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INTERNATIONAL COOPERATION IN THE DEVELOPMENT OF CONTROL OF PESTS AND DISEASES OF SUGAR BEET

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Summary International cooperation in research work grows from mutual need but the growth can be aided by good organisation. In the sugar-beet world this organisation exists in the International Institute for Sugar Beet Research or I.I.R.B. Virus yellows first stimulated international cooperation in pests and diseases research, with regular annual meetings of specialists in the Netherlands; today there exists a Pests and Diseases Group. This is organised under the Statutes of the I.I.R.B., a body comprising more than 300 members from 30 sugar-beet growing countries of which 21 European ones have members of the Pests and Diseases Study Group, 12 contributing regularly to Group meetings. Currently there are two sub-groups, "Aphids and Virus Yellows" and "Seedling Pests". Mutual exchange of information and free discussion between specialists has been accomplished and authoritative publications produced. A system of information exchange during March to June each year, as an aid to national aphid spray-warning schemes, is steadily being improved; in 1975 the use of potato trap-plants was initiated. Further objectives are the pooling of results from experiments common to several countries; progress to this end is given, especially in relation to *Onychiurus* (in cooperation with O.I.L.B.) and aphids and yellows.

INTRODUCTION

International cooperation in agricultural research is an ideal, but can it be attained? The problems of language may be surmountable, but the different problems in the different countries and the different approaches to tackling these problems may seem insurmountable. Major and international pest and disease problems of sugar beet lead naturally to some dependence on current research progress in other countries; this interdependence is, fortunately, made much more productive by the Pests and Diseases Group of the International Institute for Sugar Beet Research or I.I.R.B. (abbreviation of: Institut International de Recherches Betteravières). As the current Chairman of the Group, I wish to inform you of its activities.

I.I.R.B.: GENERAL

The I.I.R.B. was founded in Belgium in 1931 as a non-governmental international organisation; it is administered by the Secretary General from an office at Beauduinstraat 150, B-3300 Tienen, Belgium. Its aim is to promote and encourage international cooperation between all those concerned with sugar-beet problems. Political and commercial subjects are excluded from its scope of interest which covers all other disciplines and techniques related to sugar-beet growing and research, e.g. physiology, manuring, soil conditions, irrigation, mechanisation, weeds, and pests and diseases.

The I.I.R.B. at present comprises more than 300 members from 30 sugar-beet growing countries in Africa, Asia, Europe, North America and South America. Of the major sugar-beet growing countries only China (estimated 270,000 ha), Iran (estimated 176,000 ha), Germany D.R. (estimated 229,000 ha) and the U.S.S.R. (3,610,000 ha) (F.A.O. Statistics for 1974 - Total World Crop = 8,206,000 ha) are not members of the I.I.R.B. Member countries of the I.I.R.B. and the area of crop grown in 1974 are given in Table 1.

The organisation of the I.I.R.B. is conducted by an Administrative Council; a Scientific Advisory Committee, under the current chairmanship of R. Hull, guides its scientific activities. Every year a Winter Congress is held in Brussels, usually with a major theme or themes, and Itinerant Summer Meetings are held in a different country each year. The most important of the Congress papers and other papers are published in "I.I.R.B." (J. Int. Inst. Sugar Beet Res.).

I.I.R.B. expenditure is totally supported by membership, both individual and national, subscription in the latter case being based on the countries' sugar-beet production.

Table 1

I.I.R.B. Member countries; Crop area (F.A.O. 1974 statistics) and participation in Pests and Diseases Study Group

Country	Crop area 1000 ha	Membership of Pests & Diseases Study Group	Country	Crop area 1000 ha	Membership of Pests & Diseases Study Group
Austria	54	++	Netherlands	109	++
Belgium	105	++	Poland	440	+
Bulgaria	58	+	Portugal (Azores)	3*	
Canada	27		Rumania	217	+
Czechoslovakia	208	+	Spain	128	++
Denmark	67	++	Sweden	46	++
Finland	23	+	Switzerland	11	++
France	504	++	Syria	8	
Germany F.R.	371	++	Tunisia	2*	
Greece	27	++	Turkey	187ø	+
Hungary	98	+	United Kingdom	195	++
Ireland	26	++	Uruguay	14	
Israel	3*		U.S.A.	492	
Italy	200ø	+	Yugoslavia	104	++
Japan	47ø				
Morocco	68*				

* F.A.O. estimate
ø Unofficial figures

\+ Corresponding member
++ Active participation in Group meetings

I.I.R.B.: GROUP STRUCTURE

Within the I.I.R.B. various Study Groups have been set up, under the guidance of the Council's Scientific Advisory Committee, to deal only with their respective scientific and technical problems. The Statutes of the I.I.R.B. state that "the Study Groups are organised to enable specialists in any particular field of research related with sugar beet to enter into regular contact with the object of establishing international collaboration." The field of work of a Study Group is clearly specified and guide lines are laid down for its activities. Groups are responsible for fostering and harmonizing the individuality of local or national initiatives and research. Groups endeavour to organise certain studies according to a common procedure and, in addition, study means of integrating research methods and presentation of data, thereby facilitating the interpretation of the results obtained under different conditions.

Every year the results of research are presented, in a general report or in detail, first to the Scientific Advisory Committee, and then to the Winter Congress. The contributions, discussions and decisions of the Study Groups are not published or circulated in any form without the preliminary written assent of the authors when personal contributions and statements are concerned, or without the consent of the Group Chairman in regard to the results of the studies and debates. In taking part in a Group, each member undertakes to respect this agreement and to contribute, as far as possible, to the Group activities by communicating the results of his research on the problem concerned. The members make observations to their Group on current problems in their respective countries.

THE PESTS AND DISEASES STUDY GROUP

International cooperation in sugar-beet pest and disease research originated principally in the annual winter meeting of virus yellows research workers, organised by H. Rietberg, Director of the Netherlands Beet Research Institute, and first held at that Institute at Bergen-op-Zoom in 1950. Virus yellows was the main disease problem in Northern Europe, present every year and particularly damaging in some years in the 1940s and 1950s. Incidence of yellows in the different countries was reported annually and results of research work on the viruses, their vectors and control were freely exchanged. An extensive review of existing knowledge was prepared jointly by this 'Sugar Beet Virus Disease Committee' and presented at the 1959 I.I.R.B. Winter Congress in Brussels (Rietberg, 1959). The last of these meetings at Bergen-op-Zoom was held in 1959; control measures seemed effective and the disease was much less prevalent.

In 1962 the I.I.R.B. delegated scientific matters to a Scientific Advisory Committee with sub-committees for Mechanisation, Breeding and Genetics, and Pests and Diseases. R. Boiteau (France) was appointed Chairman of the latter and encouraged revival of the virus diseases sub-committee; R. Hull became its chairman and representatives from 11 Northern European countries met regularly. A joint report on virus yellows was presented at the 26th Winter Congress in Brussels in 1963 (Hull, 1963). The scope of the meetings widened with a seedling pests and diseases symposium at Broom's Barn in 1970, incorporating the existing I.I.R.B.'s sub-group considering millepedes (Chairman L. van Steyvoort, Belgium), and meetings at Brussels in 1971 on integrated control, when K. Björling (Sweden) took over chairmanship of the virus diseases sub-group, in 1973 on chemical control of nematodes and in 1974 on seed treatment with chemicals. The Pests and Diseases Group (current chairman R. A. Dunning) have held summer meetings recently in the Netherlands (Bergen-op-Zoom, May 1970) and in Belgium (Leuven, June 1975), and intend to meet again in W. Germany in September 1976.

Under the aegis of these I.I.R.B. Committees and Groups, international cooperation on sugar-beet pest and disease work has, in the past, consisted almost entirely of regular interchange of recent research results on the major pest and disease problems and their control. Because of the restrictions placed on publications, a very necessary prelude to the free exchange of new information, much data is recorded only in the contributors' notes, or in the Minutes circulated to those attending the meetings. The results of international enquiries on sugar-beet pest and disease problems have, however, been presented in papers given at the Winter Congresses (Gates, 1957; Rietberg, 1959; Hull, 1963; Dunning, 1972; Hull, 1972; Byford, 1974).

Other activities are as follows:

List of research workers and major pest and disease problems

This was prepared for 21 European countries in 1972 (see also Dunning, 1972). It is now being updated.

Food and Agriculture Organisation: Crop Loss Assessment Methods Manual

Group members have cooperated in the production by the I.I.R.B. of authoritative contributions to this manual on the beet cyst eelworm (*Heterodera schachtii*) (Heijbroek, 1973), beet yellows, beet mild yellowing and beet western yellows virus (Heathcote *et al*, 1973), the beet leaf miner (*Pegomya betae*) (Winner & Schäufele, 1973), beet stem eelworm (*Ditylenchus dipsaci*) (Graf *et al*, 1974), and on the growth stages of the sugar-beet root and seed crops (Heathcote, 1973). Others on *Cercospora* leaf spot (*Cercospora beticola*) and black aphid (*Aphis fabae*) are in preparation.

Collaborative seed testing

Collaborative testing of sugar beet used for seed-borne diseases began under the auspices of the I.I.R.B.; it now continues as a working group of the Plant Disease Committee of the International Seed Testing Association (I.S.T.A.). Work has concentrated on comparing methods of testing seed for infection by blackleg (*Phoma betae*), but tests for *Cercospora* leaf spot have also been examined. The primary objective is to establish a method of testing beet seed for disease, particularly blackleg, that gives repeatable results when used in different laboratories, and which can be adopted when ever international health certificates must be issued for beet seed. However, comparisons of the relationship of laboratory tests to behaviour of the seed under field conditions in different countries form an important part of these studies (W. J. Byford & J. Jorgensen; reports circulated within the I.I.R.B. and I.S.T.A. respectively).

Aphid and virus yellows control

This major sugar-beet pest and disease problem of Northern Europe is particularly suitable for international collaboration because the aphid vectors of the virus do not respect frontiers. Each season, regular exchanges of information are continuously being made between several countries on, first, the overwintering of the aphids and virus sources and, later, the development of aphid populations on the sugar-beet crop. Data from the Rothamsted Insect Survey, with suction traps situated on both sides of the Channel, helps to measure the primary aphid flights. In 1975 the value of potato trap-plants for aphids in sugar-beet fields (Hille Ris Lambers, *pers. comm.*), has been tested in a standard manner in several countries; the method promises to measure accurately and easily the first arrival of alatae in the beet fields and will be extended and improved in 1976.

Onychiurus damage

The significance of springtail (Onychiurus spp.) damage to sugar beet was first reported in the Netherlands (Heijbroek, 1971) and later in England (Baker & Dunning, 1975). Changes in crop agronomy and the adverse effects of soil-applied chemicals on the springtails' predators (Edwards et al, 1967) are two probable causes of the increased damage by this pest. The O.I.L.B. (Organisation International Lutte Biologique) "Integrated Control of Soil Pests Working Group" has joined with the I.I.R.B. Pests and Diseases Group in planning a collaborative study on this pest and the factors influencing its numbers and damage. Standard trial layouts and treatments (rotations, herbicides, pesticides) were agreed at a meeting of cooperating countries' representatives in Leuven in June of this year and the trials will commence in at least six countries in 1976; information obtained will be exchanged at a meeting of the workers concerned late in 1976.

THE FUTURE

The I.I.R.B. Pests and Diseases Group is well established and its activities seem likely to increase, especially in the form of collaborative studies on other major problems not referred to above, for example beet cyst eelworm. Whatever the problem, the Group structure enables it to be tackled productively, where necessary introducing new specialists for particular objectives.

Thanks to the friendly cooperativeness engendered by the previous Chairmen H. Rietberg, R. Boiteau, and R. Hull, my task of leadership will be a pleasant one; I look forward to the continuing collaboration of the many sugar-beet pest and disease workers in all the European countries.

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THE SCOPE FOR EFFICIENT PESTICIDE USE ON OIL RAPE AND MAIZE

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Summary The area sown to oil rape and fodder maize in Britain is rapidly increasing; so are the problems arising from the incidence of pests and diseases in these crops. The most vulnerable growth stages and the effect of changes in husbandry are considered. Guidelines on the economic significance of these pests and diseases are presented.

Resume Le terrain ensemence en colza et en maize fourrage enGrand Bretagne s'agrandit rapidement; ainsi que les problemes lies aux insectes nuisibles et aux maladies de ces recoltes. On considere le stade de la croissance le plus vulnerable et aussi l'effet des developpements agronomigues. On presente des indications sur la signification economique des insectes nuisibles et des maladies de ces recoltes.

INTRODUCTION

Maize has been cultivated in Britain for more than a hundred years largely as a green fodder crop fed to animals in situ or zero grazed. In recent years interest in the crop as a useful fodder crop for ensiling, to supplement conserved grass, has increased. Attempts at establishing maize grain production in Southern areas of the UK have not hitherto been successful. Until more suitable cultivars giving consistency of grain yield in early autumn are introduced the present area grown (>900 ha) is not likely to be extended. Late harvest of present cultivars grown for grain production can be highly detrimental to soil structure and the high cost of drying grain with above 35 per cent moisture is a further deterrent to acreage expansion. In contrast the acreage of maize harvested whole for ensiling is increasing rapidly in many areas of the country; the 1975 area grown being 27 000 hectares.

Oil seed rape is much more adaptable to the climate of the British Isles being a moisture loving plant and far less sensitive to variations of weather compared to the present cultivars of maize. The area of oil rape grown in 1975 was in the region of 37 000 hectares, a ninefold increase on the area grown five years previously. The current trend is towards production of the winter sown swede type, *Brassica napus*, in all parts of the country extending beyond the mid-Lothians of Scotland (lat 55°). History records oil rape culture in Britain in the 17th century but then the emphasis was on the turnip type rape, *B. campestris*, the oil being largely used for industrial purposes. Today the major portion of home-grown rape oil is manufactured as an edible vegetable oil and the seed residue is now more readily accepted as a source of animal protein now that cultivars freed of human and animal toxic constituents - erucic acid and glucosinolates - are becoming commercially available. The present day total consumption of edible vegetable oils in the UK is about 850 000 tonnes per annum of which 50 000 tonnes is rape oil equivalent to 120 000 tonnes of oil rape seed. At a modest yield level of 2 tonnes per hectare this represents the produce of 60 000 hectares of oil rape. There is scope therefore for almost doubling the 1975 area without looking for the substitution of other imported vegetable oils by rape oil. The produce of 60 000 hectares of oil rape could also produce 70 000 tonnes of rape meal for inclusion in animal feedstuff this being in the region of 60 per cent of the current usage of rape meal in the UK.

Like most other crops maize and oil rape can be plagued with pests and diseases. There is evidence that intensification of production on individual farms and in some localities has already increased the incidence of some problem diseases and pests. It is therefore opportune to discuss their significance in relation to any future targets of production.

VULNERABLE CROP GROWTH STAGES

Whilst pests and diseases can influence the growth rate of both crops at any development stage experience indicates three stages during which the toll is greatest. Often the damage observed is the accumulative effect of many interactions with other stresses during these growth stages.

1. The establishment stage:- from germination to the fourth true leaf. Oil rape and maize seedlings are extremely sensitive to unfavourable soil temperature, lack or excess of soil moisture, hindrance to young root penetration, nutrient deficiency or damage to the growing point during this stage. Additional stresses caused by pest or disease at this stage can lead to an unacceptable loss of plants and leave weakly structured plants incapable of reaching their full potential even if subsequent growth conditions are favourable. Efficient fungicidal seed treatment can provide the very necessary protection against many disease hazards at this stage whilst the importance of sowing seed devoid of disease bearing trash has already been well illustrated in recent years.

2. Bud to seed maturity stage:- Both crops are vulnerable to stresses particularly drought or other adverse climatic conditions during this period and further stress by disease or pest can lead to physiological disorders of maize ears and failure of seed set and/or seed maturation of oil rape. These effects are often additional to the direct damage caused by pest or disease. Early bud damage in oil rape by blossom beetle (Meligethes spp) can be compensated to a high degree by more vigorous growth elsewhere on the same raceme but here again it is questionable whether there is not a physiological effect likely to influence subsequent growth of the plant.

3. Ripening to harvest store:- Any variation in ripening of crops from late August onwards creates a serious problem at harvest and during subsequent conditioning of the produce. Pre-harvest lodging that could be wholly or partly due to disease or pest; eg stem weevil (Ceuthorhynchus quadridens) in spring sown rape, can lead to losses of seed or, as in the case of fodder maize, valuable animal feed during the harvest period. Lodged maize can be the cause of excessive soilage of the ensilaged product. The development of secondary pathogens following death of vegetative or reproductive parts of the plants may also lead to further losses in store. They may interfere with

the process of fermentation in ensiling maize. Recent studies on the conditioning and storage of oil rape seed (Staples, 1975) emphasise the importance of preventing mould development the initiation of which may have occurred in the field pre-harvest. Laboratory work has shown that mites freely enter damaged seed which may have resulted from earlier pest attack such as seed weevil (Ceuthorhynchus assimilis). Grubs of the white shouldered house moth (Endrosis sarcitrella), occurring in large numbers, have also been known to cause clumping of seed near the surface of oil rape seed in store causing pockets of overheated produce favourable to further mite development.

PLANT BREEDERS ROLE

There are several instances of breeder's success in producing new varieties with in-built resistance to disease and sometimes pest. Notable examples of disease resistance in oil seed rape have been illustrated recently in relation to stem canker (Phoma lingam), club root (Plasmodiophora brassicae) and light leaf spot (Cylindrosporium concentricum). The variable susceptibility of maize varieties to stalk rot (Fusarium culmorum) is reported in another paper presented during this session illustrating that at least partial resistance to disease in maize can be inbred. Field observation of individual plant resistance to disease or pest could provide invaluable basic plant breeding material and closer contact of those active in the field of pesticide evaluation with plant breeders could provide answers to many pest and disease problems.

EFFECT OF RECENT TRENDS IN HUSBANDRY

The introduction of new techniques of crop management may alleviate some pest or disease problems. Equally what may be beneficial in terms of husbandry could aggravate the effect of disease or pest.

a. Zero cultivation Direct drilling involving the minimum of cultivation is rapidly gaining in popularity as a method of establishing winter oil rape. Similarly the sowing of fodder maize into grass using rotaseeders, which merely cultivate a narrow strip in the vicinity or point of deposition of seed, is proving a successful establishment technique on suitable soils. Both systems offer savings in cost, greater retention of soil moisture and more timely sowing. There are, however, greater risks in terms of pest damage. Frit-fly (Oscinella frit) present on surviving host grasses may find easy passage to the young maize plants. Direct drilled oil rape has already been shown to be more vulnerable to damage by the grey field slug (Agriolimax reticulaties) damage. For both crops there is a risk that rooting conditions may be less favourable than in a cultivated seedbed thus exposing young plants to greater stresses in the presence of soil-borne or seed-borne diseases.

b. Precision drilling Sowing regularly spaced seed is already an established practice with maize and the benefits of more precise spacing for young plants of oil rape has now been demonstrated. Precision drilling to attain an optimum evenly spaced plant population poses greater risk where there is a likelihood of pest or disease attack and therefore the value of preventative measures is enhanced. There is a limit to compensatory growth even though spaced plants tiller and branch beyond that normally associated with established sowing techniques.

c. Manuring Recent experimental evidence (Ainsley 1975) in the UK has indicated the benefits of using high levels of nitrogen at the time of sowing winter rape. These results were obtained with slow growing high erucic cultivars following relatively mild winters. In Scandinavia on the other hand excessive early growth of oil rape, which may be encouraged by high seedbed nitrogen application, has invariably shown greater susceptibility to soil-borne diseases such as dark leaf spot (Alternaria brassicae). Symptoms of trace element deficiencies in both crops are sometimes confused with the effects of disease or pest. On the other hand interaction of disease and deficiency of magnesium or boron have been known to cause serious retardation of young plant growth. An interesting observation in French guides to maize growing is that the use of anhydrous ammonia reduces the activity of soil-borne fungus organisms but this has not hitherto been tested in the UK.

d. Weed control Maize is extremely sensitive to weed competition during its early growth stage. The existence of disease or pest damage in the presence of weeds is therefore a serious threat to the survival of a young crop. Fortunately, atrazine has proved to be an efficient wide spectrum herbicide in maize without any known phytotoxicity even at high uneconomical dose rates. The current usage of herbicides in oil rape is very often a compromise between satisfactory weed control and relatively low toxicity to the crop. In these circumstances any additional stress on the crop plant, due for instance to disease, is likely to upset this delicate balance to the detriment of the crop. Dalapon, used to control volunteer cereal weed in winter oil rape, has already been associated with greater severity of disease effect on the crop. Future trends in herbicide use in oil rape is towards admixture (cocktails) of relatively low dose of component herbicides resulting in lower toxicity to the crop but being additive in their effect on a wide range of weeds.

CROPPING SYSTEMS AND CROP HYGIENE

Many of the disease and pest problems that limit the economic production of maize and oil rape arise from ignorance or neglect of crop rotation principles. Excessive cropping of either crop can aggravate problems of soil-borne diseases. The oil rape disease situation is often complicated by the introduction of other brassicae into the rotation. Because of escalating bought-in feedstuff costs there is now an incentive to introduce short-term summer and autumn brassica fodder crops thus providing a bridge host to maintain disease inoculum that can readily affect full term brassicae crops subsequently. The current MAFF Short Term Leaflet on oil seed rape (MAFF 1975) recommends that land cropped with brassicae in the preceding three years should be avoided thus indicating the need for a minimal three year interval between any brassicae crops. The situation can be further complicated if volunteer oil rape plants are allowed to survive in intervening alternative crops and unless these are killed, using selective herbicides soon after emergence, the sowing of brassicae crops must be delayed still further. Volunteer rape plants in fields and adjoining newly sown oil rape have also been known to provide a ready source of infection of wind-borne disease spores of downy mildew (Peronospora parasitica). Brassicae weeds, such as Sinapsis alba, can also serve as carriers of disease to affect adjoining plants of oil rape and there is ample evidence of these weeds being the early habitat of pests such as blossom beetles which subsequently attack neighbouring rape crops.

Hitherto close cropping of maize has not been extensively practised in Britain and apart from evidence of build-up of smut (Ustilago maydis) in successive maize crops there have been few indications of any likely future problems. Frequent inter-cropping of maize and winter wheat may provoke a stalk and foot rot problem particularly where there is failure to dispose of stalk trash after harvest. High populations of cereal cyst eelworm (Heterodera avenae) following intensive oat or barley production can cause poor growth in maize and although maize is regarded as an end host with no subsequent build-up of viable cysts, alternating barley with maize may be detrimental to the latter crop in known situations of high eelworm population.

ECONOMIC SIGNIFICANCE OF PEST AND DISEASE

Oil rape The current contract price for oil rape seed in the UK is in the region of £110 per tonne but subject to quality standards with penalties of 2 per cent for each one per cent below 38 per cent oil content. If the yield level of saleable product reaches 2.25 t/ha (18 cwt/ac) an output of £247 per hectare can be expected. The current estimated average input for pesticides on oil rape is Southern England approximates to £20 per hectare which is equivalent to 8 per cent of output value. Any combination of pest and/or disease causing more than 10 per cent seed yield loss will therefore justify this recorded average expenditure on pesticides assuming these provide acceptable effective control.

If in the production of winter oil rape the grower faces annual loss due to attacks of seed weevil and/or pod midge (Dasyneura brassicae) of the order of 10 per cent of average yield potential he may be justified in using routine control measures provided he is confident of obtaining satisfactory control. This could involve three applications of appropriate pesticides. The justification for such action is still a debatable subject.

Fodder maize An economic assessment of damage caused by pest or disease in this crop is a difficult task. The cost of producing 1 tonne dry matter maize for ensiling can currently be estimated to be in the region of £18. This assumes production of around 10 tonnes dry matter per hectare with variable costs (seed, fertiliser and weed control) of £80 per hectare. A reduction in yield of 10 per cent dry matter reduces the value of the crop to the farmer by the equivalent of £7 per hectare thus providing a guide to the potential value of measures that may be introduced to control pest or disease.

EFFECT OF PEST AND DISEASE ON CROP QUALITY

All too often damage due to pest or disease is assessed solely in terms of loss of yield ignoring important aspects of the possible effect on the quality of the produce. In the case of oil rape production, which is largely grown on contract to trade or grower organisation agency, there are financial penalties where the oil content falls below a minimum standard as mentioned previously. Similarly there are financial penalties where the purity of the seed produce falls below 99 per cent. It is essential therefore to quote levels of yield in terms of whole clean seed at storage moisture levels of 8 per cent and to indicate the oil content of the seed based on analysis of a representative sample. In the event of future marketing into Intervention Buying it will be necessary also to declare the content of erucic acid in the oil, the maximum tolerance in oil intended for edible use from produce harvested in 1976 being 15 per cent.

With maize harvested for fodder as green crop or ensiled material there is concern that the feeding quality may suffer due to the after effects of pest or disease. Generally the nutritive value is expressed in terms of digestible organic matter. Current worry centres around the presence of malformed smutted (Ustilago maydis) ears in the ensiled produce although it is reported from Mexico that such ears are highly valued as an edible fungus; a gourmets delight!

CONCLUSIONS

Awareness can be part way towards control of a problem. Certainly in the economic production of these crops there is need to be aware of the likely toll from pest and disease. The grower himself can go a long way towards minimising the risks of damage by careful adherence to crop rotation principles and appreciating the need for between crop hygiene. The residues of one crop left in the same field or adjoining field can be the worst enemy of a newly sown crop of the same species. Weeds can also be the carriers of disease and pests. The successful grower is also aware that many of his problems stem from interaction of pest and disease with other crop plant stresses many of which could be avoided by more careful husbandry.

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MODELLING OF TICK POPULATIONS AS A PREREQUISITE TO CONTROL

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Summary The evolution of strains of ticks resistant to arsenic, DDT, BHC and the organo-phosphates poses problems to the stockbreeder, particularly overseas, and new approaches to tick control appear to be necessary. It is then revelant to consider the advisability of modelling (without necessarily being mathematical) of populations so as to determine the range of environmental factors which influence tick incidence. In well established parasite-host relationships, natural control mechanisms maintain the association in dynamic equilibrium; these may be mechanical in wild hosts, or they may be due to an induced immunity response, or to hypersensitivity. The introduction of alien hosts in large numbers into the environment upsets this balance, and whilst temporary alleviation of tick borne diseases to domestic stock might be achieved by acaricides, their reduced effectiveness, due to resistance, prompts an approach to coincidental monitoring and analysing tick incidence on endemic fauna, on introduced stock and of the association with their free living stages in their temporal and spatial occurrence on vegetation. This is illustrated by the use of a mechanical analogue as representative of a dynamic solution. The situation is complicated by the fact that ixodid ticks have three basic patterns of life history which might influence the choice of acaricide. These differences are illustrated by reference to one-, two- and three-host ticks. Attention will also be directed to the behavioural role of pheromones in maintaining levels of population and the possibility of exploiting them for control.

THE PROBLEM

In the context of this address I am using the word "modelling" very broadly, for within it there are connotations of a quantitative nature, direct or implied suggestions for the furtherance of mathematical approaches and considerations of systems analysis and simulation tests in relation to tick control work. The obvious question that is of immediate concern is, why it is necessary to take such further consideration into account at this stage in view of the history of the general success of acaricides and insecticides in pest control, particularly of ticks.

The economic success of highly productive agricultural economies depends on regulating disease and this remains largely chemical despite the outcry from conservationists and the enthusiastic hopes for successful biological regulation. An appreciation of this situation only becomes real when, for example, you follow a flock of sheep or goats, suffering from heartwater disease, a short distance and see them stagger and drop in rapid succession, so that almost all the entire flock falls out. Intensive stock farming regions are normally disease areas and that they ever become economically profitable is in no small measure due to the contribution of the chemical control industry.

In such potential disease areas ticks are almost ubiquitous and they play a dual role in affecting the health of the stock. They ingest substantial quantities of host blood due to the very high numbers which parasitize the host, and it is not unusual to fill a half-gallon drum with ticks removed from one host. Some ticks, like the bont ticks in South Africa, can cause extensive wounds which may become secondarily infected by bacteria and screw worm larvae and in this way extend the inflammatory zone and the area of lesion. More importantly ticks transmit pathogens responsible for redwater fever, tick-borne fever, louping ill, heartwater and under certain circumstances induce paralysis. These are not only debilitating diseases but are responsible for heavy mortalities and sickness. Nor is it unusual for more than one tick species to attack the same host, and each may inhabit a different region of the body. Hitherto infestations have been controlled by treating the stock with insecticides, but in South Africa, for example, many species have built up a resistance to a wide range of insecticides. This has been a gradual process and, since 1938, some strains of species, including the infamous blue tick (Boophilus decoloratus) have become successively resistant to arsenic, DDT, BHC, toxaphene, the organophosphates and carbamates. In Australia some ticks are now resistant to all but a very few insecticides. To what extent resistance may have evolved, as a result of natural selection, in two different species inhabiting the same host warrants investigation. In the tick infested regions of the tropics and subtropics farming has only been possible because of the effectiveness of chemical treatment so that the evolution of resistance becomes a paramount problem facing the industry. Two approaches are then possible - the first is to devise new insecticides, which, whilst having such ideal qualities as a long period of residual toxicity, must now conform to the most recent and more rigid environmental standards being demanded in most parts of the world. At the same time it must be recognised that ticks may, in time, also possibly become resistant to such new chemical preparations. Since the nature of the evolving resistance may, expectedly, not operate along the same biochemical pathways for all insecticides or indeed for all pests, it poses a problem of considerable intrinsic interest for the academician, whilst remaining a hard fact of life for the stockman and the chemical industry. If the realities of this as a situation for controlling ticks is valid and accepted then we have no recourse but to re-consider, as our second approach, fundamental ecological and biological issues and to see whether new concepts may be derived in which the chemical veterinary control industry has a rational part to play.

THEORETICAL CONCEPTS

In considering host-parasite relationships of a well established type the host species is protected from overwhelming parasitic challenges and the parasite is yet able to overcome setbacks, sometimes through high fertility, sometimes by depositing the immature stages in the most favourable of positions for it to ensure the survival of the species. In part, control of the parasite by the host may involve pure physical or mechanical removal of the parasites either by biting, licking or by scratching but should this fail in areas of heavy populations an acquired resistance may develop, which may involve the closing down of superficial skin blood vessels as may happen with ked and lice infestations when the parasites may be starved of blood. Dynamic changes may occur in the cellular composition of the dermis - for example an increase in neutrophils, eosinophils and lymphocytes. Introduced alien hosts are less likely to resist infestation by ticks and generally become more heavily infected - in other words, the balance of the environmental components is upset vis-a-vis that which was "natural". Because ixodid (hard) ticks feed continuously for a number of days on their hosts they are less economic in their life histories than short time feeding organisms, and may show a diffuse spatial pattern by dropping indiscriminately during the peregrinations of the hosts. This behaviour pattern opens up a variety of feeding and free-living sources for ticks infesting the grazing or hunting areas of their hosts, when compared with those ticks which are restricted to the nesting quarters of their hosts. The dynamic community relationships between such ticks and their environment may be made clear by reference to the mechanical analogue in Fig. 1. Here the discs represent factors: clockwise turn means increase. The central pulleys are the drive wheels and the peripheral pulleys are the pick-up. The whole-line drives indicate ecological action, the interruptes lines co-action and the dotted lines reaction. As "good grass" cover increases the proportion of "rough grass" must decrease because the drive is toothed. Increase of "rough cover" proportion, acting through the increased moisture of the microclimate (= toothed idler wheel B) will increase the survival of fully fed ticks. A second type of drive is optional e.g. the grass factor to the cattle stock. Increase of cattle tends to reduce the rough cover by reversing the direction of rotation of the rough cover disc. The good grass factor could be linked directly to the sheep numbers. Here, because of the selective grazing habits of sheep, represented by friction wheel A - the tendency is to increase the amount of rough cover. Increase of the sheep and/or cattle will tend to increase the numbers of ticks. Increase of good grass proportion increases the density of wild herbivores; increase of rough cover produces more suitable conditions for rodents. Increase of either one or both of these faunal components results in increased carnivore populations, all of which contribute to increasing tick density by providing additional supplies of hosts. To make a model truly quantitative requires that the amount of turn of each factor is measurable and would be reflected in the diameter of each one. This for many parameters is just not feasible in a mechanical analogue, plausible possibly in terms of a computer but since environmental components are characteristically impermanent they will vary markedly over time in any case.

QUANTIFICATION OF INFESTATION IN TERMS OF A MODEL

In an attempt to quantify relationships between different stages of three-host ticks I instituted continuous studies on Ixodes trianguliceps as a model at King's College Field Station, Rogate, Hampshire. For this purpose the tick had the advantages of having a restricted range of small hosts - rodents - (i.e. the amount of interference from other species is minimal) the tick populations at all times of the year could be readily counted in situ, the hosts were readily collected by capture - re-capture techniques so that the host population was not affected (apart from some shrews which died in traps despite all precautions). It had the disadvantage, however, of being a nest inhabiting species, copulation occurred off the host and presumed unfertilized females took longer to engorge fully. The field work was carried out by Randolph (1973) who noted that larvae may remain on the host in the field from five to nine days while laboratory bred larvae feed for 7 days; we have assumed the average feeding time to be 7 days. The feeding time records are much fewer for nymphs and adults but on laboratory and field evidence we have assumed nymphs to feed for 9.5 days and females for 17 days. During fortnightly sampling hosts are taken alive in Longworth traps for three consecutive nights. The ticks on the hosts are recorded and the latter are then released. So if larvae feed for 7 days there will be five nights immediately after each trapping period when larvae that attach will have detached before the next trapping period (Fig. 2). Assuming an equal chance of attachment each night only 9/14 (64.3% of the larvae will be counted); similarly nymphs feeding for 9.5 days will not be sampled on two occasions immediately after each trapping i.e 12/14 (85.7%) of the nymphs will be counted. As long as females remain feeding for at least 12 days they will all be counted by the fortnightly census and require no factorial element. To determine relative populations then the numbers of larvae are multiplied by 100/64.3 and of nymphs by 100/85.7. For 1971-72 the infestation rates of small mammals so trapped were 2917 larvae, 195 nymphs and 35 females and for 1972-73 the corresponding figures were 4642 larvae, 195 nymphs and 29 females. The numbers of males collected on the host in both years were 3 and 4 respectively. Complications introduced by emigration and immigration of hosts over the annual cycle are ignored here, but recognized, as our concern here is with total loads. In other words, without the intervention of man-made control measures, the drop in natural population was very significant from larval to nymphal stages and less so from nymphs to adults. These results indicate that the most vulnerable period for supporting natural control might be by attack at the larval-nymphal stage in such a three-host tick as I.trianguliceps. This suggests that there is need (i) to re-examine this situation in other three-host ticks, which are not as intimately associated with host nests as is I.trianguliceps to determine the validity of the relative figures for each stage under natural conditions and (ii) to determine whether larval ticks differ from nymphs and adults in their threshold of response to insecticides, as seems to be at first indicated from their reaction to other physiological parameters. The sensitivity of larvae to desiccation for example, is often seen by their dried bodies enmeshed in the hairs of hosts naturally, whereas those of later stages are less readily found.

LIMITATIONS

The weakness of this phase in the life histories of ticks is also illustrated in some two-host ticks where larvae and nymphs occupy one microhabitat on the body and the adults another. For example, the infestations of the ears of both wild and domestic animals by immature stages of the two-host tick Rhipicephalus evertsi results in the secretion of wax by the hosts. The initial infestation by the larvae occurs in the folds of the inner parts of the pinna and in the external auditory meatus, where the larvae attach and feed. As a foreign body reaction the host produces wax from the wax-secreting cells. On completion of feeding the larvae moult in situ and the emerging nymphs attempt either to re-attach on the same site or at some distance to feed again. The amount of secreted wax is frequently sufficiently great to form a barrier between the nymphal mouth parts and the skin surface as to prevent complete feeding in a proportion of the nymphal population. And, since a threshold value of blood is necessary for metamorphosis to proceed, (Arthur and Londt, 1973) any ticks failing to attain this do not develop further. The very considerable aggregation of wax in the ears of wild Cape hares, one of its normal hosts, contain not only the cast skins of larvae, but also the bodies of nymphs which have failed to attach and feed. In other words, this phase would appear to represent a natural point of attack on the host.

Nevertheless, there are limitations to attacking the larval-nymphal interphase for control. In some three-host ticks e.g. I.rubicundus, the Karoo paralysis tick, immature stages are rarely found parasitizing domestic stock, although adults do. The larvae and nymphs are most abundant on the elephant shrew and the Cape hare: only exceptionally are females found on other wild fauna. Accordingly, it is an impracticable situation and obviously this calls for control of feeding females on domestic stock. With some other like species there may be other avenues worthy of exploration. The bont tick, Amblyomma hebraeum, is one such species, of considerable economic importance in South Africa, whose incidence and occurrence on wild hosts have only been currently looked at. But what is of interest here is that fertilization occurs on the host and, until this is effected, females are unable to feed. The male requires a blood meal to complete spermatogenesis and on its completion the sexes become attractive to each other. It has been reported (Berger, et al, 1971) for example, that in the American amblyomma tick (A.maculatum) the male is attracted to the female, but Gladney (1971) states the opposite which is in accord with our observations on the bont tick in South Africa. The chemical properties of the extruded pheromone suggest that it is a weak acid, possibly a phenol. Females which fail to mate do not feed to complete engorgement although they may probe and remain temporarily attached for up to 24 hours. Now over periods of up to six months there is evidence that the numbers of male bont ticks on domestic stock increase cumulatively and each one has the potential of inseminating a large number of females, each of which is capable of producing viable offspring. But there are obvious gaps in our biological knowledge here, in particular on such matters as the number of females which can be fertilised by one male and the effects of age of the male tick on the numbers and viability of eggs produced by later inseminated females. Nevertheless, it is pertinent to determine whether an artificial pheromone could be produced in the laboratory and what use could be made of it in the field: solid carbon dioxide can, as you are doubtless aware, attract ticks from quite a wide area. Whilst recognizing the practical difficulties the concept is not without foundation however it might be realized: the introduction of irradiated males onto the stock might be possible, too.

One-host ticks, whilst containing some of the most potent disease carriers to stock, pose special problems. Dr Londt and I (1973) simulated the parasitic cycle of Boophilus decoloratus, the blue tick of South Africa, on calves and found that the larval-nymphal and nymphal-adult period of metamorphic change are well protected phases (Figs. 3a and b). The larvae feed for about five days and when specimens are cleared with clove oil for example, at the end of this time there is no evidence of visible developmental changes. Larvae retained their external body form for a further two or three days after completion i.e. from the sixth to the eigth day after larval attachment. During this time their weights decreased and such "larvae", when cleared, showed substantial nymphal development over the three days. Moreover, the "pharate" nymph (Fig. 4) is now provided with its own cuticle separated by an "air space" from the still-retained larval cuticle. This would give added protection for the "pharate" nymph against insecticide penetration. At the end of three days this nymph is ready to feed immediately. Similarly, the immobile pharate adult, also protected by two cuticular layers, appears within two or three days of cessation of feeding of the nymph and is capable of attaching, as the adult, to the host on emergence. This, of course, contrasts with three-host ticks which remain mobile after each stage drops from hosts and which on attaining a new host are probably more liable to succumb to attack by picking up acaricidal residues during their wanderings over the host to select feeding sites. Since blue ticks are picked up every day, as indeed are other ticks, the most appropriate point of attack would seemingly be, theoretically at least, on larvae about to feed.

These broad considerations on modelling and simulation may serve to emphasize the need for more detailed studies on a wide range of biological problems preparatory to the use of acaricides and to the need to examine more closely their effects on all stages of the tick bearing in mind the weakest link in their life histories.

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Fig. 1

Model of tick-environmental inter-relationships (after MacLeod, 1962). For further explanation see text.

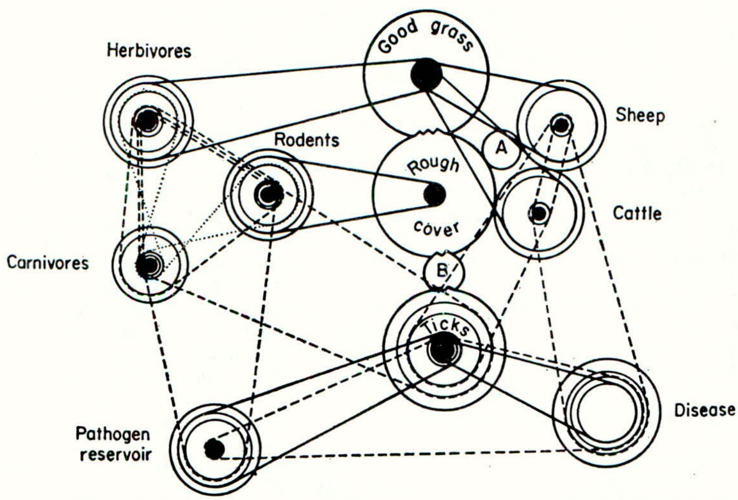


Fig. 2

The significance of trapping and non-trapping periods on the assessment of tick populations under natural conditions. For explanation see text.

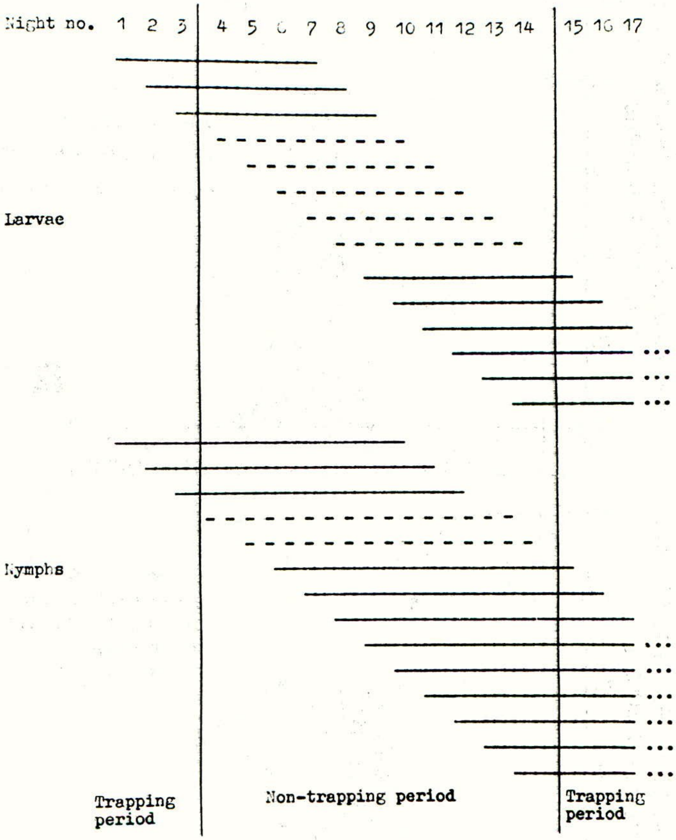


Fig. 3

(a) The percentage of larvae, pharate nymphs and emergent nymphs of Boophilus decoloratus present on each successive day of the parasitic cycle between the first and twelfth days after the original larval infestation of the host.

(b) The percentage of nymphs, pharate adults and emergent adults of B. decoloratus present on each successive day of the parasitic cycle between the tenth and nineteenth day after the original larval infestation of the host.

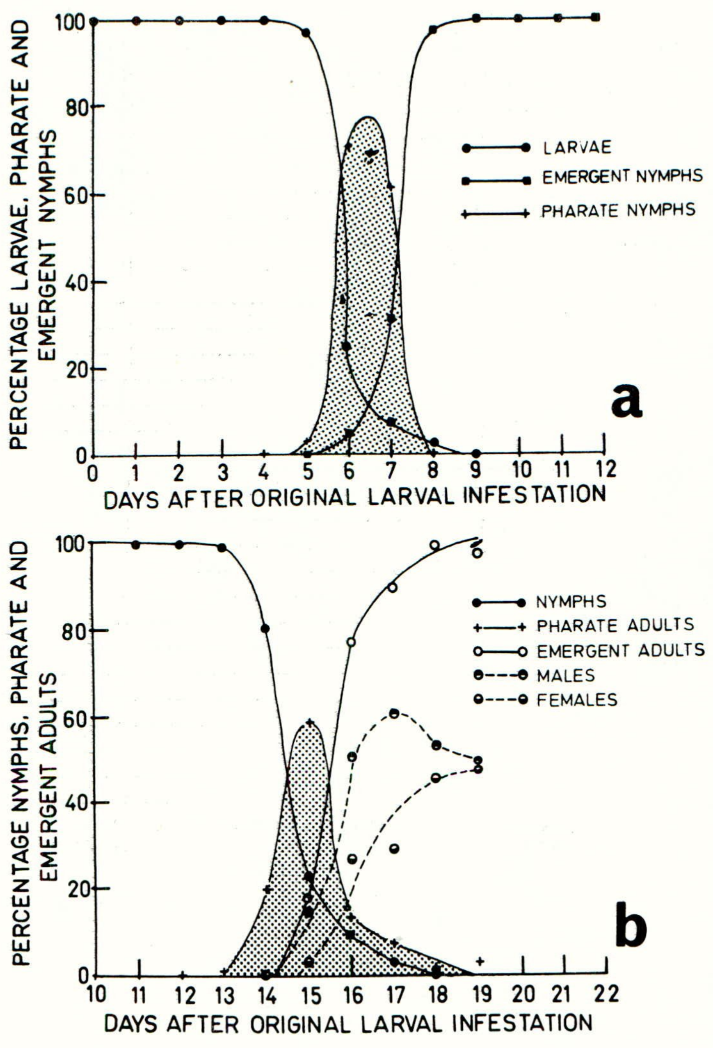
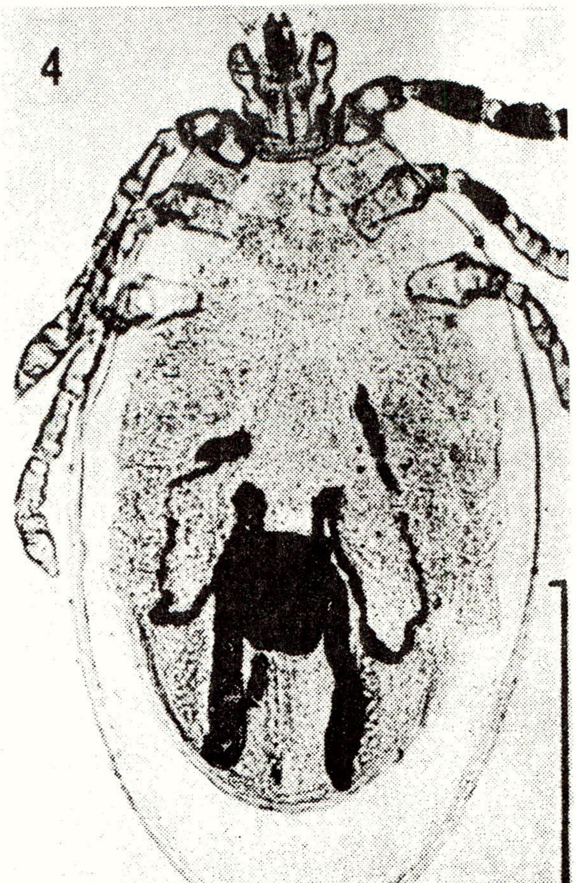


Fig. 4

A cleared preparation to show the pharate nymph within the larval cuticle on about day 6 after the original larval infestation.



FUNGICIDES FOR POTATO TUBERS

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Summary In recent years the research devoted to potato tuber diseases and their control both in the U.K. and elsewhere has increased. The principal disease which has lent impetus to this work is gangrene (*Phoma exigua* var. *foveata*), but others of varying importance include dry rot, skin spot, silver scurf, *Rhinzoctonia* and the bacterial disease blackleg.

Extensive work on the nature of these diseases has been carried out but only in the last six years have effective fungicides been developed to replace disinfection by organo-mercury compounds; these are active, wide-spectrum compounds, and can give good control of most of these diseases.

Two types of fungicide are now in current use for this purpose, 2 amino-butane applied as a fumigant and some of the benzimidazoles, mainly thiabendazole applied as a mist. The first mentioned loses its effectiveness only slowly in terms of time of application after harvest, but so far has been cleared only for use on seed potatoes. The latter can be applied also to ware potatoes and can reduce skin spot and silver scurf on the progeny tubers.

The advantages and disadvantages of each method are compared in relation to the use of organo-mercury solutions. Whatever chemicals may be used, advantage must also be taken of other factors such as early-lifting so as to obtain maximum benefit from the treatment.

It is not long ago that discussion of fungicides for potatoes would have centred around protective spraying of the haulm in control of potato blight and, with the exception perhaps of tuber blight, one did not immediately think of tuber diseases. Conversely, fungicides for cereals meant seed treatment. Nowadays to a certain extent the position has been reversed and there is considerably more interest in fungicides for cereal leaf diseases and in those for potato tubers.

Disinfection of seed potatoes is not of recent origin, and amongst the first to advocate fungicidal treatment was Bolley (1891) in the USA more than 80 years ago. With very few exceptions, notably tecnazene dust (Anon. 1948) applied for the control of dry rot (*Fusarium solani* var. *coeruleum*), the materials used were either organic or inorganic compounds of mercury.

What was or still is the justification of the use of such compounds and of the search for more effective ones? There was first the attempt in the USA to reduce transmission of the seed-borne common scab organism *Streptomyces scabies* into clean soils, one which I think we would not consider in this country today. There was also the serious problem of 'seed piece decay' (Clayton, 1929) associated with *Erwinia* spp. and *Fusarium* spp., which would intensify blackleg and emergence problems in the

UK were we to adopt the procedure of cutting seed tubers before planting. Transmission of Verticillium wilt (V. albo-atrum) and blackleg (Erwinia atroseptica) (Robinson, et al., 1960) have been reduced by using organo-mercury compounds and blight (Phytophthora infestans) in seed tubers was controlled in potatoes harvested when infected haulm was present if immediate disinfection was carried out (Greeves, 1937).

Again, Rhizoctonia attack on young sprouts can be very damaging under some conditions and can be minimised by treatment of the seed. Organomercury compounds are still used for this purpose in the Netherlands and there are no doubt areas in the UK which might benefit by its control.

In this country we still have the problem of skin spot (Oospora pustulans) whose importance in practice waxes and wanes from season to season and will continue to do so unless we eliminate the disease or the variety 'King Edward' disappears from the market. Although we do not now experience the same economic losses of seed by dry rot (F. solani var. coeruleum) such as we did thirty years ago, this disease still takes its toll in the post-planting period by causing emergence reduction. Silver scurf (Helminthosporium solani) may not have such general economic importance but it is entirely transmitted by seed tubers and can seriously affect the quality of prepacked ware.

It is debatable whether one could seriously justify the widespread use of fungicides in the UK, were they used to control only the diseases which have been mentioned so far, good as this might be. The disease which has stimulated activity in this direction is one which was relatively rare thirty years ago, namely gangrene (Phoma exigua var. foveata). While the search continues for the chemical which will control all the so-called latent diseases, any material which does not provide a high degree of control of gangrene is not likely to find favour with the grower or merchant.

The other seed-borne disease I should mention is, of course, blackleg and so far this has not been easy to control in practice by disinfectants except, in certain circumstances, by mercurials (Table 1). However, differentiation must be made between latent infection of the seed tuber and tuber decay in storage, and these are not necessarily connected.

What is the present range of fungicides which can be employed in dealing with these problems? Discussing the first group, the mercury compounds, will highlight some of the difficulties and drawbacks in the search for the ideal material. Historically in the UK, mercury in several organic forms, but chiefly that of a methoxyethylmercuric chloride (MEMC) dip ('Agallol'-Bayer) at 150 ppm mercury, has been used. The disinfection should be carried out as soon after lifting as possible and can provide a good control of dry rot (Foister, 1940; Foister & Wilson, 1943), skin spot (Greeves & Muskett, 1939; Foister, 1943) and gangrene (Boyd, 1960; Boyd & Penna, 1967; Logan, 1967). Furthermore, Jennings, et al., (1964) showed that Rhizoctonia at the stem bases was considerably diminished by this treatment.

In this connection it seems to me that some credit must be given to Sir T.A. Wedderspoon, who developed the small-scale experimentation on organomercury disinfection into commercial practice in 1956 and in this way maintained general interest in the practicability of chemical control of latent diseases.

The introduction of pressure washing seed tubers prior to disinfection was found by itself to reduce dry rot and gangrene, presumably by removing contamination from the tuber surface (Boyd, 1960). However, this treatment also increased the level of soft rot and blackleg in the resulting crop (Graham, 1963; Jennings, et al., 1964; Logan, 1964). Where it was omitted on the other hand, blackleg could be decreased as shown in Table 1 (Boyd & Penna, 1969), if we measure this by symptoms developing when such seed is planted. Application of a bactericide prior to washing the tubers also reduced blackleg incidence (Graham, 1963) and agrimycin dip (streptomycin + oxytetracycline) (Bonde & Hyland, 1960), agristrep dust (streptomycin) or 'Semesan Bel' (organo mercurial) (Robinson, et al., 1960) reduced bacterial decay in seed pieces and also subsequent blackleg. As well as illustrating the effect of washing, Table 1 shows the influence of riddle damage on the development of blackleg and the reduction by mercury disinfection of blackleg transmission after riddle damage at lifting. Graham and Volcani (1961) also were able to reduce blackleg incidence by the use of organomercurials or streptomycin disinfection, but as in other work results were not consistent. Nevertheless, the fact that the development of latent blackleg infection can be reduced, although perhaps not consistently, by the use of chemicals may give some hope for further success in this direction. At present, however, there is no suitable bactericide for use on potato tubers.

Table 1

Percentage plants showing blackleg symptoms on 1 September after various treatments of seed at harvest - washing (W), riddling (R), mercury disinfection (D), and hand-picking (H) - 1968-69

Treatment	Majestic	King Edward
R	15.0	3.0
W R	18.3	18.3
W R D	14.3	12.3
R D	8.3	1.0
H	11.3	2.3
W H	13.6	19.3
W H D	12.6	12.0
H D	1.3	0.7

Mercury disinfection can also stimulate sprout development (Boyd, 1960), although the cause of this has never been explained, and it can increase stem numbers and the proportion of the seed fraction in the crop (Jennings, et al., 1964).

The disadvantages in the use of mercury compounds are well known; they are extremely toxic and waste disposal presents a problem. Drying of the treated seed imposes an additional procedure and the fact that only seed and not ware may be treated is a considerable drawback necessitating the mechanical separation of these fractions immediately after harvest. The other disadvantage, namely the need to treat tubers within a relatively short time of lifting, is shared by all other materials used to reduce infection on the current crop, although the length of this interval may vary.

The compound tecnazene is still used to a considerable extent in Scotland and in the experience of some growers it reduces gangrene. Gray and Malcolmson (1967) used this as a 3% dust and obtained some reduction of gangrene, and we have tested this over three years by applying it to both 'Redskin' and 'King Edward' seed in boxes just after riddling at harvest, and then to 'Redskin' prior to clamp storage.

In the latter case we used the dust 'Fusarex" (Plant Protection)at 134 g/t a.i. and the granules 'Bygran S.' (Wheatley Chemical Co.) at 34 g/t a.i., both recommended rates. Gangrene development in the clamp and subsequently in boxes after riddling from the clamp are shown in Table 2. The disease was considerably reduced with increasing concentration of tecnazene, although not to a level comparable with those obtained by other methods. The benefits here, of course, is that tecnazene can be applied to both seed and ware.

The compound 2-aminobutane (2AB) ('Butafume'-BASF),which has been used as a fungicide on citrus fruits in the USA, was developed as an alternative to mercury compounds principally as a control for gangrene and skin spot (Graham & Hamilton, 1970; Graham, et al., 1973a; Graham, et al., 1973b). It is used as a fumigant introduced over a period of about 30 mins into a gas-tight chamber containing the potatoes at the rate of 200 mg/kg and recirculated for a further 2 hours.

Table 2

Percentage gangrene development after tecnazene treatment at lifting into clamps October 1973, var. 'Redskin', 1973-74

Tecnazene A.i. (g/t)	Ex. clamp 31 Jan	After boxing 16 Apt	Total
134	4	13	17
34	15	26	41
0	20	35	55

A very high degree of control of gangrene and skin spot with some reduction of silver scurf can be achieved by this treatment. The results in Tables 3 and 4 will be discussed in comparison with those of other fungicides. Residues of 2AB remain in the treated tubers, and permission for treatment of ware is still under discussion so this method at present can apply only to seed potatoes.

So this again necessitates separation of ware and seed soon after harvest. This interval however does not appear to be so critical as with other materials, presumably because of penetration of the gas into the tissues, but a limit of 3 weeks is recommended at present. On the other hand, if potatoes are lifted too early or are immature, or are freshly damaged by lifting machinery, 2AB may induce a slight pitting of the skin on which superficial mould growth may occur. This can detract from the appearance of the tubers but it has no effect upon sprouting, nor has subsequent development of gangrene been observed. In practice, therefore, tubers are usually treated several days after lifting and grading.

Another disadvantage is lack of control of dry rot by 2AB, and the occasional complaint of the ineffectiveness of 2AB invariably is concerned with dry rot and not gangrene.

Quinn, et al., (1975) found that 2AB fumigation had no substantial effect upon the yield from treated seed although in most cases there was a small but not significant increase in the proportion of seed. In our experience over 3 years there was no detectable difference in ware or seed yield whereas a consistent usually significant increase of the seed fraction followed organomercury disinfection.

In 1969 Hide, et al., (1969) introduced a new feature into the control of tuber diseases. They showed that the systemic fungicides benomyl (BEN) and thiabendazole (TBZ) applied as dusts or dips to potato tubers shortly after harvest were able not only to control gangrene as well as skin spot and silver scurf in storage, but also to reduce levels of the last two in the progeny of the treated tubers. In Maine, USA, Leach (1971) showed that both these materials could also control dry rot caused by Fusarium roseum sambucinum after 2 min dips or dust application.

Some of the results of comparative trials of the effectiveness of benomyl (10%) and thiabendazole (1%) applied as dusts and of 2AB fumigation and mercury disinfection 150 ppm (MEMC) are shown in Tables 3 and 4. In addition, a 3rd year stock derived from stem-cuttings was used for comparison and 0.5 t clamps of untreated and benomyl-treated potatoes of the same stock were made from which samples were taken at intervals for treatment. Table 3 shows the development of gangrene on the various treatments and on the progeny of sound seed planted in the following year.

Table 3

Gangrene development after various treatments 1971-72, and on progeny grown from sound tubers from these treatments 1972-73. var. 'King Edward'

Treatment from lifting 18 Oct 1971	Gangrene % Seed In clamp	Gangrene % Seed After box	Gangrene % Progeny
RIDD : BOX	-	38	8
RIDD : MEMC : BOX	-	4	9
RIDD : 2AB : BOX	-	1	8
UNT : CLAMP : RIDD : BOX : JAN	62	28	2
BEN : CLAMP : RIDD : BOX : JAN	26	45	20
UNT : CLAMP : RIDD : BEN : BOX : JAN	62	22	10
UNT : CLAMP : RIDD : TBZ : BOX : JAN	62	28	8
STEM-CUTT. : 2AB : RIDD: BOX	-	2	8

The principal points of interest are the good reduction by MEMC, the almost complete control by 2AB and the inability of benomyl dust applied to the clamped tubers finally to influence gangrene development. The initial apparent reduction (26%) in the clamp was almost certainly due to masking of lesions by the white benomyl dust and this probably accounts for the increase (45%) after boxing when treatments were finally assessed. Again, no effect was given either by benomyl or TBZ when applied to tubers taken from the clamp in January; dry rot development was negligible.

It is clear also that there is no relation between gangrene development in the seed and the progeny.

The effect of these treatments upon skin spot and silver scurf is shown in Table 4. The skin spot eye infection index (EII) (Nagdy & Boyd, 1965) was used for assessment of this disease and a surface infection index (SII) was used for silver scurf on the same basis as that for skin spot (Boyd, 1957). Development of skin spot after MEMC and 2AB treatment was almost completely inhibited and was reduced by benomyl applied at lifting or in January. TBZ applied in January was not effective. In the progeny there was a clear reduction of skin spot only when the two benzimidazoles were used either at lifting or in January.

Benomyl applied at lifting to clamped tubers gave a considerable degree of control of silver scurf but the principal reduction was in tubers boxed at lifting compared with those which had been clamped. Benomyl and TBZ only when applied in January influenced silver scurf development in the progeny in this experiment.

The effect on the progeny is a valuable asset in the maintenance of the health of the next generation of tubers. Initially this was thought to be a result of the systemic effect of the fungicides but latterly it was shown to be caused by the inhibition of sporulation of the fungi involved (O. pustulans and H. solani) and thus reduction of transmission to the progeny.

Table 4

Skin spot and silver scurf development after various treatments 1971-72, and on progeny grown from sound tubers from these treatments 1972-73. var. King Edward

Treatment from lifting 18 Oct 1971	Skin spot (EII)		Silver scurf (SII)	
	Seed	Progeny	Seed	Progeny
RIDD : BOX	34	27	13	33
RIDD : MEMC : BOX	0.1	15	21	42
RIDD : 2AB : BOX	0	16	11	24
UNT : CLAMP : RIDD : BOX : JAN	19	24	49	44
BEN : CLAMP : RIDD : BOX : JAN	7	3	15	38
UNT : CLAMP : RIDD : BEN : BOX : JAN	10	3	39	17
UNT : CLAMP : RIDD : TBZ : BOX : JAN	20	8	42	22
STEM-CUTT. : 2AB : RIDD : BOX	0	5	2	27

It is known that skin spot transmission is normally dependent on the level of inoculum on the seed (McGee, et al., 1972) and Table 5 shows very highly significant correlation (r) in skin spot EII between seed and progeny in a series of 14 treatments in both 'Redskin' and 'King Edward'. However, where 10 different benomyl or thiabendazole treatments were applied at various times in the same experiment, skin spot on the progeny was not only lower than where benzimidazoles had been excluded but the range was smaller and there was no significant correlation between seed and progeny. Thus even where application was made to tubers in which the level of skin spot was fairly high just before planting, symptom expression on the progeny was greatly reduced irrespective of that on the seed planted.

Table 5

Skin spot eye infection indices of seed planted after various treatments 1971-72 and of the progeny after storage 1972-73

	Redskin		King Edward	
14 treatments excluding benzimidazoles				
	Seed	Progeny	Seed	Progeny
Range	0 - 19.3	0 - 16.5	0 - 33.8	0 - 42.0
Mean	5.9	7.8	9.3	18.5
r	0.961***		0.845***	
10 benzimidazole treatments				
	Seed	Progeny	Seed	Progeny
Range	0 - 16.0	0 - 2.5	6.1 - 21.0	2.5 - 9.2
Mean	7.5	1.3	9.0	5.6
r	-0.33 NS		0.30 NS	

The same pattern obtained for silver scurf. Such reduction of skin spot and silver scurf may follow in the progeny crop even when application is made during storage, for example, when seed is being riddled from the bulk of stored potatoes. This would remove one of the disadvantages of treatment immediately after lifting and would be most valuable in the routine maintenance of high grade stocks with a low disease content (Hirst, et al., 1970).

However, this does not help at the moment in the control of gangrene where recontamination of treated stocks, whether by means of soil or wind-blown pycnospores, is not fully understood. There is no consistent correlation between infections of the seed and the progeny. Not only so, but occasions have been recorded when benomyl dust application increased the level of gangrene (Hide & Griffith, 1973; Logan, 1974; Tickle & Boyd, 1973). This, Logan (1974) suggests, was caused by the availability of benomyl for absorption by the roots, and after translocation this inhibited the synthesis of phenylalanine ammonia lyase, an enzyme associated with host stem resistance mechanisms. Thus increased stem infection would be followed by increased formation of pycndia of *P. exigua* var. *foveata* and eventually increased contamination of the progeny by pycnospores.

If this is one of the possible disadvantages of dust application, the alternative of a dip cannot be recommended because of the possibility of blackleg and soft rot increase, since neither benomyl nor thiabendazole have the necessary bactericidal properties. However, a benomyl dip has been used in France apparently with some success against almost all the tuber-borne diseases although there is no mention of blackleg (Anon, 1974). On the other hand Tisdale and Lord (1973) have shown that thiabendazole is much more active as a fungicide when applied in aqueous solution at pH 3.0 than as a dust.

Table 6

Disease development after various treatments at lifting and at periodic removal from clamp, King Edward 1974-75

Date	Treatment	Gangrene %	Skin spot (EII)
28 Oct	Untreated	8	55
	MEMC	2	11
	2AB	0	6
	TBZ	1	16
14 Nov	Untreated	4	71
	2AB	0	12
	TBZ	4	34
13 Dec	Untreated	4	67
	2AB	1	36
	TBZ	4	67
30 Jan	Untreated	2	76
	2AB	0	62
	TBZ	2	82

To avoid the tedious drying procedure involved in any dipping process, Logan, et al., (1975) have described a mist application using a 2% suspension of 60% WP thiabendazole ('Storite'-RPH) at 2 l/t of potatoes. This again is applied immediately after lifting as a continuous process as the seed is being riddled. It is permitted for use on ware, and it would thus be possible for the whole crop to be treated without removal of the ware at lifting, if a suitable method were devised.

In a preliminary comparative test with TBZ and 2AB in 1974-75, not much gangrene (8%) and practically no dry rot developed on the 'King Edward' stock used. The stock was lifted, riddled, and treated on 28 October within about 48 hours of lifting, and all treatments including mercury (MEMC) gave a satisfactory control of gangrene and skin spot. An untreated clamp was made at the same time and on 3 successive dates samples were removed for treatment. The data are shown in Table 6 and the main conclusion appears to be that 2AB loses its effectiveness much more slowly after harvest than TBZ in control of both gangrene and skin spot. This supports evidence by Graham, et al., (1975) that 2AB fumigation can reduce further development of gangrene when applied even as late as early March. Presumably 2AB is able to penetrate more deeply than TBZ into the tissues and arrest the developing fungi after penetration. In this connection there have been instances in practice where fumigation of valuable stocks, which have shown gangrene development in January, has arrested further development of the disease.

Through all this discussion of chemicals, it is easy to forget conditions of cultivation which by themselves will reduce disease incidence or, in conjunction with fungicidal application, will provide a more effective control. We speak about applications being made at the time of harvest. But potato lifting is a moveable feast: it may be anywhere between the end of July, as in the Netherlands, or the middle of November, as occasionally in some late districts in Scotland, depending on weather conditions. Over this period ambient temperature varies considerably and from September it gradually declines, often to low levels where mechanisms of resistance to fungal invasion act very slowly.

Hence we advise growers to lift potatoes as early as possible, particularly where the low temperature diseases skin spot and gangrene are likely to occur. This seems to be one reason why these diseases are of little importance up to the present time in areas where such a procedure is normal practice. At the same time, it emphasises the necessity for an adequate chemical method of control, particularly of gangrene and skin spot, being adopted in the areas where high quality seed is grown, where there is a relatively short growing season and where the grower is at the mercy of inclement weather.

One must also remember another line of progress orientated towards a general reduction in the level of disease incidence in all stocks, which it is hoped through time will be achieved by the stem-cutting procedure as now practiced under the Scottish Seed Potato Certification Scheme. However, since it is highly improbable that these diseases will be completely eliminated by stem-cutting alone, and since some of them, e.g. skin spot, can increase in a stock from a minimal level of inoculum to severe infection within one season, effective chemical control has an important part to play and must always be available. Moreover, this must not be confined to one fungicide for the development of tolerance by the pathogen must always be borne in mind.

Growers would normally expect an increased yield by planting stocks of virus-tested stem-cutting origin (VTSC), and usually this does occur. However, we must analyse the causes of such an increase. It may be the result of the lower level of fungal disease on the seed, or it may be due to the lower level of virus infection. Where "healthy" sprouted seed of a VTSC and of a normal stock are compared, any increase is likely to be due to the lower virus content of VTSC. If seed treatment is applied to an ordinary stock and the diseased tubers removed from the untreated part one should not normally expect a total growth and yield response attributable to treatment. Apart from any influence on the progeny tubers, the real benefit is in the reduction of losses by storage or emergence diseases.

In experimental work where new crop protection chemicals are being tested, whether it be with grain or potatoes, the testing procedure should always simulate normal commercial conditions as closely as possible. Sometimes the choice of suitable naturally-infected stocks presents a problem, but it is always less convincing if the reports describe inoculation of tubers followed immediately by application of the control measure.

Other materials have been, and are being tested for effectiveness, particularly in gangrene control, and it would be encouraging to think that all those being marketed had received adequate independent assessment. Several fungicidal dusts, including diphenyl and some antibiotics as well as formaldehyde (Gray & Malcolmson, 1967) were found not to provide effective control. Fuberidazole and mixtures of benomyl and captafol where synergism has been reported are being examined (Copeland & Logan, 1975).

Methods of application are just as important as effective fungicides. Examples of dipping, dusting, fumigation and mist application have already been given. Another recently introduced method is thermal fogging whereby the fungicide is applied in a fog by means of a fogging apparatus and penetrates into the bulk of the potatoes. Dichlorophen has been advocated for use in this way, although when it was applied as a dip (Boyd & Tickle, 1974) at the recommended concentration both gangrene and dry rot were considerably increased. Claims of successful application by fogging have been made using a mixture of thiabendazole and an organic iodine compound. Obviously this method is applicable only to stores with a suitable ventilation system, where the material applied may be used on both ware and seed, but much will depend on the uniformity of distribution.

In the meantime the search continues for wide spectrum, non-toxic, fungicides which also have bactericidal activity, highly effective on ware, seed and the progeny, and are easily applicable to potatoes in bulk. The search for these ideals, however, should not blind us to the effectiveness of those materials currently available.

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