advisory centres tested the tentative methods in the field and by 1948 methods had been proposed for nine diseases; all but one of these involved counting infected plants using a specified sampling procedure. The exception was potato blight for which a descriptive key was provided (Anon 1947). The usefulness of such uniform methods of recording was quickly appreciated by the advisory plant pathologists working in the field and so immediately after the National Agricultural Advisory Service was formed the advisory plant pathologists, after a joint meeting in 1947 with members of the British Mycological Society's Committee, set up a Disease Assessment Committee to develop further methods for their particular needs: the other Committee was disbanded (Anon 1948). A few years later, in 1950, a small unit was established at the Plant Pathology Laboratory to help further the work on disease assessment methods but with particular reference to their use for estimating national losses caused by plant diseases. Since then developing, testing and extended survey use of field assessment methods has been a collaborative effort between the Plant Pathology Laboratory and advisory plant pathologists with help from appropriate research workers.

Methods for recording the incidence of diseases in the field need to be quick and easily used by different people to give uniform records. They are needed for many rather different purposes; for instance they may be needed to record the progress of an epidemic, to distinguish between the efficiency of different fungicide treatments or to determine differences in varietal susceptibility to diseases. The detailed methods used by research workers are often too time-consuming and unnecessarily detailed for such field use but they can often be successfully adapted.

GENERAL PRINCIPLES

It was also about 1950 that Chester (1950) in the United States made an invaluable contribution to disease assessment by compiling a comprehensive treatise on plant disease loss appraisal including all the relevant world literature on the subject. All the successful methods that have been developed are based on the principles he set out so clearly: these principles are not as widely appreciated as they should be.

The basic requirements for field assessment methods are that they should:-

a) enable reasonably accurate assessments of disease incidence to be recorded numerically;

b) be so defined as to be repeatable so that different people will make similar assessments;

c) whenever possible, provide a basis on which estimates of loss can be made.

Each disease and each host plant presents different problems and the development of methods often necessitates many detailed observations on both the pathogen and host. Some of the problems and ways of overcoming them have been described by Large (1966). For disease assessment, recording plant diseases can be considered in two groups. Firstly, the 'systemic' diseases for which counts of affected plants, usually recorded as percentages, can be used and incidentally can often then be readily converted to loss estimations. Rot diseases of fruits and tubers and other storage organs can also be recorded in this way. The accuracy of such methods depend on the ease with which the symptoms can be recognised and the adequacy of the sampling methods used. Surveys in this country for several diseases have been made using such methods (Large 1966). Secondly, for the majority of diseases, methods involving the identification of grades of infection are needed. The all too frequently used grading scales described merely as slight, moderate and severe or in categories 0-5 or 0-9 with no further explanations, are not helpful. Descriptions of the different degrees of infection are essential if different workers are to be able to compare their experiences. The attempts so far made to provide such descriptions are usually in the form of descriptive or diagrammatic keys.

DESCRIPTIVE KEYS

The first descriptive key, used in this country, for potato blight (Anon 1947) has stood the test of time remarkably well and has also been used widely in many other countries. One of its greatest assets is the wide range of uses it serves: the early stages of an epidemic can be adequately recorded using the lower categories, represented by the 0.1 and 1 per cent levels which are described in terms of numbers of lesions on individual plants; while for later stages, of significance when yield loss due to foliage attack is the main consideration, descriptions of field appearance of the plants are provided (Large 1958). For apple scab descriptive keys referring to numbers of lesions present on specified sample units on trees have also proved useful (Croxall <u>et al</u>. 1952 a) and b)). A similar descriptive key for tomato leaf mould was used by Beaumont (1954) for fungicide trials.

A slightly different approach was taken for a field key for cereal mildew developed primarily for making estimates of yield loss and most relevant on plants at growth stages between heading and before ripening (see Large 1954). This key gives descriptions of the levels of infection usually found on the top four leaves individually for different percentage infection levels of the total leaf area on these four leaves: a diagrammatic key illustrating different levels of infection was also included. Using this key a relationship between percentage infection and yield loss was established for a series of trials (Large and Doling 1962).

DIAGRAMMATIC KEYS

For many diseases the different levels of infection have been successfully illustrated by diagrams depicting the typical appearance of the disease on a standard representation of the plant or part of plant on which the disease occurs. Some workers have prepared photographs, usually in black and white but colour prints have also been advocated: these aids do not seem to be as generally useful as diagrams, particularly because other blemishes are apt to be confusing.

Experience in compiling and using standard diagrams has shown very clearly two important aspects that need to be covered. Firstly, the unaided eye tends to overestimate the amount of infection present particularly about the 50 per cent cover level. Also, up to this level the eye tends to assess the diseased areas while over this level it tends to assess the healthy tissue. A very good illustration of this unaided 'eye' effect is given in a recent paper on the assessment of tomato leaf mould (Smith <u>et al</u>. 1969): eye estimates reached a maximum overestimation of about 12 per cent at the middle of the infection range.

Secondly, visually distinguishable infection levels are often in logarithmic sequence and hence a series of levels each double the one below appears to give the most helpful series. One of the earliest diagrammatic scales, the Cobb scale for cereal rusts produced in 1912, illustrated the infection levels 5, 10, 20 and 50 per cent. Most of the successful and widely used scales have some or all of the levels 1, 5, 10, 25, 50, 75, (95), 100 per cent infection.

The key for common scab of potatoes (Large and Honey 1955) was one of the earliest to be used in this country: the levels were based on this principle and although fractions were then used the 1/16 and 1/8 diagrams are visually indistinguishable from 5 and 10 per cent. This diagram can be used in two ways. Often the recording of infection in tuber samples needs only to differentiate between tubers with more or less than a certain level of infection: a figure for the percentages of tubers with more than the specified level is then sufficient. For more detailed studies an index may be required. Lapwood (1966) used the levels depicted in the diagram together with one lower one representing 1/32 of the area affected, for his research investigations on the disease. He recorded the number of tubers with more than each of the illustrated infection levels and then took the median percentage figure between each of the limiting levels for his index calculations.

Another widely used key, for use on whole plants, was devised by Clarke and Corke (1956) for field assessment of black currant leaf spot. This key depicts 30 representative bushes with different amounts of leaf infection associated with different levels of defoliation caused by the disease. For recording, these are used as guide levels and individual bushes are scored for 'actual' percentage attack. Unfortunately this key cannot be used for the early stages in the development of the disease.

A slightly different type of diagram was devised by James (1967) for estimating the percentage area of barley leaves attacked by leaf blotch. The lesions caused by the disease vary considerably in size and may or may not be associated with death of leaf tissue beyond the lesion itself. During work on the losses caused by this disease a relationship was found between infection on each of the top two leaves at growth stage 11.1 and yield loss. It became obviously desirable to record the incidence of other diseases in a similar way at the same time. Consequently the diagram included in the descriptive cereal mildew key and a modification of diagrams available for yellow rust infection (Manners 1950) are now being used.

The use of these diagrams for the different diseases has enabled us to make surveys for diseases occurring in commercial barley crops in this country (James 1969) and is proving useful for recording trials designed to provide data on losses caused by the diseases. It has also shown the importance of the need for careful definition of the growth stages at which records are made. It is hoped that further use of this approach, using appropriate leaf sampling methods will prove useful for field trial and survey work on other crops in the future.

References

ANON. (1947) Trans. Br. mycol. Soc. 31, 140.

ANON. (1948) Trans. Br. mycol. Soc. 31, 341.

BEAUMONT, A. (1954) Pl. Path. 3, 21.

CHESTER, K. S. (1950) Pl. Dis. Reptr, Suppl. 193.

CLARKE, G. M. and CORKE, A. T. K. (1956) Rep. agric. hort Res. Stn Univ. Bristol for 1955, 196.

CROXALL, H. E. *et al*. (1952a) Pl. Path. 1, 39.

CROXALL, H. E. *et al*. (1952b) Pl. Path. 1, 89.

JAMES, W. C. (1967) Proc. 4th Br. Insectic. Fungic. Conf. 1, 111.

JAMES, W. C. (1969) Ann. appl. Biol. 63, 253.

LAPWOOD, D. H. (1966) Pl. Path. 15, 9.

LARGE, E. C. (1954) Pl. Path. 3, 128.

LARGE, E. C. (1958) Pl. Path. 7, 39.

LARGE, E. C. (1966) A. ref. Phytopath. 4, 9.

LARGE, E. C. and DOLING, D. A. (1962) Pl. Path. 11, 47.

LARGE, E. C. and HONEY, J. K. (1955) Pl. Path. 4, 1.

MANNERS, J. G. (1950) Ann. appl. Biol. 37, 187.

SMITH, P. M. *et al*, (1969) Ann. appl. Biol. 63, 19.

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SLUGS AND THEIR CONTROL

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Summary Little quantitative information is available on the status of slugs as pests of horticultural and agricultural crops, but it is clear that they cause considerable damage throughout the temperate regions of the world. Some progress has been made towards establishing life cycles and distribution of numbers of slugs in space and time. Methods are being developed for predicting damage on a field scale and research on timing and formulations for chemical control is in progress. New chemicals, particularly carbamates, are showing promising activity against slugs.

INTRODUCTION

No published estimates are available on the economic losses caused to most crops but Strickland (1965) estimated from Potato Marketing Board Surveys that in an "average" year, 35,000 to 40,000 tons of potato tubers are lost because of slug damage, at a cost to the farmer of £3 million. In addition, extra costs of riddling and sorting potatoes and loss in value of whole crops due to the presence of some holed tubers are incurred. Strickland also estimated that 41,000 acre equivalents of wheat would be lost annually if no control measures were taken. N.A.A.S. advisers suggest (Hunter, in press) that about 20,000-30,000 acres of winter wheat are redrilled in an average year due to slug damage.

Slugs also cause extensive losses to sugar beet, newly sown grass leys, carrots, brassicas, flowers and bulbs and this damage probably exceeds the value of damage to wheat and potatoes. It has been suggested that the cost of slug damage to brussels sprouts in Huntingdonshire and Bedfordshire alone exceeds that to wheat throughout England and Wales. A further aspect of the economic importance of slugs, which has received very little attention, is their role in the transmission of plant diseases (e.g. cabbage leaf spot - Hasan and Vago, 1966) or parasites of domestic animals (e.g. sheep lungworm - Williams, 1942).

In an attempt to estimate the importance of slugs on a world scale, Ministries of Agriculture in all temperate countries were asked for their views on the status of slugs as pests. From their replies and official leaflets or bulletins published in their country, slugs were ranked as of major or minor importance. Of the 21 countries consulted, 14 replied. In three of these countries, U.S.S.R., Belgium and Sweden, slugs were regarded as pests of major importance. In the remaining 11 countries, they assumed a similar status to that in the U.K. Considerable damage occurred on some crops in some seasons, but this was localised and sporadic. Many replies confessed that little information was available and in no case was there an estimate of the acreage involved. It was apparent, however, that on a world scale slugs are pests of some significance.

BIOLOGY AND ECOLOGY

There is very little information on the distribution and abundance of slugs and the life cycles of even the commonest species have not been fully established. The grey field slug (<u>Agriolimax</u> <u>reticulatus</u>) usually has breeding seasons in the spring and autumn of each year. When cultures of these slugs are kept out of doors with an adequate supply of food and moisture, they can reach maturity in as little as three months. However, natural populations do not always have adequate food and moisture and may take a whole year to mature. Thus, there may be two overlapping generations at any particular time: a spring generation giving rise to the spring generation of the following year and an autumn generation giving the next autumn generation. The black garden slug (Arion hortensis) has usually an annual cycle, hatching about July and maturing to lay eggs when about a year old. A few of these slugs hatch later in the year and are not ready to lay their eggs until they are about 20 months old. The keeled slug (Milax budapestensis) has an annual or biennal cycle. The eggs hatch in the spring and early summer and those slugs which hatch early in the year are able to lay eggs within a year. The later hatching slugs do not mature before the summer of the following year and for some reason do not lay their eggs until the autumn. These eggs hatch in the following spring - a generation interval of almost two years.

There is probably considerable variation in the life cycles of slug species between different years and between different parts of the country. A recent comparative study of the life cycles of the black garden slug in East Anglia and in South Wales revealed that there was an annual cycle for this species in both regions, but the South Wales slugs bred up to a month earlier. There is now some evidence that the life cycle of the grey field slug can vary even more (Hunter and Symonds, unpublished). Much more work is required on the simple biology of these animals.

No definite conclusions about the effect of environmental factors on the distribution and abundance of slugs can yet be made. Three short population studies (South, 1962, 1964; Hunter, 1966, 1968a, b, c; Hunter and Symonds, unpublished) showed that the density of slug populations are affected mostly by the weather. Populations are reduced in density by drought during the summer and frost during the winter. Weather may have a still greater effect on population density by regulating the length of generation interval than by varying the death rate during cold or dry periods (Hunter, 1966). It is probable that visiting flocks of birds can significantly reduce slug population density, but it is unlikely that resident parasites, predators or disease make more than a minor impact.

PREDICTION OF SLUG DAMAGE

Slug damage is particularly prevalent after crops such as peas or clover, where there has been an adequate supply of shelter during the summer (Gould, 1962). Damage can also be expected after a wet summer or a mild winter when numbers have not been depleted by drought or frost.

Methods of predicting damage on a field scale are now being evaluated. It is not possible to predict slug damage with the precision that is attempted for eelworms, where an estimate is made of the level of attack to be expected if no control measures are adopted. Slugs are aggregated and fairly sparsely distributed so that large samples of soils are required to provide enough animals for estimating population density. However, less accurate methods of population estimation would allow advice to be given and whether or not the crop appears to be at risk.

The present methods are based on small samples of the crop put down in the field just before the main crop is planted. For wheat, groups of 10 wheat grains are put out in the field; the grains are protected from mice and birds by enclosing them either in lengths of P.V.C. tubing, or in disposable petrie dishes which are perforated by holes large enough for the slugs to enter. Preliminary tests have shown that, although this method is promising, more work is required on the timing for prediction readings. For potatoes, Maris Piper or King Edward tubers are placed just under the soil surface about a month before planting. In a preliminary trial, the prediction tubers gave a reasonably good indication of crops which subsequently suffered significant damage (Table 1).

Table 1.

Prediction of slug damage to potatoes

Field	1	2	3	4	5	6	7	8	9	10
% damage to prediction tubers	65	15	15	10	10	10	5	0	0	0
% damage to crop Sept. 5th	8.9	3.3	2.6	3.1	2.7	2.5	1.2	0	0	0
% damage* to crop Oct.4th	39	32	23	29	15	-	-	0	-	0

* No readings taken where the crop was already lifted.

CONTROL

Because of the probable marginal effect of resident predators and parasites on slug populations, it is unlikely that any biological method of control can be usefully employed against slugs. Cultural and chemical methods of control show greater promise.

Unfortunately, cultural methods of reducing slug populations are often incompatable with maintaining the soil structure of heavy soils where slugs are commonest. Extra cultivations can kill slugs (Hunter, 1967) and avoiding ploughing in crop residues or surface vegetation can reduce numbers. Farmers should avoid leaving trash on the soil surface during late summer, do everything possible to improve seedbed conditions (Gould, 1962), avoid growing susceptible varieties of potatoes (Gould, 1965; Winfield, Wardlow and Smith, 1967) or lift slug-susceptible crops as early as possible.

Development of chemical control of slugs can be expected to follow two paths. Firstly, a number of improvements could be made to baits. More toxic active ingredients could be used so that most slugs feeding on the baits are killed. This has been achieved with the introduction of methiocarb and it has been shown (Crowell, 1967; Hunter and Johnston, in press) that other carbamates are also toxic. Metaldehyde baits give significantly better control with higher concentrations (Hunter and Symonds, unpublished) suggesting that metaldehyde formulations could also be improved. Baits could also be improved by adding "attractive" agents. Recent work by Stevenson at Rothamsted suggests that it may be possible to isolate the attractive ingredients of the more susceptible varieties of potatoes. Application rates could also be increased, provided that treatment remains at a cost acceptable to the farmer. The number of "killing points" per unit area should be greater than that offered by most baits at present on the market (Hunter and Symonds, in press). Webley (1962, 1963, 1964, 1965) has demonstrated the dependence on weather of slug control by baiting, and it would clearly be an advantage if at least the less mammalian-toxic baits could last longer. Persistence could be achieved by adding a protective coat to the bait (Webley, 1966), encapsulation (Potter, 1967)" or by adding glues or stickers to the bait.

Secondly, new formulations are required to overcome the intrinsic disadvantages of baits. Sprays would be of value for a quick kill of slugs on crops such as strawberries or brassicas. Slow release granules, incorporatea into potato ridges at planting, could give control of slugs as they move in towards the seed tubers in the spring. Seed dressings would prove useful for controlling slugs on winter wheat. Gould (1961) demonstrated that seed dressings of metaldehyde and copper compounds are not very satisfactory, but some of the more toxic carbamates may be suitable. There is also some evidence that some carbamates are repellant to slugs and could also be used for seed dressing.

INTEGRATION OF CONTROL MEASURES

The most effective way of integrating control measures with the ecology of pests is often to apply treatments when pest populations are low, but farmers are unlikely to take routine proportions against an animal which only intermittently becomes a pest. Control can, however, be integrated with the life cycles. The breeding seasons of slugs occur over most of the year, but treatments can be applied before most of the eggs are laid. For example, if a seed dressing does not become available an attempt should be made to control the main slug pest of wheat, the grey field slug, before the autumn breeding season. Control of slugs on potatoes should be most effective in the spring before the spring breeding season of the grey field slug and the summer breeding of the garden slug. Some keeled slugs will already have laid at this time, but many will be killed before they can lay their eggs in the spring. A spring treatment for slugs on potatoes would also allow the chemical to be incorporated into the soil for control of underground species.

Integration of control measures also implies that care should be taken when applying wide-spectrum toxicants like the carbamates, so that wild life and beneficial soil invertibrates are not seriously depleted. It does not necessarily follow that toxic wide-spectrum chemicals present more hazards to wild life and beneficial soil invertibrates than less toxic narrow-spectrum ones. The more toxic chemical may be applied less frequently, at lower rates and in a less available form.

CONCLUSION

It is hoped that recent renewed interest in the slug problem by universities, agricultural chemical firms and Government research establishments will result in more efficient methods of chemical control and better knowledge of how to use these chemicals. However, more research is required before prediction methods are available to warn farmers that particular crops are at risk and adequate treatments are available to give a reasonably high probability of success.

REFERENCES

CROWELL, H. H. (1967) J. Econ. Entomol. 60, 1048.
DUTHIOT, C. M. (1961) Pl. Path. 10, 165.
DUTHIOT, C. M. (1964) Pl. Path. 13, 73.
GOULD, H. J. (1961) Pl. Path. 10, 142.
GOULD, H. J. (1962) Pl. Path. 11, 147.
GOULD, H. J. (1965) Pl. Path. 14, 109.
HASAN, S. and VAGO, C. (1966) Plant Dis. Rept. 50, 764.
HENDERSON, I. F. (1969) Ann. app. Biol. 63, 167.
HUNTER, P. J. (1966) J. Anim. Ecol. 543.
HUNTER, P. J. (1967) Pl. Path. 16, 153.
HUNTER, P. J. (1968a) Malacologia 6, 369.
HUNTER, P. J. (1968b) Malacologia 6, 379.
HUNTER, P. J. (1968b) Malacologia 6, 391.
HUNTER, P. J. and SYMONDS, B. V., Ann. appl. biol. (in press)
HUNTER, P. J. AND JOHNSTON, D. L., J. Econ. Entmol. (in press)
POTTER, C. (1967) Rep. Rothamst. Exp. Sta. for 1966".
SOUTH, A. (1964) Ann. appl. Biol. 53, 251.
SOUTH, A. (1965) and J. Anim. Ecol. 34, 403.

STRICKLAND, A. H. (1965) J. Roy. Soc. Arts (1965), 68.
WEBLEY, D. (1962) Ann. appl. Biol. 50, 129.
WEBLEY, D. (1963) Pl. Path. 12, 19.
WEBLEY, D. (1964) Ann. appl. Biol. 53, 407.
WEBLEY, D. (1965) Ann. appl. Biol. 56, 37.
WEBLEY, D. (1966) Nature 212, 320.
WILLIAMS, D. W. (1942) J. anim. Ecol. 11, 1.
WINFIELD A. L., WARDLOW, L. R. and SMITH, B. F. (1967) Pl. Path. 16, 136.

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METHODS OF PREVENTING BIRD DAMAGE

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In our attempts to prevent or reduce damage by birds we have basically two options: either to remove the birds or to protect the crops. Neither approach is likely to provide a complete or simple solution to our problems and the action that is taken in any particular situation should depend on circumstances. It is not my intention to consider any techniques in detail but rather to discuss the framework of possibilities having regard to the limitations imposed by biological, practical, social and economic factors.

BIRD CONTROL

The concept of preventing damage by killing the offending animals must be as old as agriculture itself. When the destruction is related to a specific damage situation then the protection achieved is proportional to the success of the killing operation. In these circumstances there is no attempt to reduce the bird population as a whole but simply to kill those individuals that attack the crop. The value of the exercise can be assessed by a simple cost-benefit analysis and this will be valid whatever level of damage reduction is achieved.

A very different situation exists when an attempt is made to reduce the population size in the belief that total damage is directly related to the total number of birds. Such a straightforward relationship rarely exists in the case of damage to crops and even in the case of collisions between birds and aircraft the strike rate is not a simple function of numbers. What is even more important to realise is that, within a population, mortality from different causes is not necessarily additive. Thus an increase in predation - in this case killing by man - is often offset by a reduction in mortality due to other causes. Since nuisance birds are among the most vigorous of species it can be confidently predicted that an annual kill of the order of 75% of the population would be required in order to effect any real reduction in the population. Such a high rate of kill on a mobile and widely dispersed species is difficult to achieve under any circumstances. Thus, having regard to the strictures that are usually placed on the killing of birds it should be recognised that true population control is an unrealistic objective. Nevertheless it may often be useful to kill birds within a limited and well defined situation and the question arises as to technique. The Protection of Birds Acts of 1954 and 1967 provide the first guidance since certain methods are prohibited and others permitted only under licence. The methods that may be used by an "authorized" person are shooting and the use of a net or cage trap. Their main advantage lies in the fact that they can be highly selective and, theoretically at least, afford no hazard to protected species. Shooting is the more demanding method in terms of labour but gives rise to a supplementary benefit of scaring birds, which in fact may be more valuable than the killing. However, neither method can deal adequately with large numbers of birds and both must be considered rather inefficient. The use of poisoned or stupefying substances is more appropriate to the destruction of large numbers of birds but here the problem is one of safeguarding protected species. Ideally substances should be selectively toxic at the species level and some progress has been made in this direction. For the moment however selectivity is usually achieved through refinement of the baiting technique, while the use of a stupefacient rather than a lethal agent provides an additional safety factor. The use of a toxic gas to fumigate premises infested by birds is an alternative possibility although in Britain this method has been legal for less than two years and has so far been little used.

Perhaps the method of bird control that is attracting most attention at the present time is the use of chemo-sterilants. The current search for more effective human contraceptives has led to the discovery of numerous chemical compounds which interfere with the physiology of reproduction. Some of these substances effectively inhibit the reproduction of birds but their use in the field presents at least as many problems as the use of a poisoned bait. It is inherent in the mode of action of these chemicals that they cannot affect the occurrence of bird damage in the short term since there is no immediate change in bird numbers. Any reduction in damage can only occur in the long term and as a consequence of genuine population control. This is an unrealistic approach on a national scale owing to the sheer enormity of the task but where the distribution of a species is discontinuous then it may prove possible to effect control within the natural limits of particular local populations. The pigeon populations of cities and towns spring to mind as possibly being vulnerable to baiting with chemosterilants and research on this subject is proceeding both here and in the United States.

CROP OR COMMODITY PROTECTION

There is no need to dwell on the merits and drawbacks of cages and nets for the exclusion of birds from vulnerable crops. On a garden scale they may be satisfactory but commercially the cost is usually considered prohibitive; however the advent of the integrally extruded mesh made of strong, durable, inexpensive plastic may significantly change the economics of protecting high value crops. Black cotton was at one time used extensively against birds and the modern version, a cobweb of fine rayon fibres, has proved very popular in vineyards and orchards. For winter use, as a means of protecting fruit buds against bullfinches, a cocoon-like treatment can be considered and I believe such processes to be already feasible if not yet practicable or economic. Such a process might not only give physical protection against the depredations of birds but also camouflage the buds so that they would be unrecognisable as food. This effect might be enhanced if the material was brightly coloured.

A more usual approach to the protection of crops and structures against birds is the application of some chemical reputed to have repellent properties. Such a material might be expected to affect the olfactory, gustatory or tactile senses of the bird. The sense of smell is generally believed to be very poorly developed in most species of birds and thus aromatic substances are not likely to prove very efficacious in repelling them. The sense of smell is, however, closely related to taste and it might be difficult to separate one from the other in some circumstances. Birds possess few taste buds compared with mammals yet hens and pigeons have been shown to be capable of discriminating between certain simple flavours. However, taste seems to play little or no part in food selection this being based mainly on size, shape and, to a less extent, colour in the species studied. It therefore seems improbable that a hungry bird would be repelled by a substance affecting taste alone. The third sense to be considered is that of touch and there is no doubt that this is well developed in birds, the tongue and buccal cavity being particularly sensitive. In my opinion it seems at least probable that many of the repellents believed to act through the sense of taste in fact exert their effect by imparting an unpleasant texture to the food. This effect might be apparent only within a narrow band of particle size and this could possibly account for some of the variability that is normally noted in the birds' response. It is well known that birds are highly sensitive to the nature of the surface on which they stand and a number of very successful repellents consist of greasy or gelatinous coatings which can be applied to perching places. Such materials are quite unsuitable for use on edible crops although the treatment of dormant fruit trees is a possibility. There is a danger, nevertheless, of seriously affecting the physiology of the trees if the lenticels are permanently blocked and also of damaging the cork cambium.

A condition that I will call "conditioned repellency" but better known as "bait shyness" can arise when an animal eats a sub-lethal amount of a toxic substance. It is less well known in birds than in mammals but it does occur. Perhaps a close study of this phenomenon would yield useful information on the mechanism of repellency.

Although the degree of crop protection achieved by the use of repellents is, in my opinion, very small indeed the demand for materials of this nature increases all the time. The greater the precision with which a crop is grown the greater is the impact of damage and as other pests and diseases are brought under control the relative importance of bird damage steadily increases. It would certainly be very convenient if bird problems could be solved by applying a repellent as a seed treatment or spray application but this succeeds only in certain circumstances.

FRIGHTENING DEVICES

Visual and acoustic stimuli can also be used to repel birds and together they form the basis of most scaring mechanisms. Any sudden noise or unusual object has a startling effect but this soon wears off and birds cease to respond. Often this is because the sound or image is not meaningful to the bird. For instance a loud bang is only a noise unless the bird has learned to associate such noises with danger through being hunted. Current thinking on bird scaring favours the imitation of natural danger signals which will have immediate significance to the bird. Models of predatory animals if carefully made and presented can resemble the real thing and create varying degrees of alarm in birds but practical difficulties are often experienced in doing this and much more work has been devoted to the use of acoustic signals. The standard technique, now fairly well known, is to record the distress call of the troublesome species and to play this back to birds in the field. It is most useful against social species that rely strongly on vocal communication and of least use against solitary birds and those that communicate by visual signals; unfortunately the wood-pigeon (Columba palumbus) is in the latter category. A typical reaction is for birds to fly up, approach the source of the sound, circle a few times, then disperse. The important difference between this and most other bird scaring techniques is that both the call and the pattern of behaviour with which birds respond to the call are innate. Any tendency for birds to habituate to these calls will have negative survival value and should therefore have been eliminated by natural selection. Although the response behaviour of the birds may be modified after repeated exposure to the broadcasts it is my experience that complete habituation does not occur. Unfortunately the broadcasts create a lot of noise and the technique is only suitable for use in remote areas. It is hoped to reduce the total output of sound by using different calls which will produce a response when played for a very short time. There is no prospect of overcoming the noise problem by the use of ultrasonic frequencies since the hearing range of most birds is very similar to that of man. The curious biological effects produced by very low frequency sound, flashing lights and pulsed radiation all require further investigation to discover whether they can usefully contribute to the problems of scaring birds.

Finally I should like to draw attention to the avoidance of bird problems, for more can be done in this direction than is usually realised. Seed can often be drilled a little deeper than usual, it can be more carefully covered and spillage can be avoided. Where bullfinches are numerous it is as well to avoid growing the varieties of fruit most susceptible to damage and the birds can be further discouraged by trimming hedges and generally reducing the amount of available cover. When intensive cattle rearing units are established, thought should be given to the handling and presentation of the feed with a view to preventing access by starlings (Sturnus vulgaris). Attacks on newly born lambs by crows (Corvus corone) and great black-backed gulls (Larus marinus) can be reduced by good husbandry and especially by in-bye lambing. In the case of stored products a great deal can be done by designing buildings to be bird proof and if the exterior is devoid of ledges it will not be colonized by feral pigeons (Columba livia var). Bird damage is not likely to weigh heavily in the mind of someone about to build a warehouse or plant a new orchard yet over a period of say 30 years birds could be a significant factor in productivity. Even though the opportunities may be few and far between we should aim to prevent rather than cure.

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BIOCHEMICAL MODES OF ACTION OF FUNGICIDES

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Summary A dynamic picture will be given of vital functions of the fungal organism.

The site and mode of action of a series of agricultural fungicides on these vital functions will be indicated and discussed.

To give a lecture on the mode of action of fungicides means to talk, at the biochemical level, about the mode of interaction of fungicides with fungi. This subject can be approached from either the side of the fungitoxic agent or the side of the organism. We thought that for todays discussion it might be of interest to put the organism in a central position and not, as is done so often, the compounds. The plants which have to be protected will remain out of discussion.

Thus I should like to focus on the normally functioning fungus and put up the question: What does the fungitoxic agent do to this organism, where and how does it attack? Which are the vital functions that are disturbed by the presence of the agent? I will attempt to draw up a dynamic picture of the vital functions of the organisms and of the harm the fungicides are doing to them.

Fungicides commonly used in agriculture as well as some experimental fungicides will be considered in this discussion. There is, however, so much to tell that I have had to make a choice. Thus I will leave the antimildew agents more or less out of discussion; in their action the plant may sometimes be closely involved.

In 1966 Ekundayo published a picture of a transverse section through a germinated spore of Rhizopus arrhizus as seen by the electron microscope. It clearly shows some of the organelles of the cell: the wall, the cytoplasm, the nucleus, the mitochondria. The ribosomes are too small to be visible. They are small bodies, lying scattered in the cytoplasm.

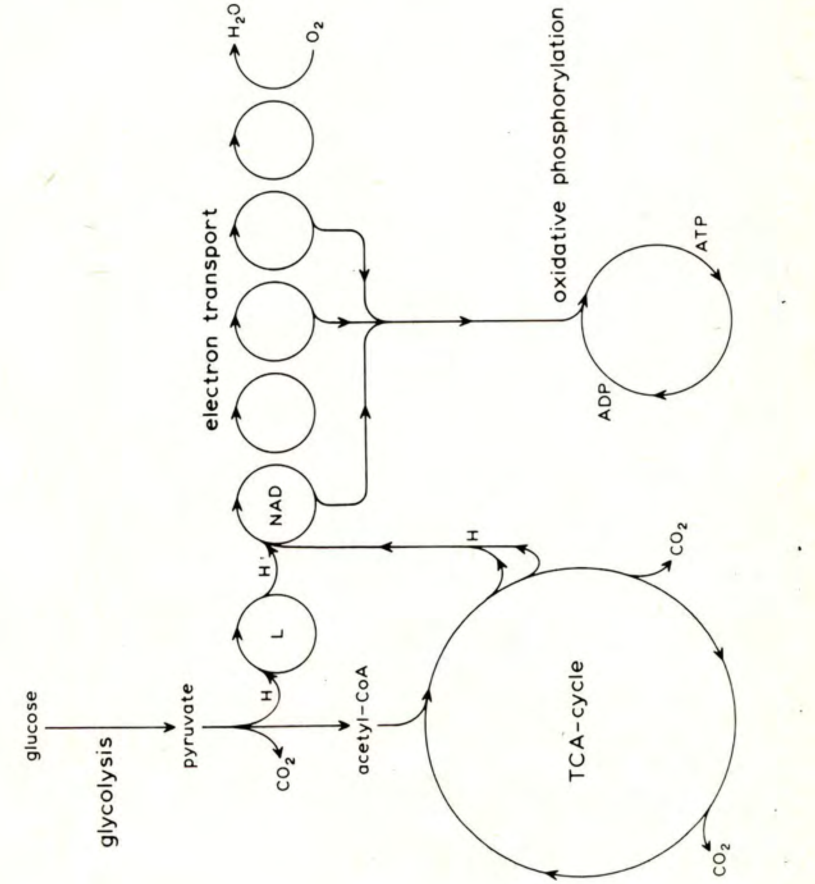
Each of these organelles has a special function in cell life. The processes leading to the production of energy or in other words ATP formation start in the cytoplasm where glycolysis of glucose to pyruvate takes place. Since some years we know that the oxidation of pyruvate proceeds in fungi via the tricarboxylic cycle like in higher plants and animals (cf. Ainsworth). This process as well as hydrogen or electron transport and oxidative phosphorylation which lead to ATP production are located in the mitochondria.

For growth not only energy production but also biosynthesis is required. In the cytoplasm the low molecular compounds like for instance amino acids, purines and vitamins are synthesized; in the ribosomes protein synthesis takes place and, mainly in the nucleus, DNA and in part RNA production is effected.

This surely is a very rough picture of some vital activities and their location in the fungal cell. Yet it is helpful for a consideration of the mode of action of fungicides. All the work that gradually has been done in this field seems to indicate that most of these compounds at their lowest growth inhibiting concentration act rather specifically only on one vital cell function, localized at one certain site. Thus one can speak of fungicides which are primarily inhibitors of energy production whereas others are inhibitors of biosynthesis and still others destroy the structure of the cells.

Figure 1

Processes involved in the production of ATP from glucose (simplified)



L = lipoic acid

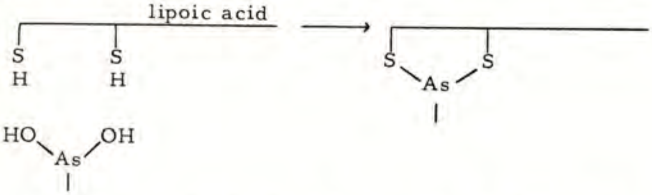
N.B. Only part of the hydrogen which is transferred to NAD by the various dehydrogenases has been indicated.

Let us look at energy production (or ATP formation) by the aid of Fig. 1. In the fungus a sequence of four main processes leads to production of ATP: namely glycolysis of glucose to pyruvate; oxidation of pyruvate to CO_2 via acetyl-CoA and the tricarboxylic cycle; hydrogen or electron transfer via flavin enzymes and cytochromes to form water with oxygen present, and finally: oxidative phosphorylation to form the energy-rich compound ATP from ADP. These four processes are coupled in such a way that inhibition of each leads to inhibition of oxygen uptake or in other words inhibition of respiration, as well as to inhibition of ATP production.

Many enzymes are involved in these four processes, but I would like to draw your attention to two sites which appear to be particularly vulnerable to fungicides. They are the oxidation of pyruvate and oxidative phosphorylation.

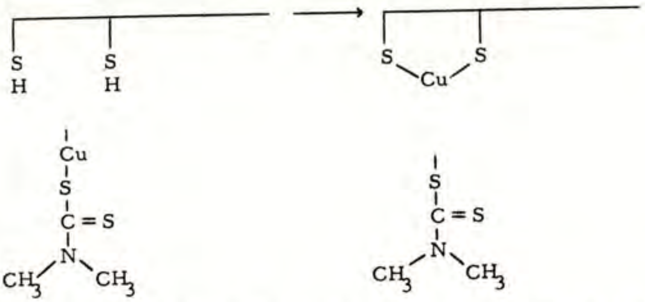
Since some 15 years, we know that in the oxidation of pyruvate to CO_2 and acetyl-CoA (and also in the oxidation of α-ketoglutarate) lipoic acid serves as an acceptor for the hydrogen liberated. In its turn this cofactor lipoic acid passes on the hydrogen to the cofactor NAD to form NADH. The enzyme required for this reaction is lipoic acid dehydrogenase. It was not until four years ago that the rôle of this lipoic acid system in the oxidation of pyruvate was also recognized in fungi (Wren and Massey, 1965).

Both lipoic acid and lipoic acid dehydrogenase are dithiol compounds. It has long been known that arsenite and organo-arsenicals inhibit the oxidation of pyruvate. Since these arsenicals combine easily with dithiol compounds one assumes that their toxic action on pyruvate oxidation may be due to combination with lipoic acid and lipoic acid dehydrogenase in the following way (cf. Webb):



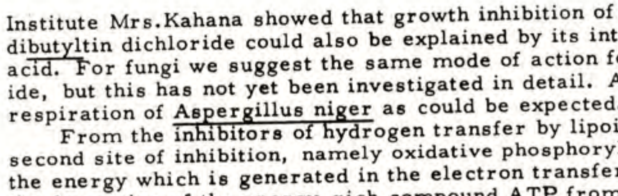
I am telling you all this because there is evidence that several fungicides act also at this site, namely the dialkyldithiocarbamates, like thiram; pyridine thiol N-oxide (PTO), perhaps better known as omadine, and 8-hydroxyquinoline. We know that these three compounds have to form a 1 : 1 complex with Cu in order to inhibit fungal growth in low concentrations; free Cu ions are always present at the same time (Kaars Sijpesteijn and Janssen, 1958, 1959; Janssen and Kaars Sijpesteijn, 1961). Under these conditions of growth inhibition respiration has slowed down and pyruvate accumulates. Pyruvate oxidation appears to be inhibited and it seems very likely that this inhibition has to be explained by interference of the 1 : 1 complexes with lipoic acid or with the dithiol group of lipoic acid dehydrogenase. Lipoic acid by virtue of its dithiol nature combines easily with metals.

Veeger and Massey (1960, 1962) have, moreover, shown that purified lipoic acid dehydrogenase from pig is strongly inhibited by minute amounts of copper. This was later confirmed for lipoic acid dehydrogenase of Saccharomyces cerevisiae by Wren and Massey (1966). It therefore seems likely that by means of the 1 : 1 complexes of the fungicides mentioned, Cu can be carried into the cell and into the mitochondria to the site of action of lipoic acid and its dehydrogenase. Cu might there combine with the dithiol compounds and inactivate them in the following way:



We assume that the same mode of action applies to the 1 : 1 complexes of Cu with oxine and with PTO. At low concentrations then DDC, oxine and PTO would not themselves be the actual toxic agents. They would only serve to carry Cu into the cell. Only if present at higher concentrations —and largely in excess of Cu— DDC, oxine and PTO are active as such. More work is required here to decide whether in that case these compounds act by withdrawing essential metals from the fungus.

There still is another compound which is assumed to inhibit the function of lipoic acid by reacting with this compound. I think here of diphenyltin dichloride. It is somewhat less fungitoxic than the triphenyltin compounds which I will mention later on (Kaars Sijpesteijn et al.). Fungal growth is inhibited by about 20 ppm. By the work of Aldridge and Cremer it has been shown that diethyltin dichloride combines easily with dithiol compounds like BAL. They made acceptable that the toxic action of this tin compound to mammals is due to reaction with the dithiol compound lipoic acid. In our



Institute Mrs.Kahana showed that growth inhibition of *Escherichia coli* by dibutyltin dichloride could also be explained by its interference with lipoic acid. For fungi we suggest the same mode of action for diphenyltin dichloride, but this has not yet been investigated in detail. At any rate it inhibits respiration of *Aspergillus niger* as could be expected.

From the inhibitors of hydrogen transfer by lipoic acid we now go to a second site of inhibition, namely oxidative phosphorylation. By this process the energy which is generated in the electron transfer process is used for the formation of the energy-rich compound ATP from ADP.

Aldridge and Cremer (1955) pointed to the difference in mode of action of the tri- and the disubstituted tin compounds. As we have just seen the disubstituted compounds interfere with the function of lipoic acid. The toxic action of triethyltin chloride on rats was ascribed by them to inhibition of oxidative phosphorylation.

The mechanism of oxidative phosphorylation is not yet well understood and the intermediate compounds and enzymes involved are largely unknown. This is about the same confused situation as existed for pyruvate oxidation 15 years ago. Therefore it is difficult to indicate where and how triethyltin compounds inhibit. Their site of action is usually indicated as "the site which is sensitive to the antibiotic oligomycin". It may be interesting to mention here that, in their turn, tin compounds —like oligomycin— are

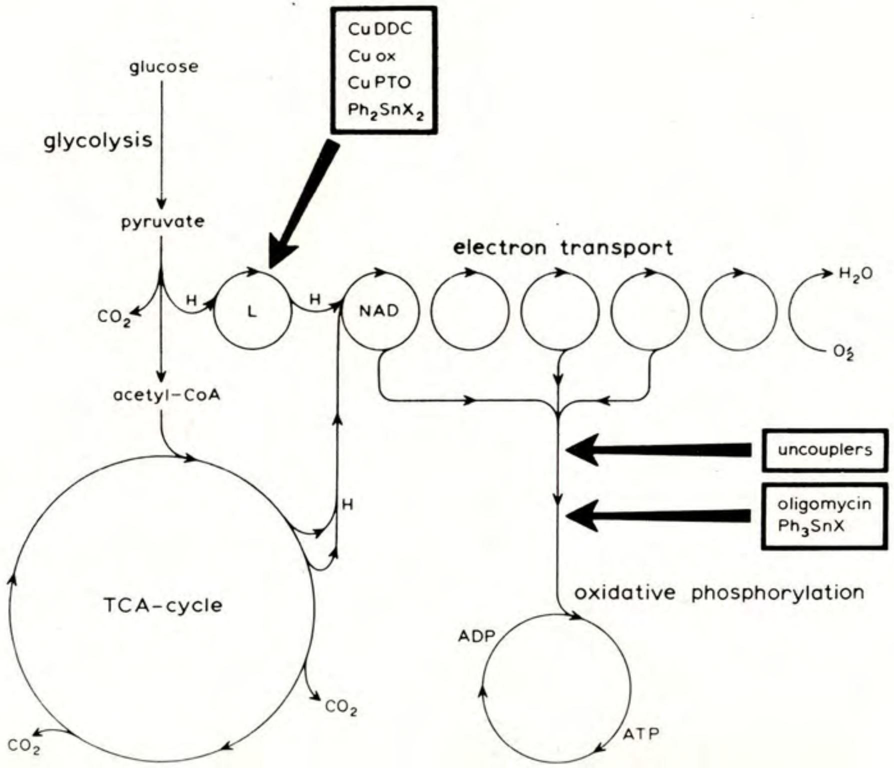


Figure 2

Sites of interaction of fungicides with energy production from glucose now being used as a tool to help unravel the processes going on in oxidative phosphorylation (cf. Lehninger).

No work has yet been reported on the mode of action of triphenyltin compounds on fungi, but I think that, in analogy to the finding of Aldridge and Cremer with rats, we may suppose that in fungi they also act on oxidative phosphorylation. This view finds support in the fact that oligomycin is a fungicide as well and also in the recent findings of Watson and Smith, who were the first to make a thorough study of oxidative phosphorylation in filamentous fungi. They found that this process in Aspergillus niger shows great similarity to that going on in animals cells; it is also inhibited by oligomycin. Tin compounds were not investigated.

We have recently studied the effect of triphenyltin acetate on respiration of Aspergillus niger. Whereas 1 ppm suppresses growth almost completely, 3 ppm were found to depress respiration of washed suspensions for about 50% for a period of at least 20 hrs. This depression of respiration is in line with the hypothesis that this compound acts by inhibition of oxidative phosphorylation; however, it is no proof yet for this mechanism.

There is still another site in oxidative phosphorylation which is highly sensitive to certain fungicides. It is the site just before the one which is inhibited by oligomycin. Inhibition of this site leads to the uncoupling of respiration from phosphorylation. Dinitrophenols and other phenolic compounds are known to act as uncouplers, but the exact mechanism of inhibition is still unknown. Karathane presumably acts in the same way.

So far we have looked at three particularly vulnerable sites in the processes leading to energy production, namely one in pyruvate oxidation and two in oxidative phosphorylation (Fig. 2). All three sites are located in the mitochondria.

Why are these three sites so vulnerable? This may be figured as follows. It is known that the potential activity of many enzymes is far in excess of requirements. For this reason even a considerable inhibition of their activity does not necessarily cause a significant disturbance of metabolism. On the other hand there are steps in metabolism which appear to be rate limiting. Therefore any decrease in their activity will diminish the overall rate of the process. Such rate limiting reactions have been called the pacemakers of metabolism (Krebs). The three vulnerable sites described above are in fact such pacemaker sites.

Up till now I have left out the group of fungicides which are often indicated as -thiol reagents. The respiratory pathway contains several sites that are sensitive to such reagents, namely -SH enzymes and the -SH compound coenzyme A. The fungicides I am aiming at are captan, folpet (Siegel and Sisler, 1968), nabam, maneb, zineb, tetrachloroisophthalonitrile (Vincent and Sisler), phenylmercuric acetate and others. They inhibit respiration, or the active compounds, into which they first have to be transformed, do so. Pacemaker sites in the respiratory pathway that are sensitive to these compounds are for instance glyceraldehyde-3-phosphate dehydrogenase, and coenzyme A, which again, is part of the pyruvate dehydrogenase system.

So far for inhibitors of energy production. It may be clear that such compounds do not immediately kill the fungus. If energy production is inhibited to a very high degree the organism will be unable to grow, and will eventually die. If inhibition is less severe the activities of the organism will only be slowed down and they may be able to grow at a very low rate. At higher concentrations gradually more enzymes will become inhibited leading to a quicker death of the organism.

I would like to spend now some time on biosynthesis and its inhibition and we will see that the newer fungicides presumably all act here. For biosynthesis energy is required. Therefore it will be clear that inhibition of energy production will inevitably lead to a limitation of biosynthesis and consequently to limitation of growth. Alternatively, if biosynthesis itself is inhibited by specific compounds, there is no reason why respiration or energy production should be slowed down. Thus we see that fungicides which act by interfering with biosynthesis as a rule have a fungistatic action. They do not inhibit respiration but only prevent the organism from growing.

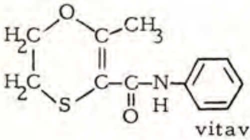
Biosynthesis of low molecular compounds takes place in the cytoplasm. As an example I should like to remind you of sulfanilamide. As you will know it acts by inhibition of the incorporation of p-aminobenzoic acid into the vitamin folic acid. This applies not only to its antibacterial but also to its antifungal action.

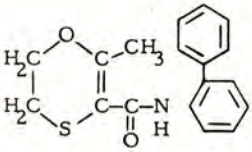
More fungicides are known to inhibit the synthesis of macromolecular compounds. Some of these are inhibitors of protein synthesis. As I mentioned before protein synthesis takes place on the ribosomes. Research on the functions of RNA has shown in the last decade that in the cell nucleus messenger RNA is formed which contains the code for a protein to be synthesized. This messenger RNA combines with the ribosome. The different amino acids required for protein synthesis are fixed to specific transfer RNA's. These RNA's loaded with an amino acid attach to the messenger RNA on the ribosome. Subsequently the amino acid is transferred from the transfer RNA into the polypeptide chain. And this incorporation in the chain is the process which is inhibited by the fungicide cycloheximide. Siegel and Sisler showed this for Saccharomyces pastorianus (1965). The active part of the cycloheximide molecule is the glutarimide group, but how this group acts is still unknown (Siegel et al.).

Now we get to a few newer fungicides of which it is still impossible to indicate their exact site and mode of inhibition. Only some suggestions can be made.

Little is known up till now on the mode of action of oxathiin derivatives like for instance vitavax. This systemic compound selectively inhibits only one group of fungi namely the basidiomycetes.

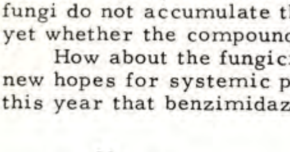
Edgington has, however, reported that a close derivative of vitavax (F 427) shows far less selectivity of action. It inhibits growth of a great variety of fungi not belonging to the basidiomycetes. This suggests that the selectivity of vitavax is not due to selectivity in mode of action but rather to penetration barriers that do not exist for the derivative.

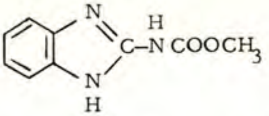

vitavax


F 427

Recent work of Mathre suggests that the oxathiins may act by interference with protein synthesis. For he found that fungi which are sensitive to vitavax rapidly accumulate it in the ribosome. In contrast, insensitive fungi do not accumulate the compound to any extent. No data are available yet whether the compound inhibits respiration.

How about the fungicide benomyl which during the last years has opened new hopes for systemic protection of plants. Clemons and Sisler reported this year that benzimidazole carbamic acid methyl ester (BCM) is rapidly

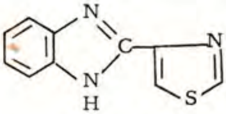

benomyl



BCM

formed from benomyl in aqueous solution. Vonk, at our Institute, could confirm this and we also could confirm that both compounds appear to be equally fungitoxic. However, because of the great instability of benomyl its activity may well be entirely due to the formation of BCM. We found, moreover, that neither of these compounds can inhibit respiration of washed cells of Aspergillus niger, not even in a concentration 100 x as high as required for growth inhibition. This suggests interference with biosynthetic processes.

Let us now first look at the systemic fungicide thiabendazole. Its activity



thiabendazole

has much in common with benomyl and BCM although it seems somewhat less active. The slide will convince you that thiabendazole shows structural similarity with benomyl and more especially with its derivative BCM. Also a concentration of 100 times the growth inhibitory value of thiabendazole could not inhibit respiration.

All these data give me the impression that benomyl, BCM and thiabendazole might have the same mode of action, the benzimidazole moiety being the active part of the molecule. It might therefore be of interest to check whether the mildew strains which according to Schroeder and Provvidenti have become resistant to benomyl also are resistant to thiabendazole.

Staron et al. have reported some years ago that thiabendazole inhibits protein synthesis in fungi, but they do not present any experimental evidence. The benzimidazole structure might perhaps be more suggestive for an interference with the biosynthesis or the function of purines, perhaps in the synthesis of nucleotides like adenosine- or guanosine phosphates. This may suggest a mode of action somewhat similar to that of azauracil of which Dekker has found that it has to be converted into a ribose phosphate to become fungitoxic. If this is true, benomyl itself will first have to be converted into BCM before a ribose phosphate can be formed.

I will now only mention in passing that biosynthesis of DNA in the nucleus may be the site of action of chloroneb according to Hock and Sisler (1969) and the cell division process may be the site of inhibition of griseofulvin according to Huber and Gottlieb (1968).

About the mode of action of phthalimide phosphonothionates and the related imidazole derivatives nothing is known as yet (Tolkmith).

Also I will not enter into a discussion of dodine and the polyenes which destroy the structure of the cell walls.

Rather I would like to show you a last slide which summarizes the fungicides acting on energy production, on biosynthesis and on cell walls. Although I wanted to leave the plant out of discussion I cannot withhold you a most remarkable conclusion. For it appears that the fungicides which inhibit energy production do not include real systemic fungicides. On the other hand the other fungicides especially those acting on biosynthesis are all true systemic compounds.

How can this be interpreted?

Since at the enzyme level metabolism in plants and fungi is basically similar, inhibitors of energy production will have an immediate effect also on plant tissues after entrance. Only compounds which are very insoluble or which otherwise have been made unavailable to the tissues can be tolerated by the plant. On the other hand, compounds which like the second group act on biosynthesis will prevent rapid fungal growth, but plant growth is so much slower that no immediate harm is done.

For a proper understanding of mode of action of fungicides I would have liked to add more information on selectivity and resistance but time does not allow me.

I hope that this lecture has shown you that much work remains to be done in this interesting field.

Table 1

Fungicide:	systemic
Inhibitors of energy production	
thiram	-
diphenyltin dichloride	-
triphenyltin acetate	-
karathane	-
nabam	-
captan	-
tetrachloroisophthalonitrile	-
phenylmercuric acetate	-
Inhibitors of biosynthesis	
sulfanilamide	+
cycloheximide	+
vitavax	+
benomyl	+
thiabendazole	+
azauracil	+
griseofulvin	+
chloroneb	+
Cell wall destructors	
dodine	±
polyenes	±

References

AINSWORTH, G.C. and SUSSMAN, A.S. (1965). The fungi. Academic Press, New York

ALDRIDGE, W.N. and CREMER, J.E. (1955). Biochem.J. 61, 406

CLEMONS, G.P. and SISLER, H.D. (1969). Phytopath. 59, 705

DEKKER, J. and OORT, A.J.P. (1964). Phytopath. 54, 815

EDGINGTON, L.V. and BARRON, G.L. (1967). Phytopath. 57, 1256

EKUNDAYO, J.A. (1966). J.Gen.Microbiol. 42, 283

HOCK, W.K. and SISLER, H.D. (1969). Phytopath. 59, 627

HUBER, F.M. and GOTTLIEB, D. (1968). Can.J.Microbiol. 14, 111

JANSSEN, M.J. and KAARS SIJPESTEIJN, A. (1961). In: Fungicides in Agriculture and horticulture. S.C.I. Monograph No. 15. Soc.Chem.Ind., London

KAARS SIJPESTEIJN, A. and JANSSEN, M.J. (1958). Nature 182, 1313

KAARS SIJPESTEIJN, A. and JANSSEN, M.J. (1959). Antonie van Leeuwenhoek 25, 422

KAARS SIJPESTEIJN, A., LUYTEN, J.G.A. and VAN DER KERK, G.J.M. (1969). In Torgeson, D.C.: Fungicides. Academic Press, New York

KAHANA, L. and KAARS SIJPESTEIJN, A. (1967). Antonie van Leeuwenhoek 33, 427

KREBS, H.A. (1958). In: The Strategy of Chemotherapy. Cambridge Univ. Press

LEHNINGER, A.L. (1964). The mitochondrion. W.A.Benjamin, Inc., New York

MATHRE, D.E. (1968). Phytopath. 58, 1464

SCHROEDER, W.T. and PROVVIDENTI, R. (1969). Pl.Diss.Reptr. 53, 271

SIEGEL, M.R. and SISLER, H.D. (1965). Biochim.Biophys.Acta 103, 558

SIEGEL, M.R. and SISLER, H.D. (1968). Phytopath. 58, 1123 and 1129

SIEGEL, M.R., SISLER, H.D. and JOHNSON, F. (1966). Biochem.Pharmacol. 15, 1213

STARON, T., ALLARD, C., DARPOUX, H., GRABOWSKY, H. and KOLLMAN, A. (1966). Phytiatrie-Phytoparmacie 15, 129

TOLKMITH, H. and MUSSEL, D.R. (1967). World Rev.Pest Control 6, 74

VEEGER, C. and MASSEY, V. (1960). Biochim.Biophys.Acta 37, 181

VEEGER, C. and MASSEY, V. (1962). Biochim.Biophys.Acta 64, 83

VINCENT, P.G. and SISLER, H.D. (1968). Physiol.Plant. 21, 1249

WATSON, K. and SMITH, J.E. (1967). Biochem.J. 104, 332

WEBB, J.L. (1966). Enzyme and metabolic inhibitors. Vol.III. Academic Press, New York

WREN, A. and MASSEY, V. (1965). Biochim.Biophys.Acta 110, 329

WREN, A. and MASSEY, V. (1966). Biochim.Biophys.Acta 122, 436

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SOME NOVEL APPROACHES TO CROP LOSS ASSESSMENT IN GERMANY

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Discussion of crop losses caused by pests, diseases and weed competition is increasingly interesting for two reasons. In all countries with a highly developed agricultural management, farmers are forced to achieve an economic optimum yield. Since such injurious factors as insect pests will always directly lower the net return, the harvest losses are a most decisive factor for the economic output of farm operations. On the other hand, in the developing countries the problem of paramount importance is how to meet food requirements, for any crop losses increase the problems of starvation and malnutrition.

The first step in solving a problem has always to be a correct diagnosis. It is, therefore, essential to develop adequate methods for crop loss assessments to indicate not only the potential and actual yield, but also the economics involved in farm management. In Germany some recent studies contribute to the question under discussion.

One of these approaches in Bavaria, was published by Berger (1968). He selected 18 farms with intensive crop protection ("plus farms") and 18 comparable farms with small expenditures for crop protection ("minus farms"), and examined them thoroughly in respect of all farm economics. The average monetary input for crop protection operations was DM 28.71 for the "plus" and DM 6.80 for the "minus" farms. Berger came to the conclusion that the difference in the net income per hectare amounted as high as DM 214 to DM 79, but at the same time he pointed out that it would be misleading to credit the total difference of DM 135 per hectare to crop protection alone or, put another way, that there was a crop loss equivalent to DM 135 per hectare in the "minus farms". On the contrary, Berger's study shows that those farms which applied a higher amount of crop protection were in general more intensively managed, applied more fertilizer and used better machinery and more sophisticated farm management. Therefore it seemed difficult, if not impossible, to distinguish which part of the higher output of the "plus farms" should be credited to crop protection, and which part to other farm operations. Nevertheless, using a multiple regression analysis the author came to the conclusion that each "Mark" invested in crop protection resulted in a yield increase which corresponds to an output of DM 6.00 to DM 8.70.

I think this example shows a problem which may be involved in all yield comparisons of users and non-users of crop protection materials. An unpublished report by Nair, which we have just received from India, shows the same complex of questions. Comparing the agricultural output of crop protection users with that of non-users in four villages, Nair found that the users gained an average of 473 Rupees per acre, the non-users only 316 Rupees. But at the same time the average farm size of users was one and a half times that of non-users, 68 per cent of users had some formal education, while the percentage of illiterates was 61 per cent in the case of non-users.

It seems, therefore, that a simple comparison of farms applying or not applying pesticides cannot lead to really exact results of crop loss assessment. This assumption led recently to another approach with so far unpublished results. I am indebted to the authors, Dr. Schulte and Dr. Riehl of the Crop Protection Service of Lower Saxonia, for their willingly-given permission to use their figures. Their method was as follows: During four years, starting in 1965, surveys were conducted on a farm located in North-West Germany and owned by Mr. Georg Kleyböker, Schleptrup near Osnabrück. All crop protection treatments were recorded with regard to the products used, the amount of labour involved, the acreage treated and the different crops. All costs caused by these factors were calculated and recorded. In each treatment, plots of at least 100 m^2 were left untreated. Treated and untreated plots were harvested separately and yields were separately evaluated. The gross and net incomes were calculated for the total acreage as well as on a per hectare basis, and compared to those of the untreated plots. All data were statistically analysed.

The farming system was rather typical for N.W. Germany, characterized by a crop rotation of cereals and root crops. In 1968, a total of 94 h cereals, 2.5 h turnips and 3.5 h of broad beans were grown, which makes exactly 100 h of arable land. Additionally 22 h of pastures and meadows belong to the farm.

The following examples show how the results were obtained:

Following the given conditions, the most important crop protection operation was weed control, covering more than 90 per cent of all expenditures for control treatments. In 1968, on the total of 100 h, DM 5137.81 was spent for buying and applying pesticides, DM 4431 for weed control, the costs of seed dressing were DM 268, and DM 439 was spent on controlling mildew in spring barley. The total input of DM 5,138.00 increased the gross output by DM 18,100.00. Additionally, DM 616.00 was saved because it was not necessary to spend any money on drying the grains due to efficient weed control. This raised the additional gross income to DM 18,716.00. The total costs were - as already mentioned - DM 5,138 which means that there was an additional net income - or a loss in the untreated plots - of DM 136 per h. It may be of some interest that the control of mildew in spring barley, using a product based on chinomethionate, was responsible for a yield increase of roughly 10 per cent and contributed considerably to the positive figures of the treated acreage.

In general it may be of interest that in 1968, 80 per cent of the costs for crop protection were in materials and 20 per cent for application. Between 1965 and 1968, application costs dropped by more than a half.

It may be of interest too that since 1965 year by year, there was a lower investment for crop protection per hectare, but a higher financial output. This means that the application of more effective and more sophisticated products and methods led to a higher rate of rentability of crop protection.

In <u>1965</u>

The input for crop protection per hectare was	DM 62.48
The net gain of this input per hectare was	DM 111.00

In <u>1968</u>

The input for crop protection per hectare was or 18 per cent less than 1965	DM 51.37
The net gain of this input per hectare was or 27 per cent more than 1965	DM 135.78
The average input per hectare for the years 1965-1968 was	DM 54.26
The net output per hectare was	DM 126.05

It is not my aim in presenting these figures from a single farm in North-West Germany to calculate crop losses caused by insufficient crop protection in comparable farms. Although it may be of general interest that any "Mark" invested in crop protection resulted in an average net gain of DM 2.32 or DM 26.00 per hectare over four years, I would not like to generalize these figures. Nevertheless, a yield increase due to modern methods of crop protection such as weed control, control of mildew and of course seed dressing, seems to raise the net income per hectare in the range of 100 to 150 DM annually in cereals. This was confirmed by another study, conducted by Stanzel (1969) in Hessia. He observed, in exactly the same way as Dr. Schulte and Dr. Riehl, ten farms with an average 20 hectares of arable land during the years 1966 to 1968. On average, the farms grew 50 per cent of wheat and barley, 30 per cent rye, oats and beans, 16 per cent potatoes and 4 per cent clover and pastures. Again, compared to untreated plots, the gain in cereals amounted to 125 DM per h, which is nearly exactly the same as that obtained in North-West Germany. In root crops the result was even higher, averaging DM 397 per hectare. The figures of all three studies indicate that even under the conditions of modern, intensive agriculture the application of chemical crop protection provides, or the infestation of weeds, fungi and pests takes away, more than 10 per cent of the potential yield in cereal growing in Middle Europe. The figures may be considerably higher in root crops and field grown vegetables.

It was not, however, the aim in this paper to present actual loss figures from Western Germany nor to offer pieces of stone for composing the mosaic which finally may present the picture of the overall losses in the world's agriculture. This may be a side effect of these studies, but in general the main point to be drawn from these studies is how the results were obtained.

If a network of experimental farms could be observed in the described way, this could well result in better founded and more practicable figures on crop loss assessment than those which are presently available.

References

BERGER, K. (1968) Bayer. landw. Jb. 45, 603.

STANZEL, R. (1969). Mitt. dt. LandwGes. 24, 800.

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PH 50-82, A NEW FUNGICIDE

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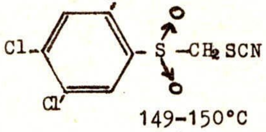
Summary PH 50-82 is the code name for [2,4,5-trichlorophenyl] sulfonylmethyl thiocyanate, one of the new fungicidal compounds of the group of thiocyanomethylsulfoxides and sulfones, tested in the laboratories of N.V. Philips-Duphar.
PH 50-82 shows a broad spectrum of activity of which the control of apple and pear scab (Venturia inaequalis) is described in this paper. Good scab control is achieved with 0.03% a.i. in a spray schedule with 10-14 day intervals between sprays.
Trial results indicate that 0.02% a.i. might be sufficient to obtain good scab control in practice.
In a spray schedule with 7-day intervals, the good scab control achieved with PH 50-82 at 0.02% a.i., and even with 0.01% a.i. holds possibilities for practice.
Furthermore, data are given on the physical and chemical properties of PH 50-82, as well as some preliminary data on toxicity, residues and decomposition of the active material.

INTRODUCTION

A laboratory and field evaluation program with thiocyanomethyl sulfoxides and sulfones (Dolman et al, 1969) yielded [2,4,5-trichlorophenyl] sulfonylmethyl thiocyanate as a promising experimental fungicide (Tempel and de Vries, 1969). Haverkate et al (1969) published about the mode of action of this compound. This compound, at present designated as PH 50-82, was used (as a 50% wettable powder) in a series of field trials on apples in 1968, along with a number of other substances in the same chemical group. The present paper deals with these results and with further work done on apples and pears during the 1969 season.

PHYSICAL AND CHEMICAL PROPERTIES OF PH 50-82

Name: [2,4,5-trichlorophenyl] sulfonylmethyl thiocyanate



Melting point:	149-150°C	
Appearance:	white, crystalline substance	
Solubility at 20°C:	cyclohexanone	15% w/v
	acetone	12% w/v
	methylene chloride	6% w/v
	monoethyl glycol ether	2% w/v
	ethanol	2% w/v
	xylene	2% w/v
	water	7 ppm
Stability:	In water (room temperature) at pH 2 and pH 7 less than 2% decomposition after 24 hrs.	

Toxicology

Only data on acute toxicity are available at present.

In mg per kg body weight:

	acute oral LD 50	acute intraperitoneal LD 50
rats	4600	37
mice	3700	37
guinea pigs	420	26

1968 RESULTS ON APPLES

On apples a total of 10 trials was laid down, in which PH 50-82 was used at 0.04% a.i. and/or 0.06% a.i., along with other related compounds. In all trials captan in 0.1% a.i. was included as a standard treatment. The trials comprised three or four replicates and included the varieties Golden Delicious Jonathan, Cox Orange Pippin and Boskoop.
The number of applications during the season varied from 9 to 14; the average interval between sprays per trial varied from 12 to 17 days.
About mid-season, after some 6 applications, the spray-intervals were extended. Ultimately there were measurable scab infections on foliage in 7 and on fruits in 5 out of the 10 trials.
In all trials the yields have been assessed. The degree of russeting has been determined after harvest in samples of 100 kg on the average (out of some 900 kg per treatment on the average).
Table 1 presents a summary.

Table 1.

Results obtained with PH 50-82 against apple scab, 1968.

	% scab infected fruits					Number of scab infected leaves							yield[1] (captan = 100)	Russeting at harvest[1] [2]) (captan = 100)
Trial no.	40	35	34	32	42	37	36	35	34	32	42	42		
Untreated		52	100	95	100			1591	722	313	2599		86	148
captan 0.1%	27	0	0	3	3	6	1	549	21	8	289	320	100	100
PH 50-82 0.04%			0		3		3		10		169	306	98	102
PH 50-82 0.06%	16	0		9		0		416		2			96	111

[1]) average of all 10 trials.

[2]) Samples were graded into four russeting degrees: heavy, moderate, slight or none. Percentages in each category were multiplied by 4, 3, 2 and 1 respectively and these products were added. The russeting values thus obtained in each trial have been expressed as percentages of the value of captan in that trial.

These results show that PH 50-82 in a concentration of 0.04% a.i. gives good scab control in relation to the standard treatment. Thus it was justifiable to consider lower rates in 1969.
On the average, fruit russeting was somewhat higher with 0.06% PH 50-82 than with captan.
With 0.04% PH 50-82 the difference was negligible. All treatments had a considerably lower russeting figure than untreated.
It would seem that a lower concentration is associated with less russeting, which is contrary to the experience with captan, where lower concentrations are usually associated with an increase in the degree of russeting of the fruit.

1969 RESULTS ON APPLES AND PEARS.

During the 1969 season investigations were extended. In the Netherlands, as well as in a number of other countries, trials have been set up with dosage rates ranging from 0.04% tot 0.01% a.i. PH 50-82.
These trials have not been fully evaluated yet. At the time of writing this article no data were available on Gloeosporium control. Definite results on scab control were only available from the Netherlands.
A number of typical results are presented in tables 2 and 3.

Table 2.

Numbers of scab-infected apple leaves as percentages of the numbers in untreated.

Spray intervals: 1 week

Trial no.	69-039			69-049		
Counts in	June	July	Aug/Sep.	June	July	Aug/Sep.
PH 50-82 0.01%	3.0	3.2	1.7	2.1	1.3	1.7
PH 50-82 0.02%	1.8	0.4	0.2	0.1	0.4	0.7
captan 0.04%	3.0	1.2	1.8	0.5	0.9	2.1
captan 0.075%	1.7	1.0	0.6	0.3	0.6	0.9
Total numbers of infected leaves in untreated	871	2436	1318	1457	2268	3531

Table 3. (Part 1)

Numbers of scab-infected apple leaves as percentages of the numbers in untreated

Spray intervals: 10 - 15 days.

Trial no.	69-088			69-040			69-044			69-089		
Counts in	June	July	Aug/ Sep.	June	July	Aug/ Sep.	June	July	Aug/ Sep.	June	July	Aug/ Sep
PH 50-82 0.02%	3.6	4.6	4.1	0.3	0.4	0.2						
PH 50-82 0.04%	2.6	2.8	2.4	0.1	0.1	0	1.6	4.6	4.4	2.6	3.4	1.8
captan 0.1%	3.4	6.4	4.0	0.1	0.2	0.1	2.2	6.3	6.5	7.3	7.3	4.4
Total number of infected leaves in untreated	2530	3700	3804	2670	5092	1930	12477	8441	10098	1259	2177	1730

Table 3. (Part 2)

Trial no.	69-118		69-117		69-109		69-116		69-113		60-119	
Counts in	June	Aug/ Sep.	June	Aug/ Sep.	July	Aug/ Sep.	June	Aug/ Sep.	June	Aug/ Sep.	June	Aug/ Sep.
PH 50-82 0.02%	2.0	0.6			3.1	1.9	2.8	5.7			10.7	9.3
PH 50-82 0.03%			2.3	2.5			4.3	6.6	1.7	0.7	17.3	7.9
PH 50-82 0.04%	6.1	3.5	1.1	4.1								
captan 0.1%	5.1	4.1	2.9	3.5	2.0	1.3	3.9	4.5	2.4	2.8	16.0	5.1
Total number of infected leaves in untreated	99	318	1749	749	545	1212	2212	3344	576	424	75	215

In two trials (table 2) a 7-day spray schedule was applied with lower rates, as in practice a number of growers prefer to do. Here 0.02% PH 50-82 showed good scab control, and considering the rather high levels of infection during the 1969 season, even 0.01% may offer practical possibilities.
With 10-15 day intervals the same magnitude of scab control was achieved by all treatments, with relatively small mutual differences; in a few trials there is even a negative dosage response (not significant) with different PH 50-82 rates. But PH 50-82 in 0.04% acts in the majority of the trials better than captan, and 0.02% is in most cases somewhat weaker than captan. Thus it is our opinion that PH 50-82 in 0.03% will achieve fully acceptable scab control in practice with 10-12 day intervals, when compared to captan 0.1%. And it does not seem impossible that, when more experience in future years is gathered, 0.02% a.i. will show to be a sufficient rate as well.
Preliminary results from other European countries and from the U.S. confirm our opinion that 0.03% a.i. is sufficient for good scab control, when compared with a captan rate of 0.1% a.i.
The information to date indicates that russeting should not constitute any problem. No effect on yield was observed.

CONTROL OF OTHER DISEASES

Trials on other crops and diseases have been carried out and are under way. Indications to date are that PH 50-82 possesses considerable fungicidal activity against a number of diseases, among them Peronospora on grape vines. On the other hand, the rates needed for the control of Cercospora on sugar beets and Phytophthora on potatoes are such that from an economic point of view no further trials are warranted for the time being.

RESIDUES

During residue work with labelled material, indications on the metabolism of the active material have been found that will form part of further investigations.
Limited residue analyses of PH 50-82 on apples with a sensitivity limit of 0.05 ppm were carried out in 1968.
After spraying with 0.04% and 0.06% a.i. PH 50-82, the average residues were 0.1 ppm with 2-3 weeks between the last spraying and sampling at harvest (3 trials); 0.05 ppm with 26 days or more between the last spraying and harvest (4 trials). In one other trial the residue was 0.10 ppm (32 days).

References

DOLMAN, H., TEMPEL, A., KOOPMAN, H., WELLINGA, K., HAMMINGA, D. (1969) Rec. Trav.chim., Pays-Bas 88,417.

HAVERKATE, F., TEMPEL, A., DEN HELD, A.J., (1969), Interaction of 2,4,5-trichlorophenylmethyl thiocyanate with fungal spores.
Neth. J.Plant Path., 75,308.

TEMPEL, A. and DE VRIES, C. (1969) XXIth.Int.Symp. on Crop Prot., Gent, to be published.

President's Closing Remarks

In closing this 5th Conference on Insecticides and Fungicides, I think I can say confidently that it ranks among the most successful we have held. In saying this I am not rating success by numbers attending, though these also greatly exceeded previous attendances, but by the content of the papers presented and by the way they were presented. For this success, we are of course primarily indebted to Mr. Higgons and his Programme Committee, and to the Session Organisers, for the thought and work they put in to ensure sessions on important and topical subjects. Except that not all the slides used by all contributors were as clear as we would like, I have only one adverse criticism to make. This has nothing to do with the Programme Committee or Session Organisers, but is aimed at the delegates. It is that, at some of the Sessions I attended, contributions from the floor were few and the discussions were less lively than I would wish. I realise that, with large audiences and the need for microphones, it is not easy to get discussions going, but I make a plea for future meetings that delegates should make some of the comments I heard outside the meeting rooms during the discussion period at the sessions.

That it was the content of the programme and not the other attractions of Brighton that brought so many delegates was amply demonstrated by an attendance of more than 1,000 at the Plenary Session on Tuesday morning and by a spot count that showed more than 900 attending the concurrent sessions on Tuesday afternoon.

The record number of 19 new compounds were described and reported on at the Conference, and the results with the systemic fungicides also were full of promise. How many of these compounds will prove valuable in practice, only time will tell, but at least we can look forward with confidence to solving some of our current problems from pests and diseases. Much has already been achieved and many pests and diseases that used to cause losses can now be controlled, but crop protection is still far from complete, and too often the only advice a plant pathologist can give for avoiding crop losses from soil-borne pests or diseases is a rotation of crops that a farmer may not wish, or be unable, to follow. A maker of blankets troubled with moth in his wool would not consider his problem solved by being told to change over to making cotton sheets. Similarly, the problems of a cereal grower are not solved by telling him to grow potatoes, sugar beet or beans.

Cropping is still too much determined by risks from pests and diseases and it must be the aim of workers in crop protection to allow farmers to grow safely the crops they wish to grow, where and when they wish. This is a great challenge, and one I think this Conference has shown is now being faced.

I thank you for your attendance here, and look forward to seeing you at future Conferences, when we shall learn to what extent the promise of better protection for crops reported here has been achieved.