Opening Remarks

by

Sir Frederick Bawden

President of the British Crop Protection Council

It is my privilege and pleasure, as President of the British Crop Protection Council, to welcome you tothis, the 6th Insecticide and Fungicide Conference, and to express the hope that it will be no less successful than the previous five. The success of these is evident from the increase in numbers of people who have attended each succeeding conference, and for this one the registrations already exceed those for two years ago and attendance promises to exceed that at the Herbicides Conference last year.

You will already know that our programme is a large one, perhaps too full, with too many papers and not enough time for discussion. However, our range of interests is so wide that this is inevitable and it can be catered for only by having concurrent sessions on different subjects. Inevitably, this will lead to complaints by people who would have wished to attend sessions that are held simultaneously, but if this is the only complaint the Programme Committee gets, the members will be left very happy.

Perhaps there is nothing as exciting this time as there was two years ago, when the first results with the new systemic fungicides were being reported. But the past two years have seen great developments in their use and, although all may not be plain sailing, they seem to be fulfilling their promise and it is very welcome to me to see that, at long last, fungicides are beginning to rival insecticides in the attention they are receiving and in their efficiency.

The programme contains sessions on several subjects new to the Conference. One I am especially pleased to see is on the fumigation of soil, because our work at Rothamsted makes it quite clear that there are many areas where the yields from new varieties well fertilised fall short of what they should be, because of soil-borne pests and diseases. As agriculture becomes more intensive, the need for soil disinfection can be expected to increase. The need has long been accepted by the glasshouse industry, and what is wanted now are methods cheap enough to use for agricultural and not only horticultural crops.

The Programme Committee has been percipient and foreseen at least two subjects that could not be more topical. One, in the Forestry Session, is Dutch Elm Disease, which is currently spreading much faster than previously in parts of Great Britain. The other, in the Session on Bacteriology, is fire blight, which is causing so much damage on the continent of Europe.

Two other sessions on new subjects that I also welcome are on control of pests and diseases of tropical crops. The importance of this subject can hardly be over-emphasised, for many such crops are left wholly unprotected and the returns from the work put into growing them are much less than they could be, or indeed must be, if people are to be adequately fed and clothed.

Ladies and Gentlemen, the Programme Committee has done its part, and it is now up to you, by your contributions, to ensure their efforts meet the success they deserve. To complete our programme, it is very necessary that readers of papers keep to the time allotted to them. I ask them to do this voluntarily, but should there be some who fail, I instruct all Chairmen to keep strictly to their time-tables.

I will set a good example, and before my allotted time is up, formally declare the Conference open.

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DEVELOPMENTS IN HUSBANDRY TECHNIQUES IN CROP PRODUCTION AGRICULTURAL CROPS

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One part of the job of an EHF Director is as a farmer. It is in this capacity that I have been asked to speak to you today to try to indicate the practical interactions of crop protection with developing husbandry methods for the agricultural crops. My remarks will relate to cereals (mainly wheat), sugar beet and potatoes.

CEREALS

The ultimate in crop protection, is I suppose, the maturation of one plant to full yield from one seed. This concept is somewhat foreign to cereal growing as currently understood but how far is it likely to become a necessary or even desirable feature during the next decade? Because major advances in cereal husbandry depend very much on the development of new varieties so the case of dwarf and hybrid wheats bears some examination against the one seed one plant concept. Imported dwarf wheats, responsible in part for the green revolution in other parts of the world, have attracted some interest even to the extent of comparative testing at EHFs in 1970! The results were very disappointing and it seems necessary to make a clear distinction between such imports and the endemic varieties currently approaching their multiplication phase. At the time of the importation of those tested last year there was much talk of high tillering and lower seed rates even to the extent that precision drilling should be attempted. In essence the endemic varieties, although by definition having a prostrate habit and ears nearer to the foliage, are unlikely to show differences in kind but only of degree in their interaction with cultural methods. Moreover, they are reputed to be no more or less influenced by a plant disease situation than are current high yielding 'normal' wheats (themselves dwarfs compared with Little Joss and Squarehead's Master!). There will undoubtedly be a range of endemic dwarf varieties which, by little or no change in current husbandry methods, may advance yields by as much as 20 per cent. They are unlikely to be more demanding of seedbed and growing conditions and because their disease resistance/tolerance pattern may be parallel to that of current varieties there seems no reason why they should not be used in close rotations or even in continuous wheat growing. Their early prostrate habit of growth may reduce their ability to compete with grass weeds so that there may be an indirect plant health effect where the grass weeds are alternate hosts.

Septoria may be a problem with the dwarf wheats but undoubtedly varieties will differ in their susceptibility. Therefore a suitable systemic spray would be welcome in anticipation of varietal resistance and seed dressings being inadequate.

The dwarf wheats have been thought of as being responsive to irrigation and to higher rates of nitrogen. The first is likely to be the case but there remains a question mark over nitrogen. It may lead to more foliar disease so that its effects would be negated unless effective and safe chemicals were available.

On balance therefore these endemic dwarf wheats promise to withstand the fairly rigorous and exposed ecology of wheat growing equally with current varieties.

A different situation exists with hybrid wheats. Hybrid wheat seed may show an increased cost of between 3 and 5 times, but against this there is the possibility of using lower (even halved) seed rates. In this case a high field emergence (and survival) will be looked for and at these low seed rates no doubt plant spacing factors will be rather more relevant than has been the case with cereals so far. In other words seed will need to be protected to a greater degree and will need to be placed rather more accurately than is usual. It remains a matter of speculation whether such precision drilling, possibly accompanied by a pelleted seed containing a 'growth cocktail', is likely to be acceptable to a majority of farmers. The concept of precision drilling of cereals does not appeal to me personally largely for purely practical reasons. These derive from the excellence of the seedbed required to enable precision drills (as currently understood) to work, the reduced rate of work both in width covered and speed of forward travel and by no means least the short supply of the comparatively sophisticated operators required to obtain a satisfactory performance from precision drills. Pelleting moreover doubles the seed cost and is, in my view, unlikely either to halve the amount of seed required or produce proportional yield increases.

For the hybrid cereals therefore we must look further ahead than the next decade to the time when plant breeders have improved their yields to a degree, where despite expensive seed, it is feasible to drill at normal rates and by normal methods. Undoubtedly when fully exploited in this way with heterosis considerably enhanced over current levels they would represent a major advance, especially where growing conditions may be limiting to pure lines.

A potential problem of their seed production dependent as it is on wind pollination is that of ergot and there is need for a material to make the stigmatic surface unacceptable to the germinating ascospores.

There are, of course, parallel developments in barley breeding. Possibly the seed production problems may be greater here because of difficulty in maintaining stocks of the male sterile parent.

On a more mundane note the cost of seed of standard cereal varieties is likely to increase disproportionately and there will be a greater tendency for home saving of seed so that adequate contract arrangements will be necessary for its dressing. Indeed in an acutely cost conscious economy could there be a new demand for home dressing? Are the materials likely to be available again and are the fine tolerance limits between effective loading and phytotoxicity achieveable at farm level? Cultivations for the cereal crop have been the subject of only limited experimentation but no one would deny the need for timeliness. Whether declining labour forces can always achieve this is open to question and if marginally grown crops result from poor husbandry they will always be at greater risk for pathogen attack. To some extent therefore one could postulate a plethora of crop protection chemicals, preferably systemic, preferably applied as a seed dressing as a substitute for adequate husbandry. Personally I find the notion totally unacceptable, if indeed at all feasible. We should, by all accounts, be in a better position within the decade to more fully understand soil/root/water relationships and as far as cereals are concerned I believe that we shall be using more robust varieties, sown under better seedbed conditions. Also, because of the upswing in their relative yields spring wheats will increase in importance and relieve the pressure on autumn sowing. Moderate but not excessive amounts of nitrogen will be used. It is also likely that mobile irrigators could apply some water to the crop and if an aphicide can be added where necessary so much the better. The major problem areas will be in the grass weeds especially couch, with their attendant alternate host function. Nematodes may increase as cereal cropping becomes more intensive. Chemical control of take-all is urgently required but is it likely to be anything more than a pipe dream? Timeliness of sowing and good seedbeds have been commended as precursors of lower levels of take-all. It is my belief that the winter field bean, providing as it does a very good entry for winter wheat, will be more widely grown as and when its own hybrid varieties are developed. But these new varieties may not carry full resistance to Chocolate Spot so that a cheap effective foliar spray is required or better still an effective seed dressing.

It does seem that the current control methods for the major leaf diseases of cereals, based as they are on choice of variety and stubble hygiene, will need continuing and possibly increasing support from fungicides. The need may well be made more urgent if and when market tolerances of small grain become tighter. Clearly if such fungicides could have a prolonged protectant period so that they may be added to herbicide or growth regulant sprays at a fairly early growth stage then their use will be that much more attractive to the farmer. An important adjunct to their extended use would be an effective leaf disease forecasting system.

SUGAR BEET

Sugar beet husbandry is at the second stage of labour reduction (mechanical harvesting was the first) and "drilling-to-a-stand" is rapidly becoming the order of the day in all but the most difficult environments for plant establishment. Consequently, the protection of the individual emerging seedling is of paramount importance. It seems likely that the period over which drilling takes place can now be condensed to take advantage of optimum field conditions both in terms of less hurried (and therefore more thorough!) seedbed preparation and to take advantage of slightly warmer soil. These will operate to the advantage of the emerging seedlings. What will operate to its disadvantage? You will be discussing specific pests that could decimate stands and I must assume here that more, rather than less pesticide may be necessary. I would like to put a farming point of view as to how this should fit in with growing practices. To the greatest convenience of the grower the concept of the growth cocktail in the pellet is attractive but two questions emerge. First, can the greater range of materials required be incorporated with safety? Secondly, it seems likely that special purpose pellets would be prohibitively expensive so that multipurpose additives would be necessary. By no means would all growers require all materials. To ensure simplicity and economical use of pre-plant protective chemicals band application with soil incorporation is attractive. We know the problems here, such as depth and directional control, slowing down of drilling rates and compatability with band sprayed herbicides. One solution would be the use of granular materials where these can be devised, applied in front of a drill which may itself include band incorporators. Band sprayed surface applied herbicide could follow the rear press wheel as at present and a totally flexible system would be created. Can such soil acting materials be envisaged and can they be formulated as granules?

Subsequent crop protection materials may be foliar systemics as at present or if soil acting, dual band application on either side of the plants could be supported by partial incorporation by a spider wheel rolling harrow. This can move soil sideways to a prescribed degree. This is the tool which is likely to replace the steerage hoe for inter-row weed control on larger manpower-conscious farms and would automatically offer possibilities for soil mulching of post-plant protective chemicals.

Consequential effects of wider row spacing for potatoes would suggest that beet themselves may be grown in 24 rather than 20 inch rows. To maintain populations (a necessary assumption at our present stage of knowledge) plants must therefore be closer in the row. Our own observations suggest that this is beneficial during the establishment phase but a question mark remains over the later periods. Denser beet may well wilt more readily and may therefore be more attractive to aphids. Whether this may lead to a need for enhanced aphicides is a matter of speculation.

Conversely multi-row harvesters could encourage the use, for instance, of

18 inch rows (because rate of harvesting with a multi-row machine is largely independent of row width) so that at least on the larger farms problems deriving from increased within-row density may not arise.

A further certain consequence of multi-row harvesting will be a tendency to concentrate lifting in the better conditions; no doubt increasing awareness of soil structure problems will also encourage this. Therefore beet will need to be stored longer than at present and work is needed to evaluate and determine suitable 'disinfectants' (possibly of a systemic type) to combat storage rots.

POTATOES

The way that potato husbandry develops during the next decade will undoubtedly be influenced by the extreme marketing pressures now being exerted. Whether specific crops for specific markets in its totality will happen is at least debatable, but by any standards the irregularities and uncertainties endemic in many current production methods will need to be curtailed. We may therefore expect those husbandry and crop protection methods likely to induce uniformity of product as being those likely to be widely adopted.

Choice of maincrop variety remains rather limited at present but in view of large differences currently found in the tuber size distribution pattern (as e.g. between King Edward and Pentland Crown) we may expect that this characteristic will feature greatly in future varieties. Combined with need to accommodate certain utilisation characteristics (chips, dehydrated potatoes, crisps and possibly starch) a bewildering choice may face the grower. A great deal of further work will be required with new varieties along the lines of that which has been done by ADAS to define the seedrate/seed size/ware tuber distribution pattern for current varieties.

Having defined that which is desirable, be it small tubers relatively closely spaced to produce large 'manufacturing' potatoes, or more usual sized multi-sprouted tubers to produce pre-pack ware we need to exploit existing tuber fungicides and look for new ones to ensure that eyes opened does equate as far as is feasible with stems produced thus providing measure of control over tuber size distribution.

The use of automatic planters will increase rapidly. The fact that sprouts may well be damaged by both cup and belt feed automatic planters should be mitigated by sprouting over a long cool period (probably in bags) with plenty of light and adequate ventilation.

The introduction of VTSC seed material may invoke additional use of tuber fungicides because there will be a greater financial inducement for ware growers to use once grown seed. The fact that they may well also wish to take a specific fraction of a crop for seed will provide a technical inducement to use some once grown seed.

A further effect of the inevitable use of high output automatic planters will be to encourage planting at the 'best' time in relation to seedbed preparation, rather than having to hasten a portion (often in unfavourable conditions) in order to provide an acceptable average planting date. Thus one can postulate that carefully chitted, closely graded, disinfected tubers will be rapidly planted in better than average soil conditions.

Which particular cultivation weed control system - herbicides or harrowing; early or late ridge formation - the degree and depth of inter-row working will undoubtedly vary from soil to soil and perhaps from season to season on the same farm. These factors are unlikely to interact to any great degree with crop protection provided no tractor or implement passes through the crop later than the end of May, later travel will cause leaf damage which may induce disease. A possible disadvantage of limited soil disturbance as in an early ridging/herbicide regime may be additional slug activity. I hope that research work on this pest continues and perhaps accelerates.

Wider rows for potatoes is now well documented and for many soils the evidence is entirely in its favour; better ridges give fewer green tubers, equivalent or better ware yields, more rapid planting and lifting, less potential tuber damage because of a better soil/tuber ratio on primary elevators and more room for tractor tyres hence less consolidation of ridge shoulders and therefore fewer clods over the harvester. It remains to be seen whether the wider rows will cause any material reduction of foliage blight as a result of better between row ventilation and of tuber blight as a result of better tuber cover. Needless to say evidence will need to be very strong for spray programmes to be significantly modified. In the continued absence of a systemic fungicide for blight and with the likelihood of more use of irrigation by virtue of mobile sprinklers many farmers would welcome the opportunity to apply chemicals in irrigation water and new formulations may be required.

From a practical point of view the desirable characteristics of a nematicide, especially for the organic soils, are that it should be capable of placement with the seed. Current practices, which resort to deep incorporation in the seedbed, can be regarded as little more than immediate first aid measures. As the need for more chemical treatment of infected land becomes more urgent so does the need for a simple application method become more apparent.

Finally, with the potato crop we must recognise the paramount importance of mechanical damage in determining the future saleability of ware potatoes and ask how far some of the resulting tissue invasion diseases could be reduced or eliminated by judicious use of systemic or surface applied fungicides.

CONCLUSION

To conclude then Ladies and Gentlemen I do not foresee a great technological explosion of precision grown cereals. There could be a need for an extended use of fungicides as adjunct to varietal resistance and effective materials for rusts and take-all are required.

For the protection of the young sugar beet plant I believe we may have to look to both pre and post plant soil incorporation of granular materials to ensure ease and economy of application for specific purposes.

Marketing pressures will promote a desire for greater precision in the potato crop and the combined effect of tuber borne fungicides and a better choice of planting conditions by virtue of rapid mechanical methods should go a long way towards achieving this.

Finally may I thank you for the opportunity to present a farming point of view because in the final reckoning it is the farmer, acting on specialist advice who must make his own decision on the extent to which he uses crop protection chemicals and how best he can integrate them with his production methods.

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THE IMPACT OF MODERN HUSBANDRY TECHNIQUES ON PEST AND DISEASE CONTROL: DEVELOPMENTS IN HUSBANDRY TECHNIQUES IN CROP PRODUCTION (HORTICULTURAL CROPS)

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Summary Horticulture is a highly diversified industry. It is subject to extreme economic pressures which have stimulated fundamental changes in the scale, location and production techniques in all the major groups of crops. Basic to changes in husbandry techniques is the ability to control weeds by chemical means. From this development have followed many others which are influencing the incidence of pest and disease attack and methods of control.

The term "horticulture" comprehends an extraordinary diversity of interests in crop production. This diversity makes it impossible to consider horticulture as a whole when discussing progress in husbandry techniques and their effects on pest and disease control, for though the entire industry is involved in change, the pace and scope within particular sections depends on the economic pressures they are experiencing as well as on innovative developments.

In common with all other industries, horticulture in recent years has experienced unprecedented rises in the cost of all components of production. Unlike them, it is, with certain exceptions, unable to recover these costs by higher prices for finished produce. Costs have had to be absorbed and this has led to careful and continuing re-appraisal of the biological, economic and management requirements of the crops in question. The effects of this examination are seen in the changing structure and disposition of the industry.

In no section are structural and distribution changes more marked than in field scale vegetable production which, together with top and soft fruit growing, is the main area where pest and disease control is being influenced by husbandry techniques. For example, during the seven-year period 1963 - 1968 the number of holdings growing more than 100 acres of vegetables increased by 12 percent, while those growing less than 20 acres declined by 27 percent, a clear indication of the changes in scale of production stimulated by mechanisation. There is reason to believe that this trend is continuing.

Concurrent with increase in scale are changes in the areas of production - a trend away from traditional areas to districts where soil, topography and marketing outlets combine to favour the larger mechanised producer. Thus in recent years, the acreage of carrots grown in Norfolk has risen by 16 percent and of dwarf beans grown in Norfolk and Suffolk by 21 percent. Brussels sprouts, while being increasingly grown in Bedfordshire, their traditional home, have shown significant gains in Lincolnshire and Norfolk, and in fact have become a fashionable break-crop in many arable farming areas.

The presence of a processing industry provided the initial stimulus for increased production of certain vegetables in suitable areas of Eastern England. Its corollary is the growing expertise in a wider range of crops and the development of ancillary industries and services that together form the basis of a specialised horticulture.

The impact of the requirements of processors upon vegetable production is much greater than their limited crop interests would suggest. The standards of freedom from pests and diseases demanded by processors are increasingly those of the supermarket buyer and the wholesale market. Uniformity of produce is no less important. These two requirements present a considerable challenge to the biologist, agronomist and grower. But the standards being set are almost impossibly high and in some cases it seems doubtful whether they can be economically achieved, though in recent years a range of technical improvements has helped to give bigger yields, greater control of ware size and in many cases, improved quality in many vegetable crops.

Striking increases in yields from most vegetable crops have been achieved during the last five years. Maincrop carrots and summer and autumn cauliflower have shown estimated gross yield increases of 24 percent compared with those obtained during the first half of the decade. The yields of Brussels Sprouts and cabbage have increased by 17 percent, while that of cauliflower has gone up by 32 percent. In part this is due to improved varieties, but more particularly to better husbandry techniques such as optimum spatial arrangements and nutrition, and control of weeds, pests and diseases.

No technique has had a greater impact on vegetable production than the introduction of effective herbicides. The economic viability of many crops rests on the ability to control weeds by chemical treatments. From this development flow many changes which, while they have increased productivity and output per acre, have also created consequential problems of pest and disease control.

For example, the range of herbicides available for Brussels sprouts has been an important factor in encouraging the extension of the crop into new areas, often as a break-crop for cereals. Herbicides have enabled direct-drilled or transplanted crops to be grown with limited labour input, and have permitted the adoption of closer spacings than those traditionally used. Both considerations are of interest to the highly mechanised producer who is geared towards once-over harvesting for fresh market or processing sales. Though once-over harvesting presently accounts only for about 8 percent of the sprout acreage it seems likely to become more widely practised so that the problems currently arising may also assume greater importance.

Two relatively minor pest problems worth noting are the occasionally severe plant losses from leatherjackets and bird attack. Both are worse in newer or isolated areas of production - the first through the presence of the pest at levels which pass unnoticed in cereals, but cause severe loss of individual plants in spaced crops such as sprouts or other brassicas - the second through isolation from other acceptable food sources. The consequential problem arising from plant loss from either cause is that gapping-up inevitably results in variation in time of buttoning, which though a possible advantage in hand-picked crops for fresh market, is clearly undesirable in a once-over harvest system.

The micro-climatic conditions within closer spaced crops also appear to be affecting the incidence of pest and disease attack. It is well known that infestation of sprout buttons by cabbage roof fly larvae is more severe when plants are spaced less than 24 inches apart. Thus, while traditionally wider spacings and hand picking combine to limit infestation and permit field rejection of damaged buttons, close-spaced mechanically harvested crops create conditions in which the ware sample may be found to be so badly damaged as to cause its total rejection. The importance of this problem was recently highlighted in the trade press which reported an instance where produce from 45 acres of Brussels sprouts had been rejected by the factory because of button damage.

Button damage arises through inadequate persistence of current post-planting insecticide treatments. Spraying with trichlorphon is usually an effective remedy but, since the last application must be applied only one month before harvest, there is often difficulty in gaining access to the crop.

Slugs are another pest that has become more of a problem in sprouts and other brassicas as plant densities have increased. The humid conditions beneath the leaf canopy appear to provide an ideal environment for their rapid development.

It is perhaps worth mentioning at this point that with the increasing scale of vegetable production advisors are finding it necessary to advise routine spraying against various pests due to the inability of the farmers to observe problems as they arise, thus increasing the selective pressure on the organism and increasing the risk of earlier resistance.

The difficulties of access to the crop for pest and disease control treatments have been mentioned in connection with sprouts, but it remains a problem in any crop where late attack is liable to cause significant damage. The control of late attacks of carrot fly in crops to be left in the ground throughout the autumn is still not solved. Chemicals which work via foliar application may be the eventual answer but in the meantime deep placement of liquids or granules beside the growing crop is not satisfactory in multi-row or mini-beds where passage of the implement results in excessive damage to the roots. This is another example of where agronomic developments with their benefits of increasing yield and control of ware size have intensified a latent problem for which there is no easy solution.

One of the most interesting developments of recent years has been the revival of bulb onion production and its extension into areas quite new to the crop. Once again the introduction of effective herbicides has been the foundation stone of this development and upon it has been built a whole new system of growing. The evaluation of varieties and the solution of problems associated with handling and storing have given new dimensions to a crop which had all but disappeared from the commercial scene.

The increasing acreage of recent years has, however, revealed the widespread incidence of stem and bulb eelworm in soils where its alternative hosts have been grown. So wide is the range of hosts and so extensive the infestation that it is doubtful whether it is possible to adopt a rotation that offers any hope of a reduction in eelworm population. Though promising new chemical treatments for eelworm control are under development, the difficulty of finding land which is both suitable for early seed bed preparation, sufficiently stone-free to facilitate mechanical harvesting and free from eelworm, underlines the whole problem of inadequate rotations with several crops. Continuity of supply programmes for contract purposes and the tendency in large scale vegetable farming enterprises to subordinate the rotation to considerations of economic viability lead to overcropping, particularly in respect of brassicas.

The concentration of crops into favoured areas with its corollary of inadequate rotation is, of course, a classic situation for the development of pest and disease problems. However much the practice may be deplored it is forced on growers by commercial necessity; by such considerations as their essential proximity to processing outlets and the key position of brassicas in the vegetable economy. In some cases the answer may be in the development of partial soil sterilisation treatments and there is increasing interest in this technique, in others the combined attack by chemist, biologist and agronomist still offers the best hope of success.

The pea crop illustrates the need for integrated control measures for it is well known that root eelworm, midge and moth are increasing problems where peas are intensively grown. Eelworm may eventually yield to chemical soil treatments, attack by pea midge may be forecast and specific sprays applied, while the control of pea moth rests both on the development of new insecticides and better application. There is still much to be done, for in spite of the attention given to peas over many years, in spite of the chemicals available and established techniques of spraying, it is a fact that substantial acreages of peas for processing were rejected this year because of heavy aphis infestation, which in turn has encouraged hover flies, which contaminated the crop through pupation.

So far I have touched briefly upon a number of developments in the main vegetable crops and their effects on pest control. The increased incidence and importance of disease also has its origin in changing production techniques. For example, mildew has been very severe in Brussels sprouts in recent years and though some of the Dutch varieties, much favoured for their other virtues, may be particularly susceptible, there is little doubt that the severe moisture stress created within close-spaced crops is a contributory factor. On the other hand, conditions within a close-spaced crop are ideal for the rapid spread of disease when irrigation is introduced as, for example, happens with halo blight in beans.

On a more limited scale economic dictates leading to intense mono-cropping of lettuce encourages the development of a weed flora resistant to the few herbicides available for this crop. These are known to be symptomless hosts of cucumber mosaic virus - a disease causing considerable crop losses in the Vale of Evesham. Lettuce mildew is also believed to be encouraged by intensity of cropping. Similarly, white rot and autumn infection by Botrytis on salad onions are thought by advisors in the Vale to be increasingly severe where close cropping is carried out. It is suggested, but by no means proven, that cavity spot of carrots is also associated with short rotation and one grower at least claims to keep the problem at an acceptably low level by adopting a minimum seven year rotation. A recent survey by ADAS in Lincolnshire has shown a startling increase in mildew, wire stem and club root in brassicas due, evidently, to the common but clearly unsound practice of siting seed beds on land which previously carried these crops.

Two recent developments which have undoubtedly had a considerable impact on disease control and consequently on horticultural practice, are thiram soaking of seeds for the control of seed-borne diseases such as celery leaf spot and Phoma of beetroot and brassicas, and the introduction of benomyl for the control of Botrytis. Both have made a direct contribution to productivity by reducing seedling losses and increasing marketable yield. The development of benomyl as a spray treatment for the control of Botrytis in dwarf beans should be of great benefit to the grower and processor by reducing infected produce and increasing marketable yield. Mr J M King has a paper on this subject in a later session. Similarly the work by Dr Derbyshire on the control of Centrospora in stored produce by benomyl dip treatment holds great promise. This is also the subject of a paper in a later session.

Turning now to some of the 'fringe' developments there is currently considerable interest in mini-cauliflower production. These are of course as susceptible as normal crops to attack by cabbage root fly. It is however doubtful whether overall treatment will provide adequate control, while band treatment may be prohibitively expensive at the close spacings which are a feature of this technique. Work at N.V.R.S. is aimed at establishing the pattern of egg-laying, for an understanding of its distribution will be important in devising the best means of control. Calabrese is another crop to which some attention is being given - this is susceptible to cabbage leaf miner, a hitherto unimportant pest.

Another development which may yet indicate specific pest or disease problems is the increasing use of polythene tunnels for forwarding crops. No particular problems have to my knowledge yet arisen but we should not dismiss the possibility, nor yet the technique on grounds of limited commercial application, for any one who has visited Italy or Israel will see that growers there have mastered the art of tunnel management on a vast scale.

As the basis of my thesis I have suggested that effective chemical weed control is the catalyst of a whole range of developments in crop production. Finally, in connection with vegetables, I would make the point that they are instrumental in the successful development of mechanical harvesting of many crops, and that this final operation in the production cycle is responsible for much post-harvest loss in onion, carrot and celery through disease. Damage through mechanical harvesting leading to storage rots is a major problem. Chemical treatments may supply part of the answer but chiefly we need a higher standard of management to avoid the waste of material that has been so expensively grown.

The challenge facing the producer of apples and pears is that of increasing the output per acre of quality fruit combined with greater regularity in cropping. The scope for improved techniques to this end is limited in respect of the older trees from which the bulk of the fruit is still obtained and effort must be concentrated on the newer plantings of more intensive tree forms. Much greater attention is being paid to the selection of soil and site, to choice of rootstock, to pruning method, soil management and nutrition in the bid to bring trees into early bearing. The possible permutations between these various factors are seemingly endless.

The most obvious change in husbandry techniques in recent years is, once again, the widespread use of herbicides. Few orchards are now clean cultivated but either in grass with herbicide treated strips or squares, or treated with herbicides overall. The effect of these changes on pest and disease control is difficult to quantify. When weeds grew thickly around tree bases then there was a risk of vole damage - and in some seasons this could be severe. With the removal of this cover it is thought that the incidence of collar rot (Phytophthora cactorum) may be increased through rain splashing of spore-infected soil. The solution to this problem is the use of high worked trees, advocated by East Malling, but of course this is only applicable to new plantings.

Gloeosporium which is endemic in older orchards of larger trees is a disease likely to become less important in the newer intensive plantings where more efficient spraying and management is possible. Apple scab will doubtless always be with us but the recently introduced systemic fungicides represent a great advance in the control of this disease. There will however be a good deal of interest in the suggestion following research at East Malling that routine summer spraying may be replaced by far fewer autumn and spring sprays aimed at limiting the amount of inoculum in the orchard.

The effect of the absence of grass or weed cover on the overwintering of scab infected leaves is sometimes raised against the use of herbicides, the argument being that the absence of cover affects the earthworm population and encourages leaf movement and preservation, thus enabling many more leaves to survive the winter than would otherwise be the case. This is obviously difficult to prove, but even if it were shown to be true, the benefits of chemical herbage control are such as to argue strongly for the continuation of the practice.

Lighter pruning is one of the factors involved in the encouragement of earlier fruiting. Its corollary is the increased risk of mildew build-up through absence of shoot-tipping but here again the detailed work at East Malling has clearly shown the conditions for successful control and the chemical industry has provided a range of effective fungicides.

The future of top fruit in this country is fraught with uncertainty. The intrinsic quality of our apples may be superlative, but competition for the housewife's purse will be fought on fruit size, colour and skin finish. However effective new chemicals for pest and disease control may be in biological terms, if they have any adverse effects on these superficial, but vital, qualities they will have no place in fruit-growing of the future.

Turning now to some aspects of soft fruit production, we see again how herbicides have permitted new concepts in crop management in black currants and strawberries - the major commercial crops. Non-cultivation is almost universally the rule, with similar opportunities for improved spatial arrangement that exist in vegetable production.

The use of simazine in black currants, it has been suggested, was responsible for the sudden increase in American gooseberry mildew a few years ago, though if this was the case it is difficult to see why, with its continuing use, mildew is now much less severe. Similarly the incidence of leaf spot (Pseudopeziza) is alleged to be related to the increase in over-wintering leaves in non-cultivated plantations. However, the point must again be made that the advantages of non-cultivation are such that a return to older methods of soil management would be totally unacceptable and if these diseases are in fact encouraged by this technique then the solution must be found in effective spray treatments. Fortunately these are available; in particular the introduction of benomyl has made the control of leaf spot more certain than with non-systemic materials and Botrytis, which was an occasional but severe problem in some seasons, seems almost a thing of the past. Thus in this crop various disciplines have combined to offer the opportunity for greater productivity. Herbicides have reduced the costs of growing; the elimination of weeds has removed the problem of snails contaminating the fruit; new fungicides have given better disease control and now mechanical harvesting from standing bushes is the imminent commercial development that could lift the last major restriction from the economic production of the crop.

The revolution in strawberry production awaits the development of a successful harvester, at least as far as the processing crop is concerned. New varieties of specific habit for mechanical harvesting are being bred while the chemicals for controlling pests and diseases to a remarkably high standard are already available. The use of benomyl has virtually solved the Botrytis problem, mildew resistant varieties are under development and the range of chemicals for red spider control is adequate for the foreseeable future.

Further developments in main crop production depend on the success of research in engineering and plant breeding, but the small, but economically significant protected crop, continues to forge ahead with new ideas. From the production of early fruit under glass cloches, continuous polythene tunnels have been widely adopted and now interest centres on the use of larger plastic-covered structures and the methods of influencing the production of autumn fruit from the variety Redgauntlet by day-length control. Our own work at Efford is concentrated on these lines. Clearly specific problems of pest and disease control may arise. What, for example, is the effect of spring-applied short-day treatments on the period of diapause of red spider mite? Will such treatments stimulate activity at a time when acaricides cannot be used for safety reasons? How can red spider mite in an autumn crop be controlled when wide-spread resistance makes the only safe materials of little value? What is the effect of the micro-climate in large tunnels on the emergence and development of red spider mite and aphids, and on the development of leaf and fruit diseases? Can we find an effective soil sterilant for Red core, for Verticillium and the general decline that affects some of the earliest land? These are some of the questions that inevitably arise as more sophisticated methods are introduced to commercial practice.

The ultimate in sophistication is, of course, the production of crops under glass where total environmental control is possible. I am very conscious that in this brief review I have not mentioned developments in glasshouse growing, nor yet in nursery stock production or the flower bulb industry. This only serves to emphasize the complexity and diversity of horticulture, an industry in a state of constant change and one which produces an endless stream of questions that can only be resolved by the integrated efforts of Government and industrial research supported by competent advisers in the field.

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CEREAL LEAF DISEASE CONTROL PRACTICABLE & ECONOMIC CONSIDERATIONS

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Summary Foliage diseases are often grouped as one problem ignoring essential differences within the group which determine their "points of weakness". Those which can survive on debris as well as attack the crop, are susceptible to control on a single field, certainly on a single farm scale by reduction of inoculum surviving between crops. Those which demand living plant material for survival are much more difficult to affect by reducing inoculum. This presents problems in what I have called social pathology, not altogether amenable to economic evaluation. Control of most leaf diseases by fungicides is attainable experimentally - economic considerations will determine their commercial use. Multiple treatments are not acceptable so that greater specificity in fungicides, desirable on ecological grounds, demands effective forecasting techniques. Broad spectrum materials, used more for their yield effects than for their control of specific disease, may be more valuable in the absence of forecasting techniques. Insurance treatments for foliage diseases are difficult to justify, except on the grounds of average returns in some instances, e.g. mildew. Use of fungicides can be improved. Much of current work is empirical and rational use will only derive from a better understanding of both pathogen and fungicide behaviour. The situation in which high dose rates have gone far to compensate for inefficiency in application may be ending. Considerations of environment now demand minimum pesticide use, which could lead to economy of material but greater expense in more sophisticated machinery for application and all that this entails. Finally, the increasing cost of R + D in pesticide chemicals and of clearance for safe use, threatens to become an over-riding factor in the overall economics of pest control.

INTRODUCTION

In contemplating control of cereal leaf diseases, it is useful to divide them into two groups (a) the facultative parasites, which can survive from one crop to the next, both on self-sown plants and on crop debris and (b) the obligate parasites, which can only survive on the living host plant. These two groups are characterised by certain features which are significant to their control. In general, the facultative leaf parasites of cereals are spread relatively short distances in water droplets during rain, e.g. the Septorias and Rhyncosporium. For this reason, they are usually more prevalent in the wetter, western parts of the country which provide frequent opportunities for spread, and appear in epidemic form in the drier eastern parts only in wet seasons. The obligate parasites are very well adapted to their rather critical requirements for survival, in that they produce spores in massive quantities which are wind-dispersed in the dry state over considerable distances. Cross-channel transport of cereal mildew is a distinct probability and records of air-mass transport of Black Rust spores from Spain and North Africa are well documented. The importance of long distance transport in the epidemiology of cereal mildews is, I think, doubtful in view of the findings of Yarham et al.(1971). It may, however, have real importance in the spread of new races from the Continent to the U.K. and vice versa.

PRACTICABLE MEANS OF CONTROL

Two methods of attack on any disease available to the grower are

(a) by operations undertaken between crops, to reduce the inoculum surviving to infect the new crop and

(b) to protect the new crop from damaging infection by the use of fungicides.

It will be obvious from what has been said, that success with reducing inoculum is more likely to be achieved with the facultative parasites than with the obligate ones, since outside distant sources of infection of the latter are not under control. However, these methods are not mutually exclusive - indeed successful control will most often follow a combined approach, coupling reduced inoculum with fungicidal protection. The value of the latter can be enhanced, or at least the task of the fungicide be made less onerous, even for the obligate parasites, if the available inoculum over an area can be reduced by concerted action.

REDUCTION OF INOCULUM

With the facultative water-droplet spread parasites, local sources of inoculum are all important but it is necessary to identify the sources of inoculum and to determine their relative importance. Barley Leaf Blotch presents an apparently simple problem in that the source of inoculum is the stubble and straw from the infected crop, and all one has to do is simply to eliminate this. The solution is less simple; however, it has been achieved successfully on a field scale, as recorded by Evans during the Arundel (1970) Survey, by means of cultivations aimed at incorporating debris into the top 2-3 inches of soil, starting soon after harvest. Immediately adjacent fields can and do act as sources of inoculum, though whether the inoculum is usually in the form of spores or in the form of debris is a moot point. Evans, again during the course of the Arundel Survey, traced infection in the first barley crop after a long ley, which should have been free from infection from debris, to straw blown in from a stack in a neighbouring field. As with mildew, autumn sown barley can act as a source of infection for the spring crop, but only becomes an important one if the spring crop is free from other sources of infection. While seed-borne infection with Rhyncosporium is not regarded as important, mainly because of the ubiquity of other inoculum sources, it could assume greater importance in their absence.

Since the Septoria diseases belong to the same group of splash-distributed facultative parasites, much the same considerations as those outlined above apply to this disease also. Seed-borne infection of S.nodorum would appear to be a potent, widespread source of infection well worth attempting to reduce. However, inoculum of this fungus is also debris-borne and the relative importance of these two infection sources is not known. The frequent occurrence of Septoria in winter wheat following crops other than wheat leads one to suspect seed-borne infection is the more important source of infection. However, if the suspicion that S. nodorum occurs on a widespread scale on grasses is confirmed, then it would seem superficially unprofitable to spend much effort in attempting to eliminate seed and debris as infection sources, in western areas at least. Elucidation of this complex problem of the sources of inoculum and their relative importance is essential if we are to know the direction in which efforts at control are most profitably to be made.

Another equally difficult facet of inoculum, namely its assessment year by year, is fundamental to any attempt one might make at forecasting. Both the difficulty and the desirability of measuring inoculum are perhaps best illustrated by the behaviour of the obligately parasitic Yellow Rust, which in 1971 developed from what seemed, judging by a total lack of records, to be no inoculum at all in 1970.

The surprising speed of development of an epidemic, given favourable conditions, is one of the characteristics of the obligate parasites and is related to the production of very large numbers of spores and to very short reproductive cycles under optimum conditions. For these reasons, inoculum reduction must be of a very high order indeed if it is to delay the epidemic to a useful extent. This is borne out by results of work in the east of England which have shown that any effect of differential exposure of spring barley to mildew inoculum from winter barley is largely vitiated by mid-June, by which time crop condition has assumed the major role as a determinant of the epidemic (Yarham et al. 1969).

Nevertheless, delaying the onset of disease could theoretically confer benefits in terms of greater root production and better crop establishment (Last 1962). The value of any such benefit to the spring crop has yet to be demonstrated, but for winter barley, the increase in root production stemming from protection of early sown crops with ethirimol seed dressings was quite dramatic in the autumn of 1970 and was reflected in a more advanced growth stage at the onset of winter (Hall 1971).

COST-BENEFIT OF CONTROL WITH FUNGICIDES

With most diseases for the control of which fungicides are used, the relation between disease levels and loss of product is manifest and questions of cost benefit to the grower hardly need to be raised.

In agricultural crops, however, the benefits are not always so manifest and this is particularly true of barley mildew. Absence of disease must clearly be used as the measure of success and estimates of the value of treatment can only be inferred by extrapolation from yield trials data on the one hand, and general survey data on the other. Trials designed to establish disease control/yield benefit relationships have only been matched in their variability by that of disease levels from field to field, so that the question "Does it pay to use mildew fungicides?" can only be answered in general terms of average and the question "Will it pay me to use mildew fungicides on this field?" is strictly unanswerable. For example, an examination of 1970 comparisons from crops or trials in the eastern region shows that an average yield increase from spraying of 2.8 cwt./acre is derived from a range varying from -1 cwt. to + 6 cwt./acre. What is nevertheless undisputed, is that the barley mildew fungicides in use and under development are highly effective and that their use is likely to prove economic in the majority of crops in most seasons. This conclusion is possible because of what is to me the most surprising aspect of mildew control by fungicides, that is the general effectiveness of a single spray application. The timing of the application is of crucial importance and in spite of one's hopes for an easily identifiable growth-stage criterion, it seems probable that timing must be related, at least in part, to disease development. In seasons conducive to early mildew development, two spray applications may be required for effective control and this will generally be true of spring crops located near to sources of infection. On direct cost comparison, seed treatment is preferable to two spray applications and experience suggests that, for some farmers anyway, the extra cost of seed treatment compared with that of only one spray, is not an unacceptable price to pay in order to sleep peacefully at night. Considerations such as this are difficult to quantify in economic terms but they are nevertheless understandably significant factors in farmers decision-making processes. In this context, I am much taken by a recent statement by Ordish et al. (1969) and I quote "The exact benefit to be derived from the use of pest control measures will have to be measured according to the particular yardstick of the particular interest that is posing the question". This is out of its context but seems particularly pertinent here.

In the last two years, barley brown rust has become much more prevalent - in 1970 the final year of what I hope is only the first of a sequence of Barley leaf disease surveys undertaken by N.A.A.S. (now A.D.A.S.) it took pride of place as the major disease. Information on disease/loss relationships of this disease is still badly needed for the assessment of need for control. Such information is also fundamental for the pesticide industry, if decisions on rust fungicide development have to be taken. In my own view, barley brown rust will recede in importance in the event of a return to the normal English summer for a year or two. It appears to be a high temperature disease which has been favoured by climate in the last two years. If this view is correct, there would seem to be little future for rust fungicides on barley, unless methods for accurately forecasting outbreaks of the disease can be developed. Even if this were to come about, it is doubtful whether pesticide manufacturers and the pest control industry could view with favour the development of fungicides which would only find a use about one year in four. Even if one includes outlets for the control of all the U.K. cereal rusts, these fungicides must have a bleak future unless either a substantial overseas outlet is available or they can be produced at a cost low enough to be regarded as an insurance treatment.

In some areas, of course, e.g. the south-west, fungicides for leaf blotch may be found to be as profitable in many seasons as are mildew fungicides. It is significant that Walker, in a lecture to South West Cereal Growers at Taunton in March of this year called for "a broad-spectrum material which will control not only mildew, but rusts and Rhyncosporium on barley, and rusts and Septoria on wheat". Strictly from the point of view of the cereal crop, such a material - at the right price - would certainly be invaluable. The general call in the pesticides field, however, is for more rather than less specific chemicals, as a protection for the environment and this point cannot be disregarded when one takes account of the total acreage which could be treated. The highly effective specific fungicide poses other problems, however, concerning its own longevity in commerce. We shall be hearing more about selection pressure and fungicide-resistant pathogens later in this Conference. Suffice it to say here that this must be taken into account in any economic assessment of cereal leaf disease control, from the manufacturers' standpoint. While it is one thing to argue the farm economics of fungicide use, one must not ignore the costs of research, development and clearance for their safe use, since these are vital questions determining the availability of the fungicides in the first place.

My comments have largely related to spring barley, but what has been said can in general, be repeated with perhaps greater emphasis about wheat. The evidence for economic benefit from use of fungicides for the leaf diseases of this crop is much weaker than for spring barley. It seems certain that, with present average costs and returns on cereals, the crop cannot support speculative increases in variable costs and as a consequence, there is an ever more insistent demand from the farmer for assurance that his outlay will be rewarded by a satisfactory return.

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APPLE DISEASES (WITH PARTICULAR REFERENCE TO MILDEW AND CANKER CONTROL)

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Summary Difficulties in controlling apple mildew, caused by Podosphaera leucotricha, arise from the frequency of suitable infection periods during the growing season, the short generation time of the pathogen, and the speed of shoot growth. Although better control has followed the introduction of new compounds capable of some movement within leaves, there is still need for a non-russeting fungicide truly systemic in woody plants.

The apple canker fungus Nectria galligena owes much of its success as a pathogen to its ability to sporulate throughout the year, in the course of which many potential avenues for host infection occur. Progress has been made in fungicide paints for treatment of individual cankers, and in the use of leaf-fall sprays of copper or mercury. Use of benomyl or pyridinitril as routine summer sprays can greatly reduce canker incidence. However, a single panacea for this disease is unlikely.

INTRODUCTION

Apple mildew, caused by Podosphaera leucotricha (Ell. & Ev.) Salm., was considered in detail at the first of these Conferences (Burchill, 1961), and it is fitting that it should be re-examined after ten years. The intervening period has seen the relative decline in the commercial importance of apple scab, caused by Venturia inaequalis (Cooke) Wint., formerly the fruit grower's most important disease problem. By contrast, apple mildew (which had increased in severity during the 1950's with the advent of organic fungicides) remains difficult to control, as does apple canker, caused by Nectria galligena Bres., the importance of which has been recognised for over 300 years (Austen, 1657). N. galligena can also cause post-harvest fruit rot, an aspect of the disease not considered in this review.

Of the other apple diseases, there is now promise that new fungicides will give better control of storage rots, caused by Gloeosporium spp., and of the brown rot diseases, caused by Sclerotinia spp. However, the relative importance of diseases caused by Phycomycetes - such as collar rot, caused by Phytophthora spp. and Rhizopus fruit rot - may well increase following the widespread use of materials with no effect on this group of fungi.

APPLE MILDEW

Difficulties in achieving control

Four factors seem to militate against good control of the disease:-

(a) Unlike _V. inaequalis_, which needs periods of wetness for infection of apple leaves, _P. leucotricha_ is not dependent on wetness but requires primarily a relatively high temperature although infection can occur when maxima are below 20°C (Roosje, 1961). Butt (1970, 1971a) found that infection occurred throughout the summer, and there was a high correlation between the concentration of airborne spores and the amount of infection each day. In addition the severity of infection was modified by the number of conidia deposited on the juvenile leaves and by the post-deposition weather. Rain, which is deleterious to mycelium and suppresses sporulation, did not prevent the germination and establishment of conidia which had been disseminated at the onset of rain and deposited on juvenile leaves at the shoot tips.

(b) The pathogen has a short generation time under normal summer conditions in the orchard. Burchill (1965) estimated an incubation period of 10-14 days between infection and release of new conidia. This enables the pathogen to recover quickly from anything but a drastic reduction in inoculum (e.g. Sharples, 1961). There is thus generally an ample supply of spores available for infection. Burchill (1965) has shown that a peak of spore production can occur in mid-June when sporulating primary mildew is most abundant.

(c) The speed of new shoot growth in early summer leads to the rapid emergence of highly susceptible juvenile leaves, which are difficult to protect with conventional fungicides. Shoot growth can continue into September, and the terminal bud is thus open to infection over a long period.

(d) Although severely-mildewed shoots are readily detected and removed during winter pruning, the fungus overwinters in buds which are often undistorted (e.g. Waugh, 1960). This drastically limits the usefulness of winter pruning and, in the spring, when cutting out can be done effectively (Baker, 1962b), time is limited.

Recent advances in control measures

Fungicides

Dinitrophenol derivatives are still widely used: dinocap, although relatively poor in controlling severe infection, is valuable because of its mildness to foliage and its suppressant effect on the red spider mite, _Panonychus ulmi_. Following the demonstration by Kirby (1964) and by Byrde, Clifford & Woodcock (1966) that, of the six isomeric phenols present as crotonates in commercial formulations, the 2,6-isomers were more active than the corresponding 4,6- dinitrophenols, a dinocap formulation based on selected isomers has been introduced commercially. Another substituted dinitrophenol ester, binapacryl, has frequently given better mildew control than dinocap (e.g. Byrde, Harper & Holgate, 1969), but exceptions have been recorded (e.g. Ingram, 1969).

Many of the newer fungicides form the subject of Research Reports in this Session or elsewhere in the Conference (e.g. triforine) and will therefore not be discussed at length. Experience in comparative trials at Long Ashton shows that, while the performance of these materials is generally equivalent to that of binapacryl, triarimol alone has given better control of secondary mildew, and that only in one season (Doma _et al_., 1971). At East Malling it has also shown promise (Butt, 1971a). There is evidence in our trials that binapacryl is less effective than benomyl in preventing primary mildew (cf. Evans _et al_., 1971).

Increased fruit russet has sometimes been encountered with the newer fungicides (e.g. Doma _et al_., 1971) and 1971 records at Long Ashton confirm this (Table 1). This problem, coupled with inadequate disease control, shows that apple mildew fungicides still leave much to be desired.

Table 1

Incidence of russet on Cox: Long Ashton, 1971

Fungicide	Concentration (% a.i.)	Russeted fruit (%)
Benomyl	0.025	25
Thiophanate-methyl	0.07	24
Triarimol	0.004	19
Captan plus binapacryl	0.09) 0.05)	6**

** Differs significantly (P = 0.01) from other values.

The spray programme

The increased knowledge of the life-history of the fungus, and in particular the pattern of spore production during the summer months (e.g. Burchill, 1965), encouraged a more rational approach to the spray programme (Butt, 1970). Maximum infection of the fruit buds occurs before petal-fall, and there is evidence (Baker, 1962a; Butt, 1971b) that this is a phase of the disease which precedes the main spore discharge peak, about mid-June. Butt (1971b) showed that dinocap applications in the period from green cluster to early fruitlet are necessary for the protection of spur-borne fruit buds of cv. Cox's Orange Pippin but the blossom period is a stage when phytotoxicity can be caused by the fungicide application. Subsequent work (D.J. Butt, priv. comm.) has shown that reduction of infection of terminal buds of vegetative shoots is achieved far more effectively by early summer sprays than by later ones, although for maximum control the programme must continue until extension growth ceases.

There is also an increasing realisation of the need, stressed by Roosje (1961), for relatively frequent application of sprays, for reasons already outlined. The problem is well illustrated by an experiment with seedlings of cv. Tremlett's Bitter in the greenhouse. These were simultaneously inoculated with conidia of P. leucotricha in a dusting tower, and treated with fungicides (by dipping) at different times before and after the inoculation day. The results (Fig. 1), for six replicates, show clearly that lime-sulphur (typical of early practice), dinocap (typical of usage in the 1960's) and triarimol gave excellent control when applied immediately before inoculation.

When the fungicides were applied three days after inoculation - thus calling curative action into play - the performance of each was slightly, but not drastically, reduced. However, when applied three or four days before inoculation - when the leaves to be assessed were still tightly rolled at the shoot tip - lime-sulphur and dinocap were much less effective. Triarimol, by contrast, still gave relatively good control. Since this compound - like all others so far examined - is unable to move by translocation from one apple leaf to another, it seems likely that small deposits on the folded leaves were effective, since considerable movement of triarimol within a leaf has already been demonstrated (Doma et al., 1971). Loss by volatilisation may also have been involved.

Although the time scale would obviously be different in the field, these results emphasize the limited duration of the effects of fungicide sprays, and show a likely reason why triarimol is superior.

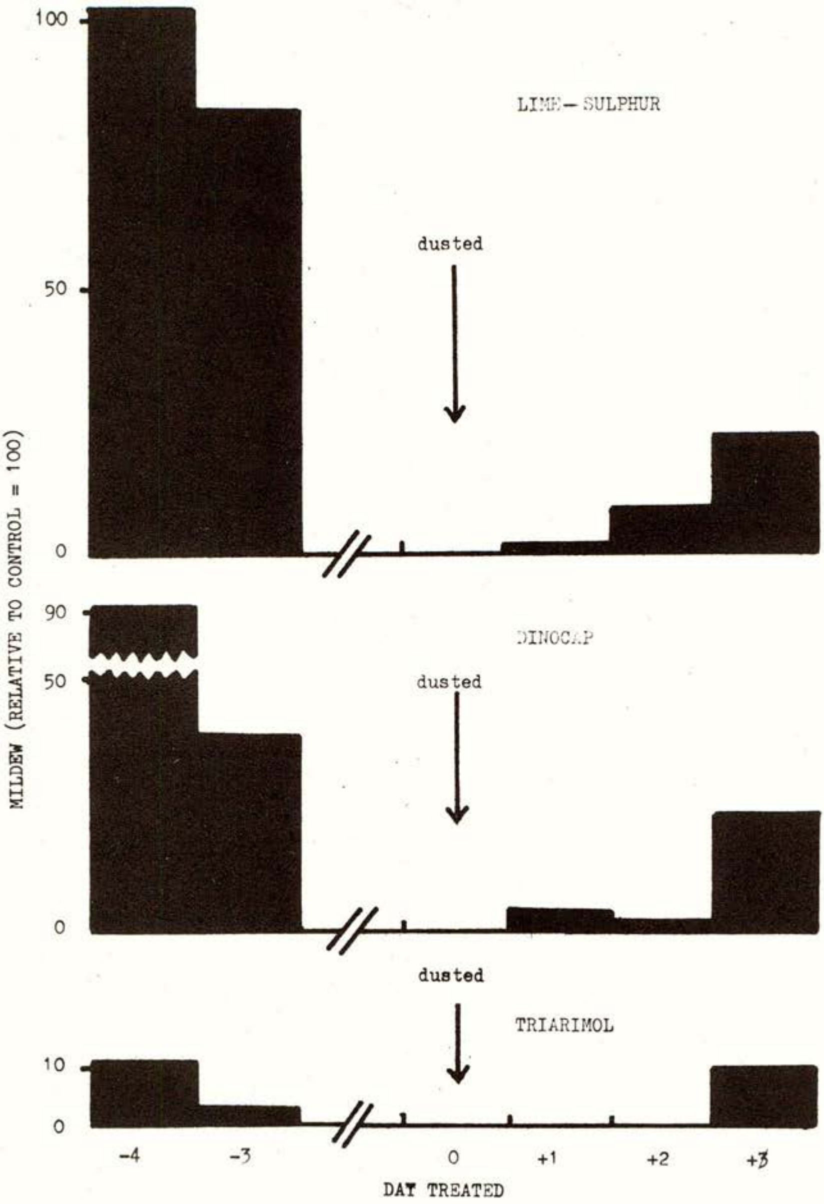

Figure 1

Effect of treatment time on performance of three fungicides against powdery mildew (See text).

Winter treatments

Overwintering inoculum in apparently healthy buds can be reduced by the use of an emulsion of DNOC and petroleum oil in winter (Moore and Bennett, 1959; Waugh, 1960; Bennett and Moore, 1963). The spray must not be deferred too long, as damage can result and the blossom date be advanced. Excision in winter and spring (Baker, 1962b) is rather more effective, but time-consuming. Although such treatments are not adequate substitutes for spring and summer sprays, they are useful supplements when the disease is severe. A commercial formulation of DNOC without oil is now available for such winter treatment.

Future Developments

Need for compounds systemic in woody plants

A deposit (0.1 µg) of triarimol on an apple leaf can give protection of an area 20-25 mm in diameter, extending to the leaf margin (Doma et al., 1971), but leaf-to-leaf translocation with this or any other compound has not been observed on apple. A fungicide active against powdery mildews with truly systemic movement in apple trees following foliar application would clearly represent a great advance; it could be used to eradicate perennating mycelium in buds (Burchill, 1961) and/or to protect the developing fruit buds/shoot tips.

Breeding for disease resistance

Mention should also be made of the progress made by Dr. F.H. Alston at East Malling in breeding the mildew-immune cultivars reported by Knight (1971). Although races of the fungus may ultimately evolve to overcome this immunity, there is a good prospect that such cultivars, with good commercial characteristics, may be available within a decade.

APPLE CANKER

Difficulties in achieving control

Four factors appear to be responsible for the difficulty in controlling apple canker:

(a) The fungus is deep-seated in the cankers, making it difficult to eradicate, even with high concentrations of fungicide.

(b) *N. galligena* produces spores throughout the year (Marsh and Munson, 1939). Conidia are most abundant from early summer to late autumn (Munson, 1939; Swinburne, 1971), but the period of ascospore production in the U.K. is less clearly defined. Munson (1939) found the greatest ascospore discharge to be in February in S.W. England, but recent work in Northern Ireland showed that maximum ascospore release was in the spring and early summer, with a minor peak in autumn (Swinburne, 1971). Seasonal and local variations in weather may well have modifying effects on the time of perithecial formation.

(c) There are many potential avenues for infection. Among the most important are the leaf scar, both at the time of leaf fall (Wiltshire, 1921; Crowdy, 1952) and in the spring when the tissue tends to crack as the buds expand (Wiltshire, 1921). Swinburne (1971) has also drawn attention to the vulnerability of the junction of extension growths of successive years. Here, bud scale scars, cracks in the leaf scars at the apex of the previous season's growth and (in

June and July) shedding of the whorl of leaves at the base of the new shoot, give three successive potential avenues of infection at a time of high ascospore discharge. Also implicated have been pruning cuts (Marsh, 1939), growth splits at the crotch in over-vigorous trees (Byrde & Waugh, 1960), wood scab pustules (Wiltshire, 1922) and woolly aphis lesions (Wiltshire, 1915).

(d) T.R. Swinburne (priv. comm.) has demonstrated the probable significance of alternate hosts, such as ash and beech, which are frequently present in hedges, and poplar, sometimes planted as a windbreak. Nectria infections on such trees may well give rise to unexpected outbreaks of canker in new apple plantings remote from established orchards, and provide a constant reservoir of inoculum for reinfection of an orchard.

Recent advances in control

Fungicide paints. The treatment of established cankers with fungicidal paints has become routine during the past decade. Mercury-containing paints (e.g. Bennett & Moore, 1964), with a variety of carriers, have generally proved the most successful in reducing sporulation. Originally these were based on phenyl mercury compounds, but a paint based on mercuric oxide has also given generally good results (Corke *et al*., 1971; Bennett, 1971a; D. Wiggell, priv. comm.). Among other compounds, 2-phenyl phenol has also reduced sporulation, though to a rather smaller degree (Corke *et al*., 1968; D. Wiggell, priv. comm.), and a benomyl-based formulation has also shown promise in Miss Bennett's trial (Bennett, 1971a).

Pre-leaf fall sprays. Many attempts are recorded in the literature, aimed at protecting leaf scars in autumn by a single protectant spray; these met with varying success (and often none). Moore and Bennett (1960), however, in experiments on M.VIII rootstocks, demonstrated the value of two autumn applications of a copper fungicide. The first, applied before general leaf fall, aimed to give temporary protection and at the same time to promote early defoliation. The second was timed to give maximum protection at the time when most leaves were falling. A third, applied as the buds swelled in spring, was suggested to protect the cracks which frequently develop at this time on the old leaf scars. Moore and Bennett stressed the importance of the defoliant effect of the first spray, in order to avoid a protracted leaf fall period.

Field trials in two canker-prone Somerset orchards readily confirmed the value of such a spray programme which, in a three-year trial, reduced the disease by about 60 per cent: as might be expected, it was more effective in controlling infections at leaf scars than at pruning wounds (Byrde, Evans and Rennison, 1965).

During these trials, growth reduction was noted on one rootstock: the occasional incidence of bud damage following the use of copper oxychloride sprays (e.g. Byrde, 1970) and the increasing cost of copper sprays has led to an examination of the similar use of mercury sprays. These also exhibit the necessary defoliant properties, at least when used at double the concentration normal for routine scab sprays (e.g. Bennett, 1971b). Moreover, Bennett showed that fewer cankers developed on trees receiving phenylmercuric chloride sprays than on those sprayed with copper in each of three seasons. However, spore counts from rain run off showed a relatively higher inoculum on mercury-sprayed trees which might prove a hazard when the protective effect of the sprays ceased.

Broadly similar results in control have been obtained in trials at Long Ashton and in a canker-prone orchard in South Dorset (in collaborative trials with Miss E.R. Schofield, A.D.A.S., South-West Region). By contrast, D. Wiggell (priv. comm.) has found organomercury sprays somewhat less effective than copper.

Control by summer sprays. When pyridinitril (Berker, Hierholzer and Lust, 1969) was included (at 0.05% a.i.) in a scab trial at Long Ashton in 1966/67, significant reduction of canker (compared with captan treatment) was observed the following year on 1966 extension shoots. This effect was confirmed when pyridinitril was again used in a scab trial in 1969, canker formation being prevented on 1969 growth. This material is now commercially available in a mixture with captan, which it is hoped to investigate further.

In another trial where 1968 and 1969 treatments had been superimposed in a form of Latin square design, there was a significant (90 to 100 per cent) reduction (compared with captan) of canker incidence on 1969 wood in June 1970, both on plots receiving benomyl (0.025% a.i.) in 1969 and also on those receiving it in 1968 (irrespective of the 1969 treatment) (Byrde, Harper and Holgate, in preparation). Similar effects have been noted in commercial orchards.

Three possibilities seem to exist to explain these effects, which are still being examined. A.T.K. Corke (priv. comm.) has shown that summer sprays, in particular benomyl and thiophanate-methyl, have an antisporulant effect on Nectria, an aspect considered more fully by Bennett (1971c).

Secondly, improved control of wood scab may be responsible. Growth often continues into September in Western England and wood scab may develop at the tip when control has not been completely successful and spraying ceases in July. However, both pyridinitril (Berker et al., 1969) and benomyl (Catling, 1969) give protection over a long period, and a final spray with either in mid-July may be adequate. Use of the latter, at least, has been found to give marked reduction in wood scab at Long Ashton, and in a commercial pear orchard (cf. Catling, 1971).

Thirdly, where the junction between extension shoots of two seasons' growth is an important avenue of infection, the compound used for scab control may have a direct effect in preventing canker infection (Swinburne, 1971).

The special problems of the nursery and young orchard. Bennett (1971a) has demonstrated the possibility of infection in the nursery from spores on scion wood, and that this may be reduced by dips or sprays of dodine or captan. The importance of avoiding canker in the nursery and in the early years in the orchard is emphasised by the demonstration by Crowdy (1949) of a latent form of the disease which can break out at a later stage.

In this connection, it is interesting that D. Wiggell (priv. comm.) has obtained promising results in young commercial orchards from the routine application of organomercury paints in January and July/August. The latter timing is aimed at preventing any resurgence of sporulation during the leaf fall period. The paint treatment was supplemented by copper sprays at leaf fall. Such treatment is only practicable on trees up to about seven years old, but this covers the establishment of the main branch framework.

Future Developments

Use of systemic fungicides. Although the expected future development of fungicides truly systemic in woody plants following foliar spraying may well aid canker control, the senescent condition of the leaves prior to leaf fall may be a serious obstacle to uptake, and preclude adequate leaf scar protection at the time of leaf fall.

Specific fungicide testing against canker. Fungicides used for canker control have invariably been developed for other diseases, irrespective of their toxicity to Nectria, and the importance of canker as a disease finds no proportionate effort in fungicide screening. Some advantage might accrue from the use of a specific screening test for canker, e.g. the use of M.VIII rootstocks by Moore and Bennett (1960) or at least the inclusion of N. galligena in routine assays in vitro. For example, thiabendazole (50 ppm) was lethal to conidia of Gloeosporium perennans, but even at 100 ppm was not completely inhibitory to N. galligena (Manners & Corke, 1971).

The complexity of canker control. In view of the many avenues for canker infection, which differ from one orchard to another, it seems unlikely that a single panacea for canker in all orchards will be developed. Thus, where wood scab is prevalent, the success of pre-leaf fall sprays aimed only at leaf scar protection must inevitably be limited (and has already proved to be so in practice in our experiments). Each orchard requires individual consideration to determine the avenue(s) by which infection is occurring, or is likely to occur, and the appropriate treatment to be applied. Nevertheless, the past 12 years have shown sufficient progress to encourage the hope that the disease will soon be a nuisance rather than a scourge.

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THIABENDAZOLE FOR THE CONTROL OF POWDERY MILDEW AND SCAB IN APPLES

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Summary Trials in 1970 at various locations in Germany demonstrated that Thiabendazole at 0.045 % a.i. and 0.06 % a.i. was effective in the control of apple powdery mildew and apple scab. No phytotoxicity was observed at the test rates.

INTRODUCTION

F.A. Preiser et al. (1970) reported on the use-spectrum and methods of application of Thiabendazole as a post-harvest treatment for the control of storage diseases of apples, pears, citrus fruits, bananas, ornamental bulbs and corms and as a foliar spray for the control of *Cercospora beticola* affecting sugar beets as well as *Fusarium* spp. in turf.

In 1970, 10 trials were commenced in the major fruit growing areas of Germany to study the effectiveness of Thiabendazole in controlling powdery mildew (*Podosphaera leucotricha*) and apple scab (*Venturia inaequalis*). The tests were conducted according to the official experimental guidelines established by the Biologische Bundesanstalt in Braunschweig.

METHOD AND MATERIALS

Thiabendazole formulated as a 60 % w.p. was applied 7 - 9 times at 14-day intervals starting between April 24 and May 8 depending on the bud stages of the trees and continuing until June 30 at the earliest and August 28 at the latest. In two trials against apple scab 11 sprays were applied, the latest on October 12. In most trials a concentration of 0.06 % a.i. was used pre-blossom and 0.045 % a.i. post-blossom. Other trials were carried out in which Thiabendazole at 0.06 % a.i. was used throughout.

Treatment plots consisted of 10-12 trees varying in age from 4-20 years. A knapsack sprayer was used to apply the Thiabendazole suspension. The spray volume ranged from 133-222 gal/acre (1500-2500 liters/ha). Conditions for disease development were generally favourable and moderate to severe infection of both powdery mildew and apple scab developed.

Powdery mildew

Varieties susceptible to powdery mildew e.g. Cox's Orange Pippin, Jonathan and James Grieve, were selected for the trial. The number of applications ranged from 7-9. Disease evaluation was performed during August or September on leaves of 25 green shoots using a rating system from 1-4, four is indicating the high infection of fungus mycelium over more than half of the leaf surface. The degree of infection has been calculated by taking into account the number of infected against uninfected leaves in percent as well as the intensity of infection by this formula:

$$\frac{N_1 + 2N_2 + 3N_3 + 4N_4}{N}$$

N_1, N_2, N_3 and N_4 means the number of infected leaves evaluated in the above mentioned rating system. N is the total of $N_1 + N_2 + N_3 + N_4$.

Apple scab

Trials for the control of apple scab were conducted on the varieties Golden Delicious, Cox's Orange Pippin, James Grieve and Jonathan.

The first evaluation for leaf infection took place in June/July, the end of airborne ascospore release. The infected leaves of 10 green shoots were counted in percent of uninfected leaves. The second evaluation for fruit infection was performed at harvest. About 500 fruits of each plot were assessed with a rating system from 1-4, four is indicating the infection of apple scab spots covering more than 0.155 in^2 (1 cm^2) of the apple surface. The intensity of fruit infection is given as explained for powdery mildew.

RESULTS

Powdery mildew

Thiabendazole reduced infection by nearly 80 % compared with untreated (control) trees and compared favourably with a seasonal spray program of standard compounds (Table 1). There was no indication of a varietal response to the treatment. Furthermore at the concentrations tested,Thiabendazole appeared to be equally effective in controlling the disease.

Apple scab

The data in Table 2 show that Thiabendazole used in a spray schedule at concentrations of 0.06 % a.i. and 0.045 % a.i. effectively controlled apple scab. The average reduction of leaf infection in four trials was 98 %, but in one test the reduction was only 66 %. The authors assume this lack of control to be due to an increased drift of the spray mixture caused by wind conditions during the applications. In the same trial Thiabendazole treated apples showed slight to no infection.

Fruit infection was well controlled by Thiabendazole application. In 4 trials the average reduction of infection was 98.4 % versus untreated control. Only in test II the infection rate increased to 15.3 %. But there the intensity of infection was low (1.17 vs. 3.08). That means that 15 % of the apples were only slightly infected with scab. This high degree of disease control was achieved under moderate as well as severe inoculum pressure.

In both the mildew and scab trials there was no evidence of leaf damage nor of fruit russeting resulting from the various treatments with Thiabendazole.

TABLE 1

Control of Powdery Mildew with Thiabendazole

Trial	Fungicide	Concentration % a.i.	No Applications	No Leaves	Intensity of Infection	% Infection
I	Thiabendazole	0.06	9	550	1.15	18.6
	Dinocap	0.1+	9	598	1.20	19.8
	Control	-	-	448	2.01	100.0
II	Thiabendazole	0.06++ / 0.045	8	495	1.13	28.1
	Captan	0.075	8	466	1.43	78.7
	Control	-	-	475	1.66	100.0
III	Thiabendazole	0.06	8	390	1.12	20.6
	Benomyl	0.025	8	369	1.09	1.6
	Control	-	-	386	2.00	100.0
IV	Thiabendazole	0.06++ / 0.045	9	100	1.10	16.6
	Benomyl	0.025	9	100	1.07	12.5
	Control	-	-	100	1.78	100.0
V	Thiabendazole	0.045	7	412	1.06	21.7
	Dinocap	0.1+	7	461	1.04	14.8
	Control	-	-	469	1.66	100.0

+ formulated material

++ concentration used pre-blossom

TABLE 2

Control of Apple Scab on Leaves and Fruit with Thiabendazole

Trial	Fungicide	Concentration % a.i.	No Applications	% Leaf Infection	No Fruit	Intensity of infection	% Infection
I	Thiabendazole	0.06+ / 0.045	8	0	500	1.00	0.43
	Captan	0.075	8	0	500	1.00	0.43
	Control	-	-	25	500	1.64	100.0
II	Thiabendazole	0.06+ / 0.045	8	3.0	1620	1.17	15.3
	Captan	0.075	8	0	2624	1.02	1.5
	Control	-	-	25.0	4017	3.08	100.0
III	Thiabendazole	0.06	8	1.6	600	1.02	5.1
	Captan	0.075	8	3.0	602	1.02	4.0
	Control	-	-	34.3	576	1.64	100.0
IV	Thiabendazole	0.06+ / 0.045	11	0	500	1.00	0.0
	Captan	0.075	11	0	500	1.00	0.5
	Control	-	-	21	500	2.01	100.0
V	Thiabendazole	0.06+ / 0.045	11	30.4	580	1.02	1.0
	Captan	0.075	11	38.7	640	1.58	33.4
	Control	-	-	89.1	224	3.48	100.0

+ concentration used pre-blossom

DISCUSSION

Before the systemic fungicides were known very often a lack of satisfactory control of apple scab and mildew was observed with standard compounds in Germany when the inoculum pressure was high or other environmental conditions favoured the growth of the fungi. These trials demonstrate that Thiabendazole offers an effective alternative to standard fungicides even with a reduction of the application rate. As shown by the experiments in Table 1 and 2 the varying concentrations tested do not indicate the obligatory application rate of 0.06 % a.i. Therefore further studies to verify this particular point are planned for the following season.

The safety of Thiabendazole seems to be a further advantage since it has an extremely low mammalian toxicity and has been admitted and applied as an anthelmintic in human and veterinary medicine for years.

The fact that Thiabendazole is effective in controlling post-harvest storage rots in pomme fruits caused by Gloeosporium spp., Penicillium spp., Botrytis cinerea and Monilia fructigena as well as powdery mildew and apple scab should therefore make it an attractive chemical for use on apples not only in Germany but in other countries.

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NEMATICIDES FOR FIELD CROPS

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Summary Several plant-parasitic nematodes harmful to field crops in Britain can be controlled with chemicals. The most effective allow a host crop to grow well in infested soil, without the number of nematodes being increased.

Stubby-root nematodes (*Trichodorus* spp.) and needle nematodes (*Longidorus* spp.) harmful to sugar-beet are adequately controlled in sandy soils by injecting mixtures containing dichloropropenes into the soil beneath the rows in which sugar-beet seeds are later sown.

Potato cyst-nematodes (*Heterodera rostochiensis*) are controlled best by dazomet, dazomet with 'Telone', aldicarb, 'Du Pont 1410', 'Tirpate' and 'Nemacur P'; treating infested soils with any of these greatly increases potato yields.

Stem and bulb nematode (*Ditylenchus dipsaci*) was controlled and yield of onions was greatly increased in sandy soil by large amounts of dazomet incorporated into the soil by rotary cultivation.

INTRODUCTION

Field crops, wherever they are grown, are usually parasitised by nematodes. The damage they suffer from the feeding on their shoots or roots differs greatly according to the crop grown, the abundance and species of nematodes and soil conditions.

The damage done by some nematodes can be prevented or diminished by suitable rotation of crops or by growing resistant varieties of crops. However, crop rotation is ineffective against those that have extensive host ranges, and a long period between susceptible crops is needed to control those that have restricted host ranges but can persist in soil for many years. The use of resistant varieties is also not necessarily a final answer, because nematodes occur as 'races' differing in their host ranges, so growing a variety resistant to one race may select and multiply other races.

All plant-parasitic nematodes spend at least part of their lives in soil and all can be killed by applying suitable chemicals to the soil. Eradicating them is impractical, but their numbers in the top-soil can be greatly diminished and crop yields in infested land much increased by applying suitable chemicals. This is no mean feat considering the volume of soil and amount of water in the top 30 cm, and it is not surprising that success frequently depends a good deal on the type of soil, its water content and temperature.

More than one hundred compounds (mostly soil fumigants, organo-phosphorus and organo-sulphur compounds) have been used to control nematodes. Many compounds kill or immobilise enough to prevent serious damage to crops, but fail to prevent surviving nematodes multiplying on host crops so that at harvest the soil may contain more nematodes than before sowing. The most effective compounds not only allow a host crop to grow well in infested soil but do so without the number of nematodes being increased.

TYPES OF NEMATICIDE AND METHODS OF APPLYING THEM

Most nematicides in commercial use are soil fumigants (methyl bromide, ethylene dibromide, dibromochloropropane (DBCP), chloropicrin, mixtures containing 1,3-dichloropropene (D-D, 'Vidden D', 'Telone') and methyl isothiocyanate liberators (e.g. dazomet, metham-sodium). Except for DBCP they are very toxic to plants, so they must be applied well before sowing. Except for dazomet and sometimes DBCP, which are in granules, fumigants are volatile liquids that are injected into soil 6-10 in deep in rows 9-12 in apart (broadcast treatment), or in rows, wider apart, above which the seeds of row crops are later sown (row treatment). Injecting the soil with a soil fumigant is cheaper and usually more effective than drenching the soil with an emulsion of the fumigant, but DBCP, which has a small vapour pressure and so is effective only in warm soils, is effective when metered into flood irrigation water. Some field crops are sensitive to DBCP applied at sowing time. Rolling and/or watering seals the soil surface and usually increases the number of nematodes killed. Liquid formulations of methyl bromide (B.Pt.4.5°C), widely used to fumigate nursery beds, and glasshouse soils, but also for some field crops (e.g. pineapple), must be applied with gas-tight sheeting over the soil to prevent rapid loss of the gas into the air. Ethylene dibromide freezes at 10°C, so is useful only in warm soils. Dazomet prill ('Basamid') and DBCP granules are best applied with an applicator that spreads the granules evenly on the soil surface (e.g. Sisis 'Lospred'), and disc harrows or rotary cultivator (e.g. 'Rotavator' with L-shaped tines) to incorporate the granules into the topsoil. For field crops in temperate regions, dazomet and dichloropropene mixtures are suitable soil fumigants.

Some organo-phosphorus compounds (e.g. 'Nemacur P' (Ethyl 4-(methylthio)-*m*-tolyl isopropyl-phosphoramidate), thionazin) and carbamoyl oxime (organo-sulphur) compounds (aldicarb, 'Du Pont 1410' (S-methyl 1-(dimethylcarbamoyl)-N-[(methylcarbamoyl)oxy] thioformimidate and 'Tirpate' (2,4-dimethyl-2-formyl-1,3-dithiolane oxime N-methyl carbamate))control nematodes at much smaller doses than soil fumigants. They are not usually toxic to plants, so they can be applied just before or at sowing time, but they are powerful inhibitors of acetylcholine-esterase so are very toxic to vertebrates and need careful handling. Some of these chemicals are not nematicides, but change the behaviour of the nematodes and prevent them from invading host tissues; those that do manage to invade roots then develop normally (Trudgill, 1971). These nematostatic substances are usually formulated as granules, which can be applied in the same way as granular soil fumigants.

MULTIPLICATION AND KILL

The percentage of nematodes that needs to be killed or inactivated for successful control is proportional to the multiplication of the nematode on the host crop. Up to 90% 'kill' is enough for nematodes that multiply up to 10-fold during the growing season of the crop (e.g. species of stubby-root nematodes (*Trichodorus*) and needle nematodes (*Longidorus*) in Britain), but 98% 'kill' may be needed for nematodes that multiply up to 50-fold (e.g. potato cyst-nematode (*Heterodera rostochiensis*)). Almost 100% 'kill' is needed for chemical control of root-knot nematodes (*Meloidogyne* spp.) in tropical or warm glasshouse soils.

ESTIMATING NEMATODE CONTROL

For practical purposes, it is only the increased yield of subsequent crops, after treating the soil with nematicides, that matters. However, some nematicides have other effects than killing nematodes that can increase yields and to disentangle the effects and to assess success in controlling nematodes it is necessary to estimate populations before and after treating the soil and again after a crop has been harvested. This is possible by counting: (i) active nematodes/g soil; (ii) nematodes or nematode-induced lesions/g plant tissue; (iii) cysts/g soil; (iv) total eggs/g soil; (v) live eggs/g soil.

The eggs of most plant-parasitic nematodes are difficult to identify, so it is usually simpler to estimate the number of active nematodes in the soil or the number that invade, or cause lesions or galls in, young plants. This can be done by growing host plants in samples of field soils in pots, and the results used to assess the kill by nematicides or to forecast the likelihood of damaging attacks in the field. Such estimates will not be wholly accurate, because a larger proportion of nematodes invade roots when the population is small than when it is large. Also such tests may not always accurately estimate the 'kill' because some nematicides delay hatching or invasion of the roots. However, they are adequate for eliminating ineffective chemicals.

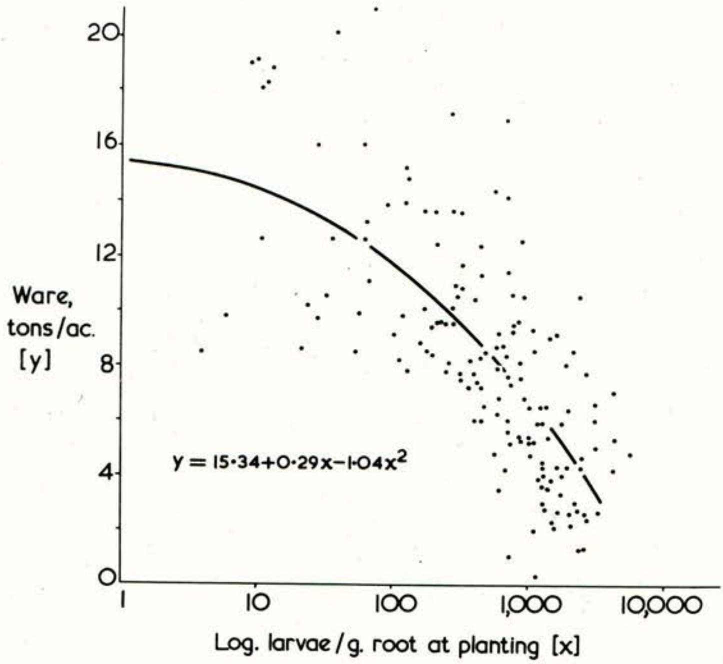

Fig. 1. Effect of potato cyst-nematode larvae invading potato roots on yield of susceptible potatoes.

For example, in fifteen field experiments in England the yield of potatoes susceptible to potato cyst-nematode in different soils, treated with various doses of different nematicides and nematostats, was negatively correlated with the number of larvae that invaded the roots of potato plants grown for four weeks in pots of the treated soils (Fig. 1).

Eggs are contained in the dead bodies of female potato cyst-nematodes ('cysts'), a feature that makes this nematode useful for comparing the effectiveness of nematicides, because eggs can be counted in addition to larvae and adults. Cysts survive for many years in soil and the number of new cysts can be estimated by subtracting the number before planting from that after harvest. If new cysts are not produced when a host crop has been grown on land treated with a nematicide, the nematode has not multiplied and control has been excellent. As about two-thirds of viable larvae hatch from the cysts when potatoes are grown, new cysts containing an equivalent number of larvae can be formed without the population of the soil increasing. Cyst counts give unreliable estimates of control when new cysts are formed because the number of eggs in a cyst can range greatly. An estimate of control is then obtained by comparing total eggs/g soil before treating the soil with a nematicide with total eggs/g. soil after harvest. Some soil fumigants (methyl bromide, dazomet and, in mineral soils, D-D) not only kill eggs in cysts but preserve them, at least until after harvest, so total eggs/g. soil underestimates control by these nematicides. Presumably bacteria that speed the decay of dead eggs in untreated soils are inhibited. Conversely, not all eggs in the cysts before treatment may be alive so total eggs/g soil may overestimate control in this instance. Usually no great inaccuracy is likely when total eggs/g. soil is used to estimate control, but to increase accuracy the number of live eggs/g. soil can be determined by incubating the cysts in New Blue R (Shepherd, 1962), when dead but not live eggs become stained. However, the technique takes too long to be used as a routine.

These, then, are some of the difficulties that arise in estimating nematode control. No single method of assessment is applicable to all nematodes and it is desirable to make more than one type of assessment.

CHEMICAL CONTROL OF SOME BRITISH FIELD CROP PROBLEMS

(i) Stubby-root nematodes and needle nematodes

In sandy soils in England stubby-root nematodes (*Trichodorus* spp.) and needle nematodes (*Longidorus* spp.), both of which are root ectoparasites and harmful to sugar beet and other field crops, can be controlled by mixtures containing 1,3-dichloropropene. The nematodes multiply slowly on host plants so 80-90% kill is adequate and this is readily achieved in sandy soils. Because the nematodes are active only when the soil is wet i.e. in April and May usually only the seedlings are harmed, so row fumigation with 6 gal D-D/ac (67 l./ha) or 4 gal 'Telone'/ac (45 l./ha) is usually enough to prevent serious injury to sugar beet. The yield response to these treatments often repays the cost of treatment several times (table 1).

Table 1

Effect of commercial row fumigation on yield of sugar in two fields of sugar beet infested with *Trichodorus* spp.

Treatment	Sugar (cwt/ac)	
D-D 6.4 gal/ac	49	44
Untreated	31	32

(ii) Potato cyst-nematode

Cyst-nematodes (*Heterodera* spp.) are widespread and important pests of field crops. The most studied is potato cyst-nematode (*H. rostochiensis*) but cereal cyst-nematode (*H. avenae*) beet cyst-nematode (*H. schachtii*), pea cyst-nematode (*H. gottingiana*), brassica cyst-nematode (*H. cruciferae*) and others are harmful pests that determine the frequency with which their host crops can safely be grown. Experiments on sandy clay, sandy loam, peaty loam and silt loam soils have shown that potato cyst-nematode in main crop potatoes can be controlled with nematicides and nematostats.

The invasion of potato roots by potato cyst-nematode larvae was greatly decreased by dazomet, aldicarb, Du Pont 1410, 'Tirpate' and 'Nemacur P'. Methyl bromide and mixtures containing dichloropropene (D-D and 'Telone') were less effective, (table 2).

Table 2

Larval invasion of susceptible potato roots

Treatment	lb a.i./ac	larvae (% of untreated soil)
dazomet	294-392	1-3
methyl bromide	780-1000	7-31
'Telone'	230-560	8-61
D-D	250-1000	9-100
'Nemacur P'	10	1
aldicarb	9-10	1-5
Du Pont 1410	10	5-8

Three hundred lb 'Basamid' (98% dazomet prill/ac (336 kg/ha)) incorporated into ridges early in spring, 7 weeks before planting in the ridges, and 780 lbs methyl bromide/ac (874 kg/ha) greatly increased the yield of Majestic potatoes in heavily infested sandy loam without increasing the number of viable larvae in the soil to 8 in (20 cm) depth after harvest (table 3).

Table 3

Control of potato cyst-nematode and yield of susceptible potatoes in sandy loam

Treatment	lb a.i./ac	live eggs/g. soil after harvest	ware Majestic (ton/ac)
Untreated	0	126	4.0
dazomet	294 (row)	66	16.0***
	392 (broadcast)	137	15.3***
methyl bromide	780 (broadcast)	75	13.9***
	Before treatment	199	

***greater than untreated at P = 0.001

Although 400 lb 'Basamid'/ac (448 kg/ha) broadcast during autumn, allowed some potato cyst-nematodes to multiply, other experiments did not confirm the advantage of ridge treatment over broadcast treatment. Applying dazomet during spring rather than autumn may control the nematodes better (table 4), but means delay in planting.

Table 4

Control of potato cyst-nematode by dazomet and 'Telone' applied in autumn or spring and yield of susceptible potatoes in sandy loam

Treatment	lb a.i./ac	Application	Total eggs/g soil after harvest	Ware Majestic (ton/ac)
Untreated	0	autumn, ridged	294	7.2
dazomet	294	autumn, ridged	43	16.0***
"	294	" , flat	47	18.1***
"	294	spring, ridged	23	20.1***
"	294	" , flat	21	19.1***
'Telone'	300	autumn, ridged	77	13.5**
	300	spring, ridged	81	11.6*
		Before treatment	13	

*, **, *** greater than untreated at P = 0.05, 0.01, 0.001 respectively

In sandy loam potato cyst-nematode can be controlled to 16 in (41 cm) depth or more by applying dazomet to the soil surface and then rotavating the soil 6 in (15 cm) deep, but in some soils control is improved by applying half the dose before and half after ploughing with a digger plough to invert the furrow slices. In a silt loam, 190 lb 'Basamid'/ac (213 kg/ha) incorporated by rotavating the soil 6 in (15 cm) deep, followed by 200 'Telone'/ac (224 kg/ha) injected 10 in (25 cm) deep, controlled the nematode as well as a split dose of 560 lb 'Basamid'/ac (628 kg/ha); 400 lb 'Telone'/ac (448 kg/ha) injected 10 in (25 cm) deep was much less effective, presumably because nematodes near the soil surface were not killed (Fig. 2).

In peaty loam, dazomet was more effective when applied in two such dressings in October or November than in August or September, probably because the soil was wetter and colder, so the fumigant escaped more slowly from the soil surface and remained concentrated for longer in the soil.

Potato cyst-nematode can also be controlled by applying small amounts of aldicarb, 'Tirpate', 'Du Pont 1410', and 'Nemacur P' to the soil at planting time. In a silt loam, 10 lb a.i. 'Du Pont 1410'/ac (11.2 kg/ha) increased yield from 12.5 ton ware King Edward/ac (31 tonnes/ha) to 21.0 ton/ac (53 tonnes/ha) yet the nematodes increased very little. As good control was obtained with 'Tirpate' and 'Nemacur P' and the best control was obtained with aldicarb (table 5).

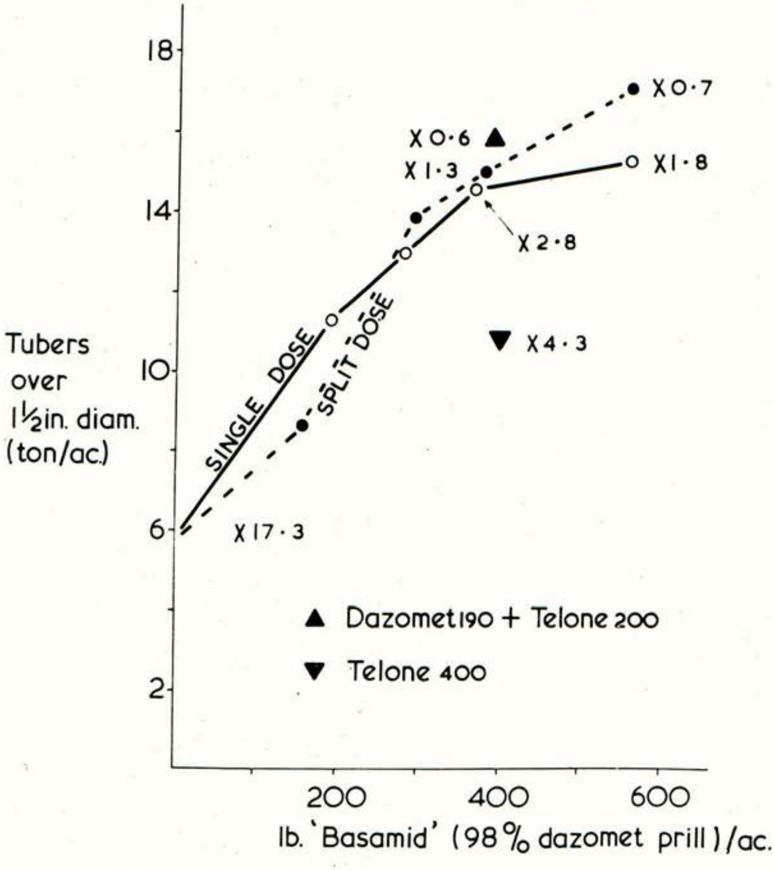

Fig. 2. Effect of dazomet and 'Telone' on yield of susceptible potatoes (var. King Edward VII) and multiplication of potato cyst-nematode in silt loam. Multiplication factors are shown, e.g. after 400 lbs 'Telone'/ac there were at harvest 4.3 x as many nematodes as before treatment.

Table 5

Control of potato cyst-nematode by chemicals applied to soil just before planting and yield of susceptible potatoes in silt loam

Treatment	lb a.i./ac	Total eggs/g soil after harvest	Ware King Edward (ton/ac)
Untreated	0	752	12.5
'Du Pont 1410'	10	57	21.0***
aldicarb	10	14	18.8**
'Tirpate'	10	63	19.0**
'Nemacur P'	10	44	18.3*
phorate	10	257	17.1*
	Before treatment	49	

*, **, *** greater than untreated at P = 0.05, 0.01, 0.001, respectively

In an irrigated peaty loam, where potatoes had not grown for 10 years but the soil was still heavily infested with potato cyst-nematode, 5 lbs a.i. aldicarb/ac (5.6 kg/ha) increased yield of ware King Edward from 12.8 ton/ac (32 tonnes/ha) to 21.9 ton/ac (55 tonnes/ha). Similarly in heavily infested sandy loam as little as 4.3 lb a.i. Du Pont 1410/ac (4.8 kg/ha) greatly increased the yield of Pentland Crown potatoes yet was enough to prevent any multiplication of potato cyst-nematode (table 6).

Table 6

Control of potato cyst-nematode by 'Du Pont 1410' and yield of susceptible potatoes in sandy loam

Treatment	lb a.i./ac	Total eggs/g. soil after harvest	Ware Pentland Crown (ton/ac)
Untreated	0	318	8.5
'Du Pont 1410'	4.3	57	17.0***
" " "	8.6	36	18.3***
" " "	17.2	56	17.7***
	Before treatment	143	

***, greater than untreated at P = 0.001

A new nematicide harmless to plants and said to have less than one hundredth of the mammalian toxicity of aldicarb, controlled potato cyst-nematode in pots as well as aldicarb.

Fig. 3 shows the decline in populations of potato cyst-nematode when:

1. potatoes are not grown; in most soils about one third of the eggs hatch or die each year (in peaty (organic) soils less than one third); 2. a nematicide is used that prevents potato cyst-nematode increasing on susceptible potatoes grown in a three-course rotation; 3. a nematicide is used that prevents potato cyst-nematode multiplying on susceptible potatoes in a three-course rotation or a resistant variety of potato is grown in a three-course rotation.

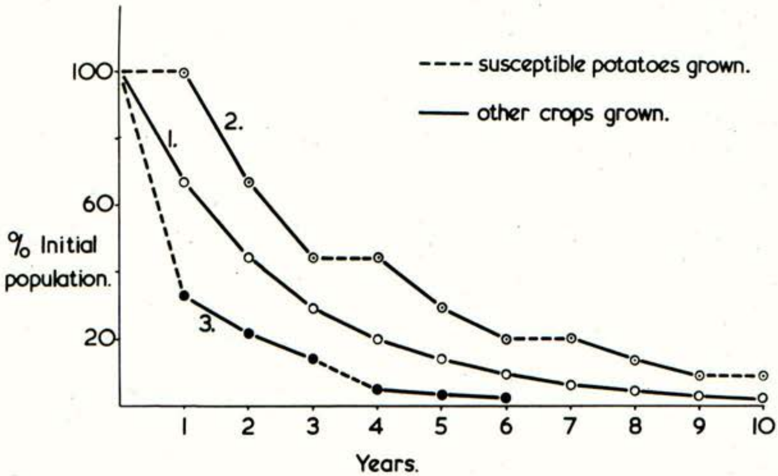

Fig. 3. Effect of different crop sequences on the abundance of potato cyst-nematode. 1. when non-host crops are grown; 2. when a nematicide prevents potato cyst-nematode increasing on susceptible potatoes in a three-course rotation; 3. when in three-course rotations a nematicide prevents multiplication of potato cyst-nematodes on susceptible potatoes or when resistant potatoes are grown.

Populations clearly decline faster when multiplication on a potato crop is prevented than when potatoes are not grown. Resistant varieties of potatoes are injured when invaded by many larvae, so effective nematicides would not only protect them from injury in heavily infested soils but also prevent any pathotypes able to multiply on the variety from doing so.

The greatest control will be achieved by the combined use of crop rotation, nematicides and resistant varieties. Assuming these three control measures are independent variables, the number of viable eggs/g soil (N) left after using all three is given by the equation:-

$$N=Y[F_n]^a[F_o]^b[F_r]^c$$

where Y = initial number of viable eggs/g soil, F_n = fraction left after using a nematicide, F_o = fraction left after growing non-host crops, F_r = fraction left after using a resistant variety and a, b, c are the number of times or years each is used e.g.:-

$$2.5 = 750[\frac{1}{20}][\frac{2}{3}]^4[\frac{1}{3}]$$

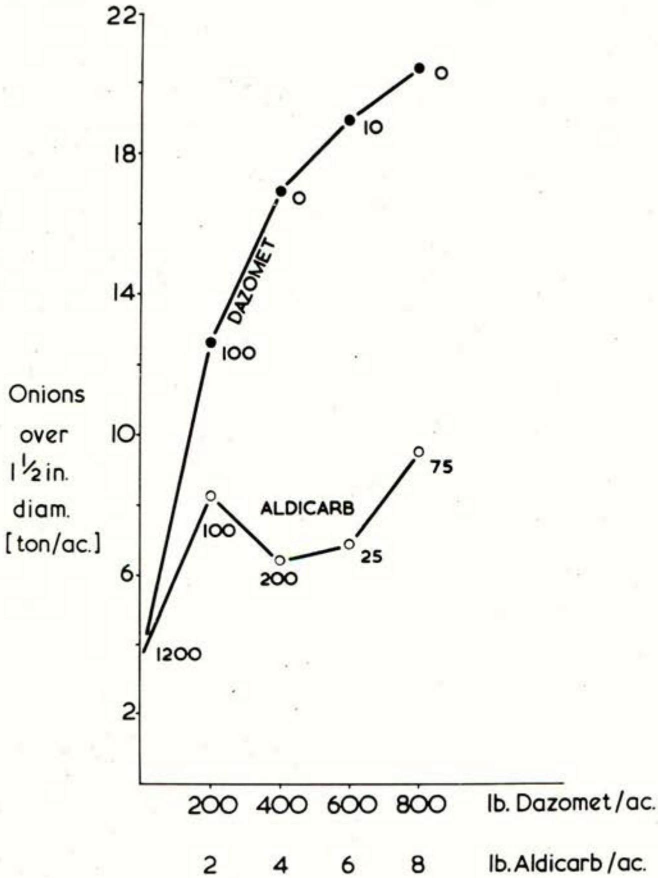

Fig. 4. Effect of dazomet and aldicarb on yield of onions and control of stem and bulb nematode. At each point on the graphs is shown the number of nematodes per litre of soil to 8 in (20 cm) depth in the onion rows after harvest.

where there has been 95% kill by a nematicide, four years without a host crop and a resistant variety has been planted. So even when the initial population is very large combining these three methods of control could prevent significant injury to the next potato crop by potato cyst-nematodes.

(iii) Stem and bulb nematode (*Ditylenchus dipsaci*)

Stem and bulb nematode, a harmful pest of field crops (e.g. oats, clovers, flower bulbs and onions) is a nematode able to multiply hundreds or thousands of times on a host crop. Although fumigating infested seed with methyl bromide, or treating bulbs in hot water or thionazin baths, and crop rotation can greatly lessen crop injury, good control of the nematode is difficult because the different 'races' of it can also multiply on many weeds. At Harpenden, Herts., 10 lb a.i. aldicarb/ac (11.2 kg/ha) largely prevented infection of spring beans (*Vicia faba*) grown in clay soil and at Woburn, Beds., irrigated onions (var. Robusta) were protected better by large doses of dazomet than by small doses of aldicarb, and yield was increased greatly (Fig. 4). It seems therefore that even nematodes with very large multiplication rates can be controlled by chemicals.

FUTURE PROSPECTS

The examples quoted show that potato cyst-nematode and other nematodes that multiply rapidly, hitherto thought difficult to control chemically in Britain, can be controlled by nematicides, especially dazomet, dazomet with 'Telone', aldicarb, 'Du Pont 1410', 'Tirpate' and 'Nemacur P'. Integrating control measures might allow smaller doses of nematicides to be used. Improved formulations could decrease the hazards of applying very toxic nematicides. The fate of nematicides in soil and crops needs further study and they will need to be cheapened before they can be used widely on field crops. Satisfactory solutions to these problems would allow more widespread use of nematicides and permit shorter, more efficient crop rotations than has previously been possible.

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POST-HARVEST LOSSES IN PERISHABLE TROPICAL PRODUCE

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Summary Perishable produce forms an important part of global food supplies, especially in the tropical world, but so far little attention has been paid to the post-harvest losses in this type of produce, especially when compared with the better-known durable types of produce such as grains, oil seeds and legumes. There is an estimated production of more than two hundred million tons per annum of perishable produce within the tropics and, as an approximate, extremely conservative estimate, post-harvest losses total more than a quarter of the total harvest.

Losses arise from a variety of causes, the most important falling under the headings: mechanical injury; physiological damage; attack by fungal pathogens or other microorganisms.

The paper discusses the available information on these types of loss and indicates some of the major lines of attack that may be adopted in reducing losses under these three categories. The use of recently developed fungicides is of particular significance.

INTRODUCTION

The 'population explosion' will double the world's population between now and the year 2000: so, conservation of global food resources is becoming an ever more pressing problem. Agricultural production is rising only slowly in the tropical regions which contain the most rapidly expanding third of the world's population, so that increased production alone cannot keep pace with requirements.

In the tropics post-harvest losses are greatest: and in their reduction a great contribution can be made to improving world food supplies, beyond that achieved by increased primary production (Harrar, 1970; Hulse, 1970). Food losses between harvest and consumption have been seriously studied only recently even in developed countries, and attention has been focussed largely on the preservation of grains, and of oilseeds and dry legumes with similar storage problems (Hall, 1969; 1970) caused mainly by insects and rodents. Grains, dry legumes and oilseeds together constitute a major part of the food of the tropical world, but "perishable" produce is also of importance, and the losses that occur post-harvest in such materials are very poorly understood. Processing losses are not considered here, having recently been reviewed (Ben-Gera and Kramer, 1969; Czyrhinciw, 1969): these lie within the domain of food technology.

"Perishable" tropical produce considered here includes the general category of fruits and vegetables, under three main headings:-

Staple foods. Perishable staples providing the main calorific base of the diet. Cassava or manioc is the most important, followed by yams, sweet potatoes, plantain-bananas, aroids, bread-fruit and some others.

Secondary foods. The culinary category of 'vegetables', such as green vegetables, onions, tomatoes, legumes with many others; and fresh fruit. Consumed in smaller quantities than staples, they are important in providing minerals and vitamins in the diet, and increasing its variety.

Export crops. Fruit, such as bananas, pineapples, citrus, mangoes and avocados, together with out-of-season vegetables grown for high quality export market. These commodities provide valuable foreign exchange for the exporter countries.

MAGNITUDE OF THE PROBLEM

In a recent paper (Coursey, 1971) we have examined production statistics (FAO, 1969) for those types of perishable produce which are grown substantially in the tropics. These statistics are incomplete, in that they neglect many unfamiliar fruits and vegetables produced in the tropics, but even on this basis the total production of perishables in the tropics comes to 212 million tons/annum: the conservation of this quantity of food is surely a matter deserving serious attention. On the magnitude of losses which occur in grains and similar "durable" crops, estimates reviewed by Hall (1969) suggest that overall, 20-25% is lost in storage in tropical countries. With the horticultural crops, remarkable little firm information is available.

Table 1

Wastage of some Fruits and Vegetables at various stages between Producer and Consumer in U.S.A. (after Friedman, 1960)

Losses (%) during:-

Commodity	Storage and Wholesaling	Retailing	Within Household
Apricots	1	4	N.F.Q.
Bananas	N.F.Q.	3	3
Cucumbers	2	4	N.F.Q.
Grapefruit	13	3	6
Lemons	8	3	5
Limes	5	N.F.Q.	N.F.Q.
Melons	2 - 13	3 - 6	N.F.Q.
Onions	25	6 - 8	10
Oranges	15	2	N.F.Q.
Potatoes	16	4 - 6	8
Strawberries	25	N.F.Q.	15
Sweet Potatoes	19	4	12
Tangerines	16	4	5
Tomatoes	N.F.Q.	6	7

N.F.Q. = No Figure Quoted by the source

Even in the U.S.A., perishable produce is described (Brody and Sacherow, 1970) as 'the victim of phenomenally high waste because of incredibly poor handling practices', the economic post-harvest loss being estimated at 200 million dollars annually. (Eckert and Sommer, 1967). However, this economic figure is enhanced compared with the actual food loss, owing to the great increases in unit value which occur as the material passes along the exceedingly complex marketing chain from producer to consumer. Estimates of material loss in fruit and vegetables in the U.S.A. were 11% for the period 1942-1951 and 8% for 1957-1960 (Friedman, 1960) - indicating the benefits obtained from a decade of intensive research and application.

There is much variation between commodities; some deteriorate more rapidly than others. Losses shown in Table 1 for various fruits and vegetables in the U.S.A. (Friedman, 1960) show also how deterioration is a cumulative effect, differing degrees of spoilage taking place at different stages of the marketing chain. Commodities such as potatoes or sweet potatoes which seem comparatively durable and might be expected to store well are actually subject to heavy losses, comparable with those in soft fruits.

Lower levels of education and technology in the developing countries imply that handling techniques are less satisfactory; fewer sophisticated facilities are available: and losses are substantially higher. A parallel appears to exist between the losses and the state of technological advancement, as shown on Table 2.

Table 2

Cull losses in Citrus Industries (after Braverman, 1949)

U.S.A. (California)	10%
Israel	15%
Italy	30%

Information relating to the tropics is extremely scarce. Table 3 illustrates the magnitude of the problem from losses in produce passing through an official marketing organisation in a Central African country (A.K. Thompson, unpublished work): although there is much variation, overall losses are catastrophically high.

The most important perishable tropical staple, cassava cannot be kept in the fresh state for more than a few days. Throughout the tropics cassava is left in the ground until required and is processed as soon as lifted: thus globally, about three quarters of a million hectares of land are occupied unnecessarily by the standing crop: there is also a loss of quality in the cassava. In another staple crop, the yam, post-harvest losses from endogenous metabolic activity alone are about 5% of the total crop (Coursey, 1967): allowing also for the effects of decay, Rawnsley (1969) suggests a total storage loss of 15 per cent of the crop in West Africa. Sweet potato suffers heavy losses even in the U.S.A.: under tropical conditions they are extremely 'wasty' although the loss reported by Thompson may be abnormal. Potatoes are more liable to loss than might be expected from their apparently durable nature: the figure of 8 per cent quoted was achieved in cold stores.

Fruit crops experience very high losses on account of their susceptibility to mechanical damage and inherently low storage life. In selected, top quality, tomatoes in Ghana, Rawnsley (1969) reported handling losses of 16 per cent; over the crop as a whole, this figure could probably be doubled. In India, Singh (1960) estimates that 40 per cent of the mango crop is lost by bad handling between harvest and consumption. With bananas it has been estimated (Ben-Gera and Kramer, 1969) that a third of the crop enters international trade, a third is used locally and a third is wasted. Even higher losses have been estimated for fruit and vegetables in some tropical situations: Lowings (1969) suggests that losses of 50 per cent are not uncommon: F.A.O. (n.d.) quotes wastages of 40 per cent of vegetables and 50 per cent of fruit in Chile: in Colombia, the extraordinary figure of 80 per cent wastage in perishable produce has been given (Hall, 1970). However, taking only the levels of loss actually reported for specific crops, and assuming that they are typical for the tropical world, a total loss of around 30 million tons/annum, or 25% of production (excluding cassava, which is rather a special case) may be estimated. This must, however, be regarded as a highly conservative estimate (Coursey, 1971).

Table 3

Wastage in various types of horticultural produce under Central African conditions (after Thompson)

Commodity	Wastage %
Avocados	43
Aubergines	27
Cabbages	37
Carrots	44
Cauliflowers	49
Lettuces	62
Onions	16
Oranges	26
Pineapples	70
Potatoes	8
Sweet potatoes	95
Tomatoes	30

How do these incredibly high losses arise? Social factors are involved, in such considerations as lack of administrative and managerial abilities, educational facilities and capital. Even in the U.S.A. "Produce is without question the least rationalized of all food industries" and, "The loss rate as a result of multiple handling..............is frightful"; (Brody and Sacherow, 1970). How much more in the tropical world?

NATURE OF THE PROBLEM AND SOME SOLUTIONS

Here, however we shall discuss technical factors. The first essential in the storage of horticultural produce, is to remember that living organs, whose physical and physiological integrity must be preserved, are concerned. Losses arise from assaults on this integrity. Losses of harvested produce may be of quantity or of quality. These may occur separately or together and are manifest in many different ways, but three main groups are evident: losses caused by mechanical injury; physiological losses; and losses caused by disease.

Mechanical injury takes many forms and arises at all stages in the history of the produce from pre-harvest operations, through harvesting to handling, grading, packing, transporting, exposure in the market, and finally in the home. Besides causing considerable direct loss, mechanical damage renders produce more prone to physiological and pathological losses. Damaged produce should never be considered for long term storage and should be disposed of as soon as possible. Mechanical losses are frequently overlooked and, because of complications of physiological and pathological losses, difficult to estimate. The possible magnitude of such losses was revealed in recent surveys (Potato Marketing Board, n.d.) in Britain, which showed that when graded 33% of the crop is so seriously damaged as to be fit only for stock feeding, while a further 12% loss from damage occurs during transit between farm to shop.

Emphasis must be given to proper packaging. Delicate, sensitive produce is often treated as though it were inert material, and the mechanical damage so engendered greatly enhances deterioration. The application of suitable packaging expertise is a first essential towards the amelioration of losses, especially if the produce is to be consumed far from the area of production. The example already quoted of 16 per cent loss in tomatoes (Rawnsley, 1969) occurred when the fruit were shipped in the conventional "inverted cone" type of basket. When baskets of "upright cone" shape (wide bottom; sides converging towards a narrow orifice) were used, and the tomatoes packed in dried grass, losses were reduced to about 3 per cent. Reduction in mechanical damage and better grading of perishable produce should concern the industry as a whole but particularly individual producers whose financial return it can greatly influence.

Physiological losses are diverse in nature. Because produce is alive, endogenous respiratory losses of dry matter together with transpiratory or wilting losses of water will always occur. In order to reduce such losses to a minimum the use of refrigeration is frequently recommended (FAO, n.d.; 1968; Hall, 1970) as metabolic processes generally decrease with a decline in temperature. Although there is no doubt that refrigeration has a valuable part to play, it cannot be regarded as the only answer. Many tropical perishables are subject to chilling or low temperature injury, i.e. physiological breakdown at temperatures near, but above, freezing (Fidler and Coursey, 1969): this limits the scope for reduction of storage temperature. Many products, especially staples, are too low in unit value to be able to bear the cost of refrigerated storage. In much of the developing world, capital for the provision of refrigerated stores is in short supply, and limited technical and management expertise is available for their effective maintenance and running.

Controlled atmosphere storage is similarly used to slow down natural metabolic processes (Uota 1963; Smock, 1966). This method is limited in application by the same economic and organisational factors as refrigerated storage.

The manipulation of the physiological condition of produce to reduce post-harvest losses is a largely unexplored field and one which deserves much more attention. Optimum harvest maturity for storage is an important factor but has been very little studied; it varies between different products. Most root crops are more susceptible to injury and physiological and pathological losses when harvested immature, while most fruit and leafy vegetables become more susceptible to losses of all kinds as they mature or ripen. The use of growth regulators in adjusting physiological maturity could well be investigated further. Curing, by brief exposure to comparatively high temperatures and humidities immediately after harvest, to encourage suberization of the skin and around wounds, greatly reduces subsequent storage losses, both physiological and pathological, in sweet potatoes (Kushman and Wright, 1969), Irish potatoes (Burton, 1966), and yams (Thompson, unpublished work). Onion curing improves skin colour and appears to be accompanied by the development of fungicidal compounds in the skins (Walker _et al._, 1929; Link and Walker, 1933). Techniques for delaying ripening of fruit by removal of endogenously produced ethylene have been exploited in the commercial shipment of green bananas at ambient temperatures within Australia (Scott _et al._, 1971) for periods of up to ten days. Such a simple provision as shading can greatly improve storage life: produce exposed to the tropical sun can reach an internal temperature of 45°C even when ambients are around 30°C (Coursey and Nwankwo, 1968), and so suffer physiological damage.

A physiological storage problem characteristic of root, tuber and bulb crops is sprouting. This can be reduced either by suitable manipulation of storage temperature or by the use of sprout inhibiting or destroying chemicals such as maleic hydrazide; iso-propyl-chlorophenyl carbamate; tetrachloronitro-benzene and nonyl alcohol. Other physiological losses resulting from abnormal growing conditions become manifest only after harvest. Examples are water soaking and internal discolouration, which greatly influence quality and storage life.

Probably the bi gest cause of post-harvest loss in perishable produce is attack by fungi, bacteria, and (to a lesser extent) viruses.

Quantitative losses result from the extensive breakdown of host tissues by micro-organisms. There is usually initial attack by one, or a few, specific pathogens, followed by massive infection by a broader spectrum of non-specific biodeteriogens which are weakly pathogenic or are saprophytic on the dead or moribund tissue (Tompkins, 1951; Turner, 1959). These secondary invaders play an important role in post-harvest pathology, as they enhance the damage initiated by primary pathogens. Qualitative losses result from blemish or surface diseases which render the produce less attractive and marketable. These are particularly important in fruit export industries where increasing emphasis is placed on quality, and even a small blemish may render the product unacceptable. Successful disease control depends on knowledge of the pathogens concerned; of the mode and time of infection; of the development of the pathogen(s) in the host, and of host/pathogen reactions. To reduce infection pressure, good phytosanitary practices should always be adopted: plant debris which may harbour microbial pathogens should be eliminated; implements, boxes, buildings, etc. should all be cleaned or sterilised before use, and all efforts made to reduce the general inoculum level.

Post-harvest diseases may be considered into two groups, in which infection occurs either before; or during or after, harvest: the latter frequently originate in mechanical or physiological injuries. Control of the former may be effected by the pre-harvest use of protectant or eradicant sprays such as copper, captan, and dithiocarbamates, to prevent infection occurring, in addition to post-harvest treatment after infection has occurred. Control measures against the latter are confined to post-harvest treatments, either physical or chemical.

Physical treatments include the use of high and low temperatures to reduce the growth of the pathogens; curing; and the use of radiation. Low temperature storage slows down the metabolism of both host and pathogens and so frequently arrests rotting, but rarely kills the pathogens so that when the produce is returned to ambient temperatures rotting may recommence rapidly; some pathogens further are low temperature tolerant.

Heat treatment suffers from the drawbacks that certain pathogens are heat tolerant and the high temperatures required to be effective can damage the produce. It has, however been used to control certain diseases, such as anthracnose of papaya and mango (Smoot and Segall, 1963), and post-harvest diseases of peaches (Smith et al, 1964). Curing to promote cork formulation and so prevent the entry of wound parasites has already been mentioned. In the use of ionising radiation as post-harvest treatments to reduce losses, gamma radiation has proved the most successful (Bramlage and Coney, 1965) but so far is little used commercially.

Successful chemical treatment depends upon the use of substances which are either fungistatic (bacteriostatic) or fungicidal (bacteriocidal) at dose rates that are not phytotoxic. Treatments can be divided into three groups: Fumigants, treated wraps and dips or sprays. Fumigants are particularly useful in treating delicate produce and for produce stored or transported in closed containers. The best known is sulphur dioxide, used to control Botrytis and other rots of grapes (Nelson and Richardson, 1961): it is, however, phytotoxic to most other fruit and vegetables. Sulphur dioxide kills fungal spores present on the fruit surface but does not destroy infections present before storage (Lutz and Hardenburg, 1968). Other fumigants used to control post-harvest disease include ozone (Schoner and McColloch, 1948; Magie, 1961) and nitrogen trichloride (Littauer, 1947; Pryor, 1950).

Chemically treated wraps are used largely in the citrus industry for localizing disease and in preventing blemish diseases from developing and sporulating on the fruit surface. Such treatments are most effective where the chemical also acts as a vapour phase fumigant, as with biphenyl-impregnated wrappers which have been used commercially for many years (Roistacher et al, 1960; Rugg et al, 1964). Other chemicals used in wrappers include sodium o-phenylphenate and various o-phenylphenol esters (Tomkins, 1963).

Many chemicals have been used as dips or sprays to control post-harvest diseases including sulphur compounds, phenolics, positive halogen compounds, dithiocarbamates, organic acids, antibiotics, and recently various systemic fungicides particularly thiabendazole and benomyl. Comprehensive reviews of such chemicals and the disease they control have been published (Pryor, 1950; Eckert and Sommer, 1967; Eckert, 1967; Tomkins, 1951; Turner, 1959; Friedman, 1960). The greatest drawbacks of most of these chemicals is that whilst they show high activity in vitro they may not penetrate the host tissues sufficiently or do not have a broad enough spectrum of activity. Eckert (1967) pointed out that screening programmes do not always reveal fungicides useful for post-harvest application, while:- "No concentrated effort seems to have been directed to the development of locally systemic fungicides for post-harvest use. Such agents would be of great value in increasing the flexibility of fruit handling operations". Recently, several systemic fungicides have been developed, initially for field use, two of which in particular have proved extremely useful post-harvest fungicides. The success of thiabendazole and benomyl, particularly in control of fruit rots of bananas (Burden, 1969; Bailey et al, 1970), clearly shows the reduction in losses that can be achieved. They do not control however, lower fungi (Phycomycetes), which are common causes of loss in tropical produce; furthermore resistant fungal strains are beginning to appear (Laville, 1971). No satisfactory chemical treatments have yet been developed for control of bacterial soft rots, which cause serious losses, especially in leafy vegetables and root crops. Limitations on the post-harvest use of fungicidal chemicals also arise from the requirements of food additives legislation, etc.

No mention has been made in this paper of losses caused by rodent or insect attack. These are usually of minor importance compared with the extensive factors discussed and also compared with the extensive spoilage which they cause in stored durable produce. Individual cases of heavy loss do however occur and the subject should not be entirely neglected.

CONCLUSION

In conclusion, it is seen that post-harvest losses of perishable tropical produce, particularly the lesser known commodities such as the staple root crops, are enormous. The problems are both important from economic and nutritional standpoints and complicated from the technological, although there are indications that they respond well to rational scientific approach.

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CHEMICAL TREATMENTS FOR THE CONTROL OF POSTHARVEST DISEASES OF CITRUS FRUITS

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Summary. The marketing of citrus fruits overseas is dependent upon the application of several fungicides to the harvested fruits to prevent excessive decay losses during transport and storage. Stem end rot is the major problem of citrus fruit grown in warm humid climates whereas green and blue molds are responsible for major losses of fruit produced in arid subtropical climates. Treatment of citrus fruit after harvest with a 1000 ppm suspension of thiabendazole greatly reduces the incidence of both stem end rot and green and blue molds. A residue of 5-6 mg thiabendazole/kg fresh fruit also retards the growth and sporulation of green mold on the surface of decaying fruit, thereby preventing contact soiling of adjacent sound fruit in the same container. Benomyl appears to provide similar protection but has not been evaluated as extensively as thiabendazole. 2-Aminobutane, a water soluble fungistat, is effective and convenient for treatment of fruit in bulk containers to control green mold, although the compound inherently is less active than thiabendazole.

INTRODUCTION

Citrus fruits are relatively hardy compared to other fresh fruits and vegetables and may be stored under refrigeration from one to several months without declining in quality. The observation that citrus fruits apparently do not suffer from holding for several days at ambient temperatures has resulted in the common commercial practice of transporting fruit, for at least a portion of their journey, at temperatures above the optimum for maximum storage life of a given variety of citrus fruit. Storage temperature has a pronounced influence on the development of pathogenic fungi and excessive decay upon arrival is the most immediate and striking evidence of inadequate refrigeration during transit. It should be clearly recognized, however, that although low temperature retards the development of decay in oranges, it rarely has a curative effect. The problem becomes evident after the fruit are held at ambient temperatures for a few days in the retail market or in the consumer's home. Low temperature is a less satisfactory control measure for lemons and grapefruit because temperatures near freezing which halt the growth of most fungi are injurious to these fruits and, consequently, may result in an increase in decay of fruit stored under such conditions (Schiffman-Nadel, 1969).

The magnitude of decay losses during long distance marketing of citrus fruits is difficult to estimate because shipments usually are inspected immediately after the fruit are removed from refrigerated ships at which time the decay fungi are suppressed. Rarely have surveys been made of the total decay losses incurred in moving citrus fruits from the grove to consumer. Fruit variety, production area and season are major factors which affect the susceptibility of fruit to decay. Navel oranges and lemons invariably have a higher decay rate than Valencia oranges and grapefruit. Oranges grown in humid climates (eg., Florida, Eastern Transvaal) predictably have more decay problems than fruit from dry subtropical areas (eg., California and Spain). Current average losses in all citrus varieties may be estimated conservatively to range from 3 to 6% decay on arrival at retail markets in Europe. This figure could be expected to double before the fruits were consumed. Since virtually all citrus fruits entering European markets have been treated with one or more fungicides after harvest, it is difficult to evaluate quantitatively the practical value of these fungicides in reducing decay. Five-year records of decay of hand-harvested oranges and mandarins in Florida indicated that 20% decay after 2 weeks storage at 21° C is a reasonable loss estimate for citrus fruits produced in humid areas and which are not treated with fungicides after harvest (Smoot, 1969). Mechanically harvested fruit is subject to an increase in green and blue mold decay because of surface injuries and values of 30-50% decay are reported frequently (Grierson, 1969). Although comparable values for fruit from arid production areas might be one-third those cited above, there can be little doubt that the use of postharvest fungicides is an economic necessity for the marketing of fresh citrus fruits overseas.

MAJOR DISEASES OF CITRUS FRUITS AFTER HARVEST

Although ten or more fungi can attack citrus fruits after harvest, major economic losses are due to the activities of only several pathogens. Green mold, incited by Penicillium digitatum, is the major decay of all citrus fruits produced in arid subtropical areas. The disease is prevalent at a similar level in humid production areas but is overshadowed by the severe stem end rot problem in these areas. Green mold is responsible for over 90% of the decay losses of fruit from subtropical areas. Air-borne spores alighting in fresh injuries on the fruit surface initiate the disease. Blue mold (P. italicum) is similar in distribution and development but is less frequently observed than green mold. One reason might be that the slower growing blue mold is overgrown by green mold in mixed infections of the two fungi. The problem of green and blue mold has two facets - individual fruits are infected and decayed, and also a disproportionate number of adjacent fruit are soiled with mold spores. The problem of soiling may be minimized by wrapping individual fruit, but this practice is declining in major citrus areas for economic reasons.

Stem end rots caused by Diplodia natalensis and Phomopsis citri are the principal postharvest diseases of citrus fruits grown in humid production areas. Pycnidiospores disseminated by rain give rise to latent infections on the sepals and buttons of the fruits. Entry of the pathogen into the fruit proper is delayed until the button of the fruit undergoes senescence or begins to separate from the fruit after harvest (Brown & Wilson, 1968). The stem end rot caused by Alternaria citri is similar to that caused by Diplodia and Phomopsis except that the spores of the former fungus are air-borne. Alternaria stem end rot is often severe on fruits stored or in transit for a long period of time as it develops slowly even at rather low temperatures as the fruit undergo senescence. The disease is a major problem on stored lemons and grapefruits.

Sour rot caused by the filamentous yeast Geotrichum candidum is a serious disease of ripe fruit held under warm humid conditions. The causal fungus is a common soil inhabitant. A few fruit inoculated during harvest bring the pathogen into storage rooms where the disease spreads rapidly from fruit to fruit by contact, or through contamination of the packing line. Sour rot is the most feared decay of lemons during summer months because, at 24°C and above, it spreads rapidly from fruit to fruit and is the most watery of all citrus fruit decays.

A. citri and G. candidum are relatively tolerant of fungicides which have been used for postharvest treatment of citrus fruits. The most successful approach to the control of Alternaria stem end rot has been through the use of synthetic growth regulators to retard the senescence of the fruit button after harvest. Sour rot can be reduced somewhat by sanitation to prevent spread in the packing house and by eliminating fully ripe fruit from long distance shipments.

REQUIREMENTS AND PROPERTIES OF POSTHARVEST FUNGICIDES

The principle requirements of a fungicide intended for postharvest application are: 1) effectiveness against the target disease at an economical rate of application; 2) no adverse effect of the treatment upon fruit quality; 3) no deleterious effect upon humans or domestic animals that consume the fresh fruit or its products. These requirements are not, of course, unique to postharvest fungicides, but they do have some important ramifications in this field. Fresh fruit are affected adversely by a postharvest fungicide treatment when 1) the peel of the fruit is visibly damaged; 2) the rate of ripening is increased or decreased; 3) the characteristic aroma or flavor of the fruit is altered; 4) the residue of the fungicide on the fruit is detectable by sight, odor, or feel. These undesired side effects might be inherent in the application of a specific fungicide but some of these problems can be overcome by formulation or application techniques. It should be emphasized that a formulation developed for application to a growing crop in the field is not likely to be suitable for postharvest treatment of citrus fruits. For example, substantial quantities of insoluble fillers in the formulation are likely to cause problems in application as well as give rise to visible residues on the surface of treated fruits. In fact, water solubility of the active ingredient is highly desirable for most postharvest applications.

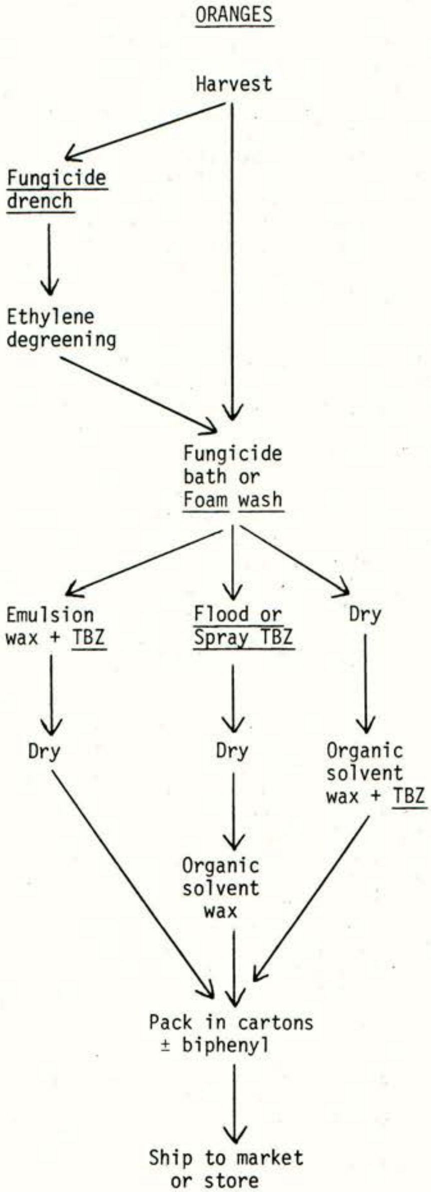
Fungicide treatments must be applied to the fruit within one or two days after harvest since it is this event which initiates the processes of both host and pathogen which culminate in decay. In fact, it may be advantageous to apply the fungicide to the fruit before harvest if a delay in treatment after harvest is unavoidable in commercial practice (Brown and Albrigo, 1971). Postharvest fungicides may be applied in a manner which provides a more or less uniform deposit over the surface of the fruit (eg., biphenyl or thiabendazole) or the fungicide may be precipitated or bound in some fashion in wounds in the peel of the fruit where mold infection is likely to be initiated. Sodium o-phenylphenate and 2-aminobutane are examples of postharvest fungicides which are selectively retained at injury sites after the bulk of the fungicide has been removed by rinsing the fruit with water after treatment (Eckert, 1968; Eckert et al, 1969a).

POSTHARVEST FUNGICIDES FOR CITRUS FRUITS

The standard procedure for at least 30 years for preparing citrus fruits for market has been; 1) to soak the fruit in a solution which both cleaned and reduced fungus infection, 2) coat the fruit with a wax to improve appearance and prevent water loss, and finally 3) to pack the fruit in boxes with papers impregnated with biphenyl to fumigate the fruit to control mold development during shipment and storage (Eckert, 1968). Prior to 1950 all exporters of citrus fruits wrapped individual fruits in tissue papers impregnated with biphenyl and packed the fruit in wood boxes. This method of shipment is rapidly being displaced by the smaller fiberboard container of fruit without individual wraps. Sheets of paper impregnated with biphenyl are placed at the top and bottom of each container. The biphenyl treatment has encountered problems of consumer acceptance since its introduction in 1936. Most of the problem can be attributed to the temporary "chemical" odor of the fruit immediately after they are removed from the shipping containers or their wrappers. A sustained effort has been made over the past 20 years to find a more acceptable method for controlling decay and soilage of citrus fruits after harvest.

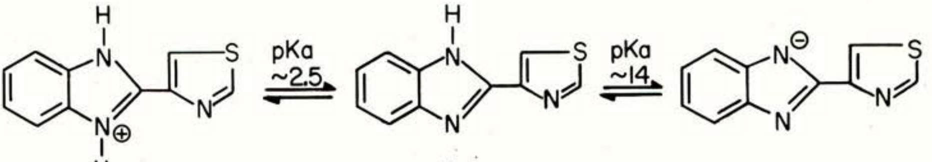
Several important inovations have been made in recent years in the handling of citrus fruits after harvest, both from the standpoint of efficiency and of decay control during marketing. A simplified flow diagram of the handling of oranges and lemons after harvest is shown in Fig. 1. Recent inovations in the process are underlined in the diagram. For several decades oranges have been soaked and

Fig. 1. Postharvest handling of California citrus fruits



brushed in a warm (40-48°C) solution of soap and a fungicide such as borax, sodium carbonate or sodium o-phenylphenate. This treatment has been effective for cleaning fruit, preventing green and blue mold, and for eradicating incipient infections of Phytophthora citrophthora. Major factors underlying the effectiveness of this treatment are heat and 2-4 minutes exposure to the fungicide solution. The residual effect of the treatment is minimal because the fruit are rinsed with fresh water immediately after treatment. However, some of the fungicide may remain in wounds on the surface of the fruit to prevent future infection of these sites. Relatively inexpensive fungicides are required for the bath treatment because the one to several thousand gallons of solution involved must be discarded periodically because of the accumulation of soil, plant debris, and microorganisms. Furthermore, the alkalinity of the sodium o-phenylphenate solution must be controlled within a fraction of a pH unit and neglect of this factor has resulted in injury of many fruits (Eckert et al, 1969a). Finally, floating the fruit through the bath is mechanically the least efficient stage of transporting fruit through the packing house. The foam washer was introduced in the mid 1960's as a more mechanically efficient means of cleaning fruit. The fruit are transported by roll conveyer through a curtain of foam of the treating solution, typically containing 1-2% sodium-o-phenylphenate pH 12, followed by passage of the fruit over a bed of rotating brushes. Finally, the fruit are rinsed with a spray of fresh water. The entire operation requires only 15 to 20 seconds for washing the fruit compared to 2-4 minutes consumed in the bath method. Continuous control of pH is not required since the foam solution is not recycled. The foam washer is less effective, however, in both cleaning fruit and in preventing fungus infection because the fruit are in contact with the cool fungicide solution for such a short time.

In 1966 a report from the University of Milan revealed that thiabendazole (I), was highly effective for the control of green mold on oranges (Crivelli, 1966). Other laboratories subsequently confirmed that a 1000 ppm suspension of TBZ in water gave excellent control of green and blue mold and stem end rots incited by Diplodia and Phomopsis (Brown et al, 1967; Eckert et al, 1969a). Sour rot and Alternaria rot were not controlled as would be predicted by the tolerance of the causal fungi in vitro. Thiabendazole is soluble to the extent of about 25 ppm in pure water, but its solubility is greatly increased below pH 3 and above pH 12, at which pH values it exists in its cationic and anionic forms, respectively. The solubility of TBZ is increased also by complexing it with lactic acid, whereas metal coordination compounds of thiabendazole appear to possess approximately the same solubility in water as the pure compound (Kowala et al. 1971).



I

Soon after the first report of the effectiveness of thiabendazole it became apparent that, despite the low dosages required for treatment of citrus fruit, the relatively high unit cost of the compound would dictate that it be utilized in a highly efficient manner. The most feasible manner of accomplishing this goal would be to deposit the exact dose required on the surface of the fruit and to maintain the residue intact for the market life of the fruit. The fruit could not be rinsed after treatment with thiabendazole because its action is fungistatic and removal of the residue would be very detrimental to the efficiency of the treatment (Gutter, 1970).

Four methods of applying thiabendazole to citrus fruits have been evaluated on a practical scale (Eckert et al, 1969b; Smoot & Melvin, 1971). 1) The fruit are floated through a bath of a suspension of thiabendazole or the suspension is flooded over the fruit on a conveyer. 2) The fruit on a conveyer are sprayed with the minimum volume of a suspension of thiabendazole required to cover the fruit. 3) Thiabendazole is suspended in a water-emulsion wax which is applied to fruit by spray and brushes. 4) The thiabendazole is dissolved in a solution of a hydrocarbon-soluble "wax" which is then misted on the fruit. All four methods of application reduce green mold decay but differ in their adaptability to commercial operations. The flood and bath application methods require fairly large volumes of suspension which must be recirculated for a number of days because of the cost of thiabendazole. The suspension must be agitated continuously and the system designed to prevent entrapment of solid thiabendazole at any point. Furthermore, the suspension should be analyzed periodically in order to adjust the concentration of thiabendazole to the desired level. The application of a low-volume spray to fruit solves the problem of dilution of the suspension, but the fruit must be fairly dry when sprayed to prevent run off of thiabendazole. However, the thiabendazole deposit may be less uniform than in the case of the flood application.

Following both the flood and the spray operations, the fruit must be dried, without brushing, and coated with a solvent-type "wax". A water-emulsion wax is not suitable because most of the thiabendazole would be removed during this operation. The application of thiabendazole in true solution in a solvent wax formulation is an efficient treatment but the quantity of fungicide that can be deposited on the fruit is limited by the solubility of thiabendazole in the hydrocarbon solvents (ca. 3500 ppm) and the efficiency of transfer to the fruit. Suspension of thiabendazole in a water-emulsion wax formulation has been the most widely adapted method for commercial application because it requires few modifications of existing equipment or procedures. The application of relatively high dosages is possible by this method, and the wax appears to aid in binding thiabendazole to the fruit. The formulation is not recycled, eliminating some difficulties inherent in the flood or bath type applications (Smoot & Melvin, 1971).

THIABENDAZOLE AS A SUBSTITUTE FOR BIPHENYL

Since biphenyl functions as a fumigation treatment it is not surprising that the search for its successor was concentrated on fungicides which were sufficiently volatile that their vapor, at ambient temperature, was inhibitory to P. digitatum. In retrospect, it could have been predicted that most of these compounds would present odor problems as severe as biphenyl. The intense activity of thiabendazole against P. digitatum and the low mammalian toxicity of the compound suggested the feasibility of depositing a quantity of thiabendazole on the surface of the fruit which would inhibit fungus growth and sporulation on decaying fruit. This would prevent contact soiling of adjacent sound fruits in the same shipping container. Several aspects of this treatment have been investigated in our laboratory for the past few years. 1) What is the minimum deposit of TBZ (mg/kg and $\mu g/cm^2$) required to inhibit fungus sporulation and would this dosage provide equal protection for fruits of different varieties and sizes? 2) What was the most effective and efficient manner to apply the required deposit? 3) Would the required deposit of TBZ be detectible on the fruit by any of the senses?

Accurately-sized citrus fruits were treated with formulations in a manner which resulted in a uniform and predictable deposit of thiabendazole on the surface of each fruit. Ten per cent of the treated fruit in each container were inoculated with a suspension of P. digitatum spores by means of a hypodermic syringe and the fruit were stored under conditions which simulated an overseas shipment of citrus fruit. The degree of fungus sporulation on each inoculated fruit was evaluated at the end of the test and correlated with the deposit on individual fruit taken from the same shipping container. Table 1 summarizes the results of treating four comparable sizes of oranges and lemons with 0.3% and 0.5% thiabendazole suspended in a shellac-based emulsion wax. The 0.3% treatment resulted in an average residue of about 3 mg thiabendazole/kg fresh fruit, irrespective of the fruit variety or

Table 1

Effect of residues of thiabendazole on the sporulation of Penicillium digitatum on citrus fruits

% TBZ in wax	Fruit Variety	Size	Diam. (cm)	Residue[a/] mg/kg	$\mu g/cm^2$	Fungus sporulation[b/]
0.3	Orange	180	5.6	3.24 ± 1.25	3.33	2.20 ± 0.69
		138	6.1	3.45 ± 1.45	3.68	2.83 ± 0.22
		113	6.6	2.75 ± 0.78	3.06	3.56 ± 0.42
		88	7.2	2.59 ± 1.03	3.29	3.27 ± 0.21
	Lemon	200	5.1	3.45 ± 1.35	3.57	3.00 ± 0.93
		140	5.6	3.06 ± 1.41	3.03	2.55 ± 1.21
		115	6.1	3.65 ± 0.52	3.67	2.50 ± 0.22
		95	6.5	3.63 ± 0.22	4.22	2.97 ± 0.25
0.5	Orange	180	5.6	6.22 ± 2.10	6.29	1.02 ± 0.27
		138	6.1	6.99 ± 0.96	7.28	1.59 ± 0.44
		113	6.6	5.75 ± 2.04	6.57	1.11 ± 0.21
		88	7.2	6.93 ± 2.46	8.55	1.30 ± 0.10
	Lemon	200	5.1	9.15 ± 2.53	8.12	0.44 ± 0.17
		140	5.6	6.95 ± 2.01	6.75	0.94 ± 0.37
		115	6.1	7.58 ± 1.64	7.76	1.48 ± 0.35
		95	6.5	6.98 ± 1.24	7.79	1.10 ± 0.30

a/ Mean and standard deviation of 6 analyses.

b/ Scale range is from 0-5, where 5 indicates heavy sporulation. Mean and standard deviation of approx. 10 fruit in each of 3 containers. Control and biphenyl treated fruit gave values of 4.5-5.0 and 4.0-5.0, respectively.

size. Small fruit did not have a significantly higher residue than large fruit as might be predicted from the greater surface/weight ratio of the small fruit. A deposit of less than 4 mg thiabendazole/kg did not adequately control sporulation of P. digitatum on the surface of the fruit. The 0.5% treatment resulted in deposits of around 6-7 mg/kg on oranges and 7-9 mg/kg on lemons. These levels of thiabendazole controlled fungus sporulation better than the biphenyl treatment and only in the case of size 200 lemons was there an indication that the residue was higher on the smallest size fruit. No difference was detected in the effectiveness of thiabendazole on lemons and oranges. These observations that 5 to 7 mg thiabendazole/kg fruit is required for the desired level of control of fungus sporulation have been repeated in several tests with oranges, lemons and grapefruit. These deposits of thiabendazole on the surface of the fruit are not detectible by odor or vision when technical thiabendazole (no filler) is incorporated in the wax formulation. However, the surface of the fruit may feel slightly rough to the touch when certain wax formulations are used. Preliminary tests have indicated that thiabendazole residues deposited from a water suspension may be somewhat more effective than residues resulting from a wax application.

PROBLEMS IN THE USE OF THIABENDAZOLE ON CITRUS FRUITS

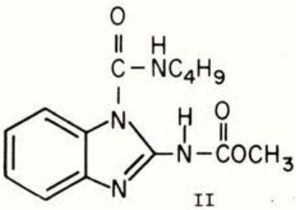
The application to fruit of a formulation containing 0.1% or less thiabendazole does not present any serious problem in commercial use as witnessed by the dozens of packing houses throughout the world which now apply such treatments to a substantial volume of their fruit. The application of wax emulsions containing 0.5% thiabendazole does create some difficulties, however. Firstly, the relatively fine nozzles used to apply an emulsion wax may become plugged by the high concentration of thiabendazole solids in the formulation. This problem has been greatly reduced by the use of technical thiabendazole (no diluents) of small particle size. Another major problem in the practical application of high concentrations of thiabendazole in wax emulsions is the difficulty of obtaining the same deposit on each fruit. The amount of wax applied to each fruit by the spray-brush type applicator can vary considerably because of different degrees of loading (either fruit or wax) on the bed of brushes delivering the wax to the fruit. The minimum thiabendazole deposit required for the desired level of control of sporulation of *P. digitatum* appears to be around 5-6 mg/kg fruit. Provisional tolerances for 6 ppm TBZ have been established in the US and most European countries. It should be stressed, however, that an average residue of 6 mg/kg on all fruit in a shipping container might not provide the desired degree of sporulation control. This value must fairly represent the residue on *each* fruit since it is about the minimum dosage which provides an acceptable level of sporulation control.

The substitution of thiabendazole for biphenyl on California lemons presents an additional problem. A substantial portion of the lemon crop is grown in cool moist coastal regions where drying fruit is more difficult than in interior climates. For this reason most lemons are treated with a solvent-type wax which dries more readily than a water emulsion wax. No one has yet succeeded in incorporating a sufficiently high concentration of thiabendazole in a solvent wax to provide control of sporulation on waxed fruit. Serious consideration is now being given to the development of more efficient dryers for lemons in coastal climates in order to utilize water-emulsion waxes containing levels of thiabendazole capable of inhibiting sporulation of *P. digitatum*.

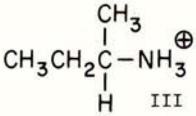
Neither sour rot nor Alternaria stem end rot which are prevalent on lemons are controlled by treatment with thiabendazole because the causal fungi are tolerant of this fungicide. Alternaria rot is reasonably well controlled by the application of 2,4-D to the fruit soon after harvest in order to maintain the physiological vitality of the fruit button. *Geotrichum* is tolerant of most fungicides and therefore the control of sour rot lies in sanitation, avoiding over-ripe fruit, and by minimizing delays in handling of fruit especially during warm weather. These resistant species of fungi should not seriously detract from the practical value of the thiabendazole treatment, if fruit exporters realize that these diseases must be controlled by other means. Strains of *P. digitatum* and *P. italicum* tolerant of thiabendazole are potentially a more serious problem. Naturally-occurring strains of *P. italicum* (blue mold) which are resistant to thiabendazole are frequently encountered. Strains of *P. digitatum* (green mold) tolerant of thiabendazole have been isolated with less frequency. The same strains appear to be tolerant of benomyl also. The possibility of encouraging the proliferation of resistant strains is a potential hazard of applying relatively low dosages of thiabendazole to fruit on several occasions. This threat would appear greatest for *P. digitatum* and *P. italicum* which sporulate profusely on lemons and oranges within 6 days after inoculation. This risk is not acceptable if we conclude that the most valuable use of thiabendazole is as a substitute for biphenyl. Examples of potentially dangerous situations with regard to the development of resistant strains are the use of preharvest sprays of thiabendazole (or benomyl) in the orchard and the drenching of fruit with low concentrations of thiabendazole immediately after harvest. The adoption of a high dosage thiabendazole treatment to substitute for biphenyl on lemons would necessitate the discontinuation of the low dosage thiabendazole treatment now applied to lemons before storage. Past experience with biphenyl resistant molds in the lemon industry has taught a valuable lesson in this connection (Harding, 1964).

OTHER NEW FUNGICIDE TREATMENTS

Benomyl [methyl N-(butylcarbamoyl)benzimidazole-2-carbamate, II] possesses physical properties and an antifungal spectrum similar to thiabendazole and has been evaluated on a small scale for the same type of postharvest applications. Although experiments to date have been limited because no legal tolerance has been established for benomyl on citrus fruits, published reports indicate that this fungicide is effective at a lower concentration than thiabendazole (Gutter, 1970; McCornack and Brown, 1970). The N-(butylcarbamoyl) group is cleaved from benomyl in an aqueous environment to give methyl benzimidazole-2-carbamate (MBC) which has essentially the same biological properties as benomyl (Clemmons & Sisler, 1969). Although the kinetics of this reaction under various conditions have not



II



III

been published, it may be assumed that a substantial fraction of the benomyl deposited on citrus fruits would be converted to MBC after several weeks storage in a humid environment. A recent report describing the cyclization of benomyl under alkaline conditions to give a triazino-benzimidazole (Ogawa et al, 1971) has added some complications to the application of benomyl in water emulsion wax formulations which range from pH 8 to 10.

Fungicides which are insoluble in water and must, therefore, be applied as heterogenous systems are not ideally suited for drenching citrus fruits in picking boxes prior to degreening or storage. The re-circulated suspensions of the fungicides become heavily contaminated with soil from the fruit and adhering to the boxes. The soil cannot be removed readily by filtration or trapping because of the particulate nature of the fungicides, and the suspensions become highly unsanitary within a short period of time. Furthermore, soil appears to bind both thiabendazole and benomyl. 2-Aminobutane (sec-butylamine, III) has shown considerable promise for this application since it is very soluble in water. The establishment of a formal tolerance in the U.S. is now under consideration by responsible government agencies.

The successful commercial application of thiabendazole has resulted in significant improvements in the handling of citrus fruits after harvest. These can be summarized as: 1) treating fruit soon after picking to prevent infections of harvest injuries (an absolute necessity for mechanically-harvested fruits); 2) the development of a thiabendazole-wax treatment which provides excellent control of decay thereby permitting the adoption of a mechanically efficient foam washer; 3) control of sporulation on oranges by treatment of fruit with an emulsion wax containing about 0.5% thiabendazole. This latter treatment potentially offers the possiblity of eliminating the need for both sodium o-phenylphenate and biphenyl.

The practical success of thiabendazole and the promise of benomyl and 2-aminobutane should not be considered the ultimate solutions for all decay problems associated with the long distance marketing of citrus fruits. These discoveries have, however, paved the way for more economical and efficient fruit handling practices. More significantly, these developments have shown that after 30 years without substantive changes in this area, considerable improvement is yet possible in the treatment of fruit to control postharvest decay.

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PROSPECTS FOR THE USE OF BACTERICIDES FOR THE CONTROL OF BACTERIAL DISEASES

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INTRODUCTION

Since the discovery of Bordeaux mixture nearly one hundred years ago the use of chemicals against plant diseases has become so commonplace that it is difficult now to conceive the time when crops were ever produced without them. The control of fungal diseases in recent years has been revolutionised by the introduction of organic fungicides and new developments in systemic fungicides promise a degree of sophistication in control undreamt of a generation ago. No comparable developments, unfortunately, have occurred in the control of bacterial diseases. With the exception of a few of the medical antibiotics, the use of which in agriculture is by no means universally approved, the materials currently available for control are basically the same as those in use fifty years ago. While spraying and other chemical treatments will continue to play an important role in checking bacterial diseases, it is now abundantly clear that major improvements in control are unlikely without the development of new and more effective bactericides. Whether such materials will be available in the future is a matter at the moment of complete speculation. It will depend presumably on commercial judgements as to whether the economic outlets for plant bactericides are likely to justify the cost of research and development.

In this paper I shall consider the economic importance of bacterial plant diseases, discuss the general principles underlying control, and review the extensive use already made of chemicals for this purpose. Finally I shall hazard a guess at the kind of materials likely to be most effective for the control of bacterial plant diseases.

ECONOMIC IMPORTANCE OF BACTERIAL PLANT DISEASES

Over two hundred 'species' or forms of plant pathogenic bacteria have been described from more than a thousand different species of host plants. Most of the major crop plants are susceptible to a bacterial disease and some, e.g. tomato, beans, rice and pear, suffer from more than one. Comparatively few of these are of major economic importance, but those that are have proved notoriously difficult to control. Fireblight, first identified as a bacterial disease nearly one hundred years ago, is still the main factor limiting successful cultivation of the pear in the warm humid regions of the U.S.A.

Although outbreaks may sometimes reach catastrophic proportions, the localised nature and erratic appearance of many bacterial diseases makes it difficult to estimate their overall effects in the agricultural economy. A report on crop losses issued by the U.S. Department of Agriculture (1965) indicated that they are generally less important than fungal and virus diseases in the U.S.A. but there were exceptions as the following examples show. Thus wildfire (Pseudomonas tabaci) was only slightly less important on tobacco than tobacco mosaic, and fireblight (Erwinia amylovora) ranked second after scab on apple. Almost half the total losses on green peppers were due to bacterial leaf spot (Xanthomonas vesicatoria) while bacterial wilt (Corynebacterium insidiosum) accounted for about a fifth of the total losses of alfalfa. Bacterial diseases caused by P. phaseolicola, P. syringae and X. phaseoli were a significant source of loss on beans and related leguminous plants. Leaf spot of peach (X. pruni) and bacterial blight of walnut (X. juglandis) were the most important diseases of these crops.

Leclerg (1964) estimated the average annual value of crop losses from disease in the U.S.A. to be 3251 million dollars between 1951-60 inclusive. Losses due to bacterial disease were not specified but a recent survey by the American Phytopathological Society (Alcorn et al., 1971) suggests an annual figure of 50-60 million dollars. Although this is small relative to losses from other diseases, it is probably not representative of the world situation. It has been possible in the U.S.A. to minimise the effects of some bacterial diseases by transferring seed and crop production to climatic areas least favourable for the development of disease. A good example of this is the concentration of the pear industry in the cooler climates of the Pacific north western states to avoid the worst ravages of fireblight. Furthermore, most of the diseases in the U.S.A. surveys relate to temperate crops, whereas the major bacterial diseases of the world occur in the tropical and sub-tropical regions amongst rural economies least equipped to deal with them. Chief amongst these diseases is bacterial wilt caused by P. solanacearum. This is a soil-borne, vascular infecting pathogen, numbering amongst its economic hosts the banana and the various solanaceous crop plants. It was first described from the warmer southern states of the U.S.A. where its depredations towards the end of the last century resulted in social consequences for rural tobacco growers reminiscent on a smaller scale of the Irish Potato Famine. Moko disease of bananas is endemic in South America and was estimated by 1952 to have already destroyed over a million plants in Costa Rica and the neighbouring Panamanian states. P. solanacearum is widely distributed in the Americas, Asia, Africa and Australia in solanaceous crops and is currently a major problem in the cultivation of the potato in East Africa. It is impossible to estimate the total losses due to this organism, but on a world scale they must be prodigious. On the basis of reports received over a period of fifty years, Kelman (1953) suggested that they would have to be reckoned in terms of hundreds of millions of dollars.

Two other examples will illustrate the importance of bacterial diseases in tropical crops; these are bacterial blight of rice (X. oryzae) and bacterial blight of cotton (X. malvacearum). The rice disease was first reported from southern Japan at the beginning of the century and now affects between 300-500 thousand hectares representing about 10% of the total rice growing area of that country. Losses of yield may be as high as 30% with moderate infections but may exceed this in severe outbreaks (Mizukami & Wakimoto, 1969). An alarming development in recent years has been the discovery of the disease in Indonesia, India, Malaysia and other Asian countries. The symptoms are more severe than in Japan, the plants being frequently killed by systemic infections (the so-called 'Kresek' disease of Indonesia) (Goto, 1964). This difference seems to be due to the greater virulence of the strains of X. oryzae and to the greater susceptibility of the long-eared, tall-stalked 'indica' rice cultivars grown in the tropical areas (Goto, 1965). This disease now ranks as one of the most important, if not the most important, of all plant diseases in Asia.

Two other bacterial diseases of rice are worth noting. Leaf streak, caused by a form of the cereal pathogen X. transluscens, is widespread in south east Asia on indica varieties but is not found in Japan probably because the native japonica varieties are resistant. Although less important than blight, leaf streak is sometimes very destructive amongst seedling rice in nurseries. Bacterial stripe disease (P. panaci), a seedling disease of upland nurseries, has been identified in Japan and the Philippines and may be widely distributed in Asia.

Bacterial blight of cotton (X. malvacearum) is present almost everywhere this crop is grown, and its devastating attacks in the early days of the Gezira scheme in Sudan are well documented. Although improved control measures and the use of resistant cultivars have mitigated the more serious effects of the disease, yield reductions from 10-30% are said to be not uncommon in some cotton growing countries (Innes, 1970) and on severely infected plants losses of 77% have been recorded (El Nur, 1970).

CONTROL OF BACTERIAL PLANT DISEASES - GENERAL CONSIDERATIONS

Special features in the host-relations of plant pathogenic bacteria have thrown greater emphasis on some control measures than others. Compared with the fungi, the bacteria are ill-adapted as plant pathogens. They have no equivalent of the air-borne fungal spore and can enter the host only passively through wounds and natural openings. They form no special resting structures and with few exceptions are short lived in the soil (Crosse, 1967). On the other hand they have an extraordinary capacity to survive in close association with the host in all stages of its life history either as commensals or infectors. All plant pathogenic bacteria are seed borne or potentially so, and many perennate with the host in tubers, bulbs and rhizomes, cuttings and other vegetative structures. In the foliar diseases of fruit trees, bacteria survive the winter in branch or stem cankers, and the cankers may alternate with the leaf phase so that the trees are permanently and cyclically infected.

New crops may be infected from bacteria overwintering in diseased plant residue, or from bacteria brought in from remoter areas by wind, rain, insects or other agencies. By far the most common source of primary infections, however, are bacteria introduced into the crop with infected or contaminated planting material. Long range transmission of bacteria in this way has been responsible for the world-wide distribution of some bacterial diseases.

Secondary spread within the crop may result from insect transmission (e.g. fireblight) or from contaminated cutting implements (e.g. vascular diseases caused by Corynebacterium spp.). The most important agent of secondary spread, however, is rain, particularly wind-driven rain. Rain plays the decisive role in the numerous bacterial leaf-spot diseases by providing simultaneously for dispersal and for the penetration of bacteria through stomata and other natural openings. Once inside the host, bacteria increase logarithmically (Ercolani & Crosse, 1966) and vast reservoirs of fresh inoculum are available for further dispersal within a few days. In prolonged wet weather, therefore, bacterial diseases very soon reach epidemic proportion as the name 'wildfire' for the tobacco leaf disease (P. tabaci) testifies.

Because of the difficulty of containing them under conditions favouring secondary spread, control measures against bacterial diseases of annual crops have tended to emphasise the exclusion of primary infection sources by use of bacteria-free planting material. In seed-borne diseases this can be partly achieved by chemical treatment but a better method in the U.S.A. has been to concentrate seed production in the arid areas of California and other western states (Grogan & Kimble, 1967). Field certification schemes and seed-indexing are also used to provide healthy seed samples. A combination of these measures reduced substantially the incidence of halo blight and other bacterial diseases of beans in Idaho in recent years (Butcher et al., 1969). Seed-indexing techniques need to be sensitive since only a trace of primary infection in a crop is sufficient to generate an epidemic when conditions favour secondary spread (Tarr, 1961; Cox, 1966). Methods described for detecting bacteria in seed samples include disease observations on test seedlings (Shackleton, 1962), multiplication of specific bacteriophage in seed macerates (Katznelson & Sutton, 1951), direct isolation and enumeration of bacteria from seed samples (Taylor, 1970) and the examination of seed under U/V light (Wharton, 1967). Similar measures have been successful against bacterial diseases of vegetatively propagated plants. Field certification schemes and seed production in disease-free areas has helped considerably in the control of potato ring rot (C. sepedonicum) in India and North America, and a culture-indexing technique for detecting E. chrysanthemi and P. caryophylli in cuttings has been largely instrumental in maintaining the health of carnation stocks in Denmark (Hellmers, 1958).

The use of healthy planting material has been less important in the control of the bacterial diseases of fruit trees and other perennial crops. Although it would be technically feasible to establish disease-free orchards and plantations, the probability of them remaining so in areas of endemic disease is not very great. Control measures against these diseases have emphasised the elimination of over-wintering cankers to break the annual disease cycle, and spraying to prevent secondary infection of the foliage and blossoms. The health of planting stock is only of great importance in disease-free areas. In the U.S.A. for example, there is legislation to prevent the re-introduction of citrus canker (X. citri) on diseased material following its successful eradication earlier in the century (Sinclair, 1968).

Resistant cultivars may be the best long-term solution for some diseases, and for lucerne wilt (C. insidiosum), which is so rapidly and efficiently spread by mowing machines, they may be the only solution. Resistant cultivars are already used for the control of leaf scald and gummosis of sugar cane (X. vasculorum and X. albilineans), wilt of tobacco (P. solanacearum), cotton blight (X. malvacearum) and a few other diseases. Whether they will provide the answer to all diseases is problematical. Attempts to breed fireblight resistance into pear during the last fifty years have not been particularly successful because of the lack of resistance genes in the host. A similar problem may arise in the breeding of rice varieties resistant to X. oryzae. Of over 8,700 rice cultivars recently tested in the Philippines for example, none was immune to X. oryzae and most were susceptible (Ou et al., 1971a). The extent to which the resistance of new cultivars will be eventually countered by variations in the pathogens is also largely unknown. The existence of variant races of X. malvacearum differing in pathogenicity to certain cotton cultivars has been reported from the U.S.A. (Schnathorst et al., 1960; Miller, 1968) and a resistant commercial cultivar of sesame in that country has succumbed to a new race of P. sesami (Thomas et al., 1962). According to Ou et al. (1971a, 1971b) resistant rice varieties have been developed and used but they have eventually become susceptible to new virulent forms of X. oryzae.

CHEMICAL CONTROL OF BACTERIAL PLANT DISEASES

Chemicals are used for 1) treatment of seed and other planting material, 2) crop spraying, 3) sterilisation of pruning and cutting implements, and 4) soil fumigation. Only seed treatments and crop spraying will be discussed in detail here. The sterilisation of pruning implements is very important in some diseases, but a wide range of disinfectants is available for this purpose, and the choice of a suitable material is usually only a matter of empirical field tests (Buddenhagen & Sequeira, 1958). Soil fumigation has been mainly tried for the control of the crown gall organism, Agrobacterium tumefaciens, but with little or no success (Deep et al., 1968; Schroth et al., 1971).

Seed treatments

Although far from being the universal panacea, seed treatments are important for the control of some diseases, when used in conjunction with other phytosanitary measures. They are probably most effective when a pathogen is mostly present as a surface contaminant. Chemicals tested include copper, mercury and quaternary ammonium compounds, sodium hypochlorite, malachite green, phenacridane chloride (Smale et al., 1961), acids, and the antibiotics.

In the U.S.A., cotton seed is freed of X. malvacearum by delinting with concentrated sulphuric acid, but this method is considered too expensive and hazardous for use in under-developed countries (Tarr, 1959). Dusting with Abavit (mercury chloride: iodide, 3:1) is a standard seed treatment in the Sudan, although recent work suggests that wet treatment with organo-mercurials may be equally effective (El Nur, 1970). Mercurial compounds are the most frequently recommended for the control of seed-borne bacterial diseases although recommendations do not always appear confirmed by field evidence. Organo-mercurials reduced seed-borne transmission of C. betae in field trials, but soaking seed in 400 p.p.m. streptomycin solution for 18 hours was found to be a better treatment (Keyworth & Howell, 1961). Soaking seed in 250 p.p.m. streptomycin for 30 minutes gave good control of bacterial leaf spot of sesame caused by P. sesami (Thomas, 1959), but treatment of bean seed with 10,000 p.p.m. had no effect on the subsequent development of halo blight in field crops (Hagedorn, 1967). Klisiewicz & Pound (1960) tried eradicating X. campestris from brassica seed with streptomycin and other antibiotics, but the concentrations of the antibiotics required to obtain adequate penetration were phytotoxic. Mercuric chloride has been advocated for the control of seed-borne X. campestris but on garden stocks Wilson (1942) obtained better results by immersing seed in 10% bleaching powder for four hours. C. michiganense can be eliminated from tomato seed by fermenting the fruit pulp for four days at 20°C and then treating the extracted seed in 0.8% acetic acid for 24 hours (Blood, 1942). Other chemical treatments recommended for the sterilisation of tomato seed include mercuric chloride organo-mercurials, hydrochloric acid and malachite green (Stapp, 1961).

Hot-water treatment of seed has been successful in some diseases but may impair germination unless carefully controlled. Treatment at 50°C for 25 minutes is a standard procedure for ridding crucifer seed of X. campestris and Sinha & Nene (1967) found a similar treatment more effective against X. oryzae than soaking rice seed in organo-mercurial compounds or antibiotics.

Chemical treatment of vegetative planting material has been attempted from time to time, but bacteria are usually systemic in vegetative structures and eradicating these without damaging the plant is at best extremely difficult. Streptomycin looked a promising material at one stage because of its systemic properties but MacFadden (1958) found the range of concentrations required to control E. chrysanthemi in carnation cuttings without injury too critical for routine use. Logsdon

(1961) reduced the incidence of ring rot in potato by treating seed with streptomycin, but the rates of application required for effective control were uneconomic and phytotoxic.

Field sprays

Field spraying has been used for the control of both annual and perennial crop diseases. Tri-basic copper sulphate sprays are a standard measure against wildfire of tobacco in the U.S.A. although experiments in the 1950s reported better control with streptomycin (Haggestad et al., 1956; Shaw et al., 1957). Streptomycin was also found superior to copper bactericides in an experiment in Rhodesia, but was subsequently ineffective in controlling late developing infections due to the emergence of streptomycin-resistant strains of P. tabaci (Cole, 1960).

Successful control of halo blight by field spraying has been reported from several bean-growing areas. In New Zealand the incidence of the disease was substantially reduced by four sprays of Bordeaux mixture (Reid & Taylor, 1945). This material was more effective than streptomycin against severe outbreaks in Montana, resulting in yields almost double those of any other spray treatment (Afansiev & Sharp, 1958). The superiority of copper over streptomycin sprays was also noted in Colorado (Dickens & Oshima, 1968). In Wisconsin and Michigan, where overhead irrigation and scarcity of disease-free seed have aggravated the problems in recent years, good control of halo blight, common blight (X. phaseoli) and brown spot (P. syringae) of bean crops has been reported with sprays of tri-basic copper sulphate and basic copper hydroxide; the best treatments increased yields by over 40% (Hagedorn et al., 1969; Saettler & Potter, 1967).

Bacterial leaf spot of field peppers and tomatoes caused by X. vesicatoria is an important problem in parts of the U.S.A., causing annual losses on tomatoes in Florida estimated at 10% (Cox, 1966). Since only a trace of seed-borne infection can result in severe epidemics, spraying against this disease is essential. Bordeaux mixture was early recommended for control (Weber, 1940) and streptomycin was also found to be effective, but best control was obtained with a mixture of streptomycin and tri-basic copper sulphate (Cox & Hayslip, 1957). Stall (1959) also observed better control with the mixed spray but considered copper sprays were adequate and more economical under conditions of mild infection. Streptomycin was subsequently observed to perform erratically, and this was eventually traced to the occurrence of field strains of X. vesicatoria resistant to the antibiotic (Thayer & Stall, 1961; Stall & Thayer, 1962). Streptomycin was not included in later trials reported from Delaware (Kim et al., 1967; Morton et al., 1968). The most effective materials in these trials were tri-basic copper sulphate and fixed copper hydroxide. Under conditions of severe infections these almost doubled the tonnage of marketable fruit.

Less success has attended attempts to control rice blight by spraying. Among spray materials tested are copper and mercury compounds, antibiotics, nickel-dimethyl dithiocarbamate and dithianon. None of these has so far proved sufficiently effective for practical use (Mizukami & Wakimoto, 1969). A search for alternative bactericides is now in progress and a new material TF128 has been recently reported from Japan to have reduced the losses of unhulled rice from 13.0 to 5.6% when added as a dust to irrigation water (Watanabe et al., 1970).

Bacterial spot of stone-fruits (X. pruni) is a major problem in many fruit growing areas of the world, especially on peach, where severe attacks disfigure the fruit and defoliate the trees. In 1929, spring sprays of zinc sulphate-lime were introduced for control of the disease in the U.S.A. and these had at the time the added advantage of reducing lead arsenate damage. Bordeaux mixture, however, was recommended by Morwood (1947) for control in Australia. Streptomycin was field-tested against the disease in Michigan during 1956 and reported to give better control of leaf spot than zinc sulphate-lime (Klos, 1958), but in Japan it was found to be inferior to zinc-sulphate lime against severe outbreaks (Kitavima, 1959). An interesting development at about this time was the use of dodine against the disease in New Jersey (Daines, 1960, 1962). This is perhaps the only example of the control of a bacterial disease with an organic fungicide. Used at a rate of 1 lb/100 gallons, dodine resulted in significantly less disease than a standard zinc sulphate-lime schedule, but it also damaged the fruit. Damage was avoided by using dodine at lower rates, or by including captan in the sprays. Terramycin is the latest material to be evaluated for control of peach leaf spot and under experimental conditions in the U.S.A. has proved generally superior to any other material (Powell, 1967; Daines, 1967; Keil & Carroll, 1967). When used commercially, however, it failed to control the exceptionally severe outbreaks in New Jersey during the wet spring and summer of 1968 (Daines, 1969). Under these conditions Keil & Weaver (1970) recommended shorter intervals between sprays.

Economic control of walnut bateriosis (X. juglandis) is essential for profitable walnut culture. Pierce (1898) in California was the first to control the disease with Bordeaux mixture sprays in spring, and his results have since been confirmed in many other areas. In a sustained search over 15 years for less phytotoxic materials, Miller & Bollen (1946) examined 30 different copper, mercury sulphur and organic compounds formulated with a variety of wetting and adhesive agents. They finally concluded that Bordeaux mixture consistently gave best control, but recommended copper-lime-sulphur-oil dusts as an alternative against less severe outbreaks. Miller (1959) later reported good control with a streptomycin-copper dust but this material does not appear to have been adopted commercially, presumably on economic grounds.

Many materials have been evaluated in culture and glasshouse screens for control of bacterial canker and leaf spot diseases of stone-fruits caused by P. syringae and P. morsprunorum (Montgomery & Shaw, 1942; Dye & Dye, 1954) but none has so far been shown to be better than Bordeaux mixture for field control. In England spring sprays were recommended against leaf spot and autumn sprays for the control of canker infections on cherry (Montgomery & Moore, 1945). The use of spring sprays is no longer advocated, however, because of spray injury, and because there is little evidence that control of leaf spot is of much advantage in preventing the economically important canker infections in the autumn. Streptomycin gave excellent control of leaf spot, mainly because it could be applied at the critical times when the use of Bordeaux mixture was precluded by spray injury. It was less effective than Bordeaux mixture, however, as an autumn spray against cankers (Crosse & Bennett, 1957; Crosse, 1962).

Perhaps the greatest success story in the chemical control of a bacterial disease is the use of streptomycin sprays to prevent fireblight infections of apple and pear blossoms (Goodman, 1953; Winter & Young, 1953). Originally only low-strength copper formulations were available for this purpose and these are still recommended in California as an alternative to streptomycin for controlling pear blight. In the severe blight areas of the middle-west streptomycin is much more effective and is now the standard recommendation. Sprays are applied at 4-5 day intervals during the bloom periods at concentrations varying from 50-100 p.p.m.

The use of streptomycin as a routine spray has transformed the fireblight situation in the apple growing areas of the middle-west of the U.S.A.

CHEMICAL CONTROL - FUTURE PROSPECTS

Chemical treatments are essential for the control of many of the bacterial leaf-spot and blight diseases, and are likely to remain so in the foreseeable future. Of the many materials tested against these diseases, none has proved more generally useful than mercuric compounds for seed treatment and the copper bactericides and streptomycin for field sprays. Better use of these materials may be possible from a fuller understanding of the epidemiology of bacterial diseases, but major improvements in control are unlikely without more effective bactericides. New bactericides are the only prospect we have for effective chemical control of the systemic and vascular diseases. During the last fifty years only one new material of major significance has emerged for use against bacterial diseases, namely streptomycin. The history of streptomycin is worth examining briefly because it illustrates the potential and the problems which could result from the introduction of new bactericides. It first appeared on the agricultural scene in the early 1950s and there was soon a stream of papers reporting its successful use for the control of a variety of bacterial plant diseases. The hopes that it might prove to be the universal panacea were never, however, fully realised. The reasons were mainly economic, but residue problems, phytotoxicity and the development of bacterial resistance were contributory factors. Two examples of resistance, in wildfire of tobacco (Cole, 1960) and leaf spot of tomato (Stall & Thayer, 1962) have already been noted. Resistance to streptomycin was also reported in *P. syringae* isolates from peach trees (Dye, 1958) and the antibiotic was described as of no further use for the field control of celery blight (*P. apii*) for similar reasons (Thayer, 1963). Surprisingly no resistance has yet been reported in field strains of *E. amylovora* although this organism has probably been exposed to more streptomycin in the field during the last 15 years than all other bacterial pathogens combined. It is possible that the aquisition of resistance by *E. amylovora* is accompanied by loss of virulence or of other characters determining its epidemiological competence in the field. There is no evidence of this, however, from inoculation studies with streptomycin-resistant strains of the organism that have been selected *in vitro*.

Drug-resistance is especially important in bacteria since it can be transmitted from one cell to another by extracellular DNA (transformation), by bacteriophage (transduction), and by direct contact between bacteria (conjugation). In some Gram negative bacteria resistance has been shown to be controlled by extrachromosal DNA, the episomes, and to be transferred with episomal replicates from resistant to sensitive bacteria during conjugation. This mechanism is responsible for the widespread distribution of drug resistance in *E. coli* and related pathogens of man and animals. If episomal transfer of resistance occurred commonly amongst plant pathogens it might rapidly limit the value of any new organic plant bactericide.

Unlike many other inhibitors of protein synthesis, streptomycin is bactericidal; this does not fully explain its effectiveness against bacterial diseases however. On cherry trees, for example, it was markedly inferior to Bordeaux mixture as a bactericide but nevertheless gave equivalent control of bacterial canker due to its ability to penetrate and inhibit growth of the bacteria in tissues (Crosse, 1962). The systemic properties of the antibiotic were early recognised and many attempts were made to improve penetration by incorporating in sprays, humectants, cuticle solvents, and surfactants (Goodman, 1962).

Although streptomycin can be translocated to aerial structures from plant roots immersed in a solution of the antibiotic, it does not appear to move readily from leaves after foliar applications (Dye, 1956; Gray, 1958; Crosse and Garrett, 1958). It is probably the persistence of the antibiotic in leaf tissues, with its resulting curative activity, which accounts for its good control of leaf and blight diseases. For better control of these diseases we need new materials with similar properties, but less costly and phytotoxic than streptomycin, and preferably with higher in vivo antibacterial activity. Materials with high bactericidal properties on the plant surface but less damaging than copper materials might find a useful role in the control of foliar diseases, but would offer less flexibility than locally systemic compounds. There is very little doubt that the greatest need at present is for fully systemic compounds capable of controlling the important systemic and vascular diseases occurring in tropical regions.

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BEHAVIOUR AND PERSPECTIVES OF CHEMICAL SOIL FUMIGATION

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SUMMARY

The purpose of this lecture was to discuss the possibilities and difficulties in the field of soil disinfestation. By the dynamics of a soil disinfestation we consider the expert use and control of the biotical, and the abiotical elements in the soil also as a function of the physical and chemical properties of both soil and fumigant.

Infinite possibilities are at our disposal for a more or less selective precultural, but phytiatric treatment of the soil for several crops. An unexpert soil disinfestation can however be harmful for the biological and even for human life.

INTRODUCTION

The purpose of chemical soil fumigation is the complete elimination from the soil of all the pathogens which might infect the plant. In practice soil fumigation has many defects, the most important source of error being the lack of attention paid to the dynamics of soil fumigation as a whole.

In intensive agriculture and horticulture, soil fumigation is known to control weeds, insects and nematodes but in recent years attempts have been made to control diseases caused by fungi and viruses. For successful fumigation, it may be necessary to know more about the intra- and inter-relationships of groups of pathogens as well as their relationships with saprophytic organisms. Sterilisation may affect the antibiotic effect of actinomycetes, may neutralise some soil-borne viruses or may liberate mineral nitrogen, particularly after steaming.

Up to now, most attention has been paid to physical methods such as steaming and to the use of chemical fumigants in high doses. Little attention has been paid to compounds of limited activity such as dichloropropene (DCP) or of a selective action such as methyl bromide (MB) or to the biological balance in the soil, even of a non-pathogenic nature, which is disturbed and made difficult of recovery.

SOIL FUMIGATION

Improvements in methods of applying fumigants have not been very spectacular. The upper layers of the soil are often poorly treated due to rapid diffusion of the fumigant through these upper layers, giving poor control of pathogens and weeds in surface areas. This effect can be corrected in intensive horticulture by covering the soil with plastic sheets for fumigants such as dichloropropene (DCP), chloropicrin (CP) or methyl-isothiocyanate (MIT). Good results under field conditions were obtained by turning over the soil a few days after treatment, also giving less phytotoxicity. It is, however, worth stressing that fumigation is never satisfactory in heavy soils where low porosity and high water content are unfavourable to fumigation. Even with methyl bromide there have been problems in Western Europe; sheeting down of the plastic only 10 minutes after application may lead to a loss of more than 5% of the dose applied.

In consequence the vapour concentration in the glasshouse space becomes excessive. Inefficient sheeting after injection of methyl bromide is hazardous to the operators and legal sanctions may have to be applied to restrain operators whose only motive is quick fumigation for maximum profit. The dangers in the use of methyl bromide are related to its low boiling point and high vapour pressure at normal temperatures and therefore it may be possible to limit the hazards by new formulations, e.g. gels and zeolites.

The effectiveness of fumigant-type soil sterilants is based on the following factors:

1. the physical and chemical properties of the fumigant,
2. the physical and chemical conditions of the soil,
3. interactions between these factors.

These soil factors affect the release and diffusion of fumigants from their formulations, e.g. the conversion of dazomet and metham-sodium to the fumigant methyl-isothiocyanate (MIT) by hydrolysis. The polarity of compounds as well as their absorbtive capacity on soil particles affect diffusion and hence their toxicity to target organisms. The polarity of the water-soluble metham-sodium is largely responsible for its phytotoxicity in moist soil while the breakdown product (MIT) which diffuses well and is apolar is absorbed onto dry organic matter in the soil.

Soil sterilisation is frequently very inefficient, partly because of the lack of basic knowledge about the susceptibilities of the target organism but also because little information is available about the chemical and physical properties of the chemical.

Even when methyl bromide is applied correctly, inconsistent results may be obtained. This is illustrated in Fig. 1 where it can be noted that Pythium and Rhizoctonia are very susceptible (100% kill being obtained at 65 cm in a sandy loam treated at 75 g/m^2 MB under a plastic sheet). Fusarium was less susceptible and Didymella almost uncontrolled unless the time of exposure was increased from 4 to 7 days. Increased time of exposure to the fumigant did not affect the response of Fusarium. An improved penetrability of the soil may be obtained by the addition of peat as shown by the results of Fig. 1 B. An increase in the relative moisture content of the soil may render the target organism more susceptible but the effect is strictly dependent on soil texture; water-logging may reduce pore volume with unfavourable results (D).

Peat which is generally 'parasite free' and poor in microflora and fauna can cause difficulties in chemical soil sterilisation. Addition of peat improves penetrability by increasing pore volume in soil but, at the same time, increased sorption occurs which leads to retention of chemical in soil for a longer time and hence to phytotoxicity. The addition of peat immediately prior to fumigation is not generally to be recommended; the dilution of the microflora which results may increase the time required for the degradation of the residual fumigant by the surviving microflora, e.g. bacteria and Trichoderma.

SYNERGISM

In soil sterilisation both synergism and antagonism have been observed. The addition of chloropicrin (CP) to methyl bromide may give improved results in dry soils.

In some trials at Leuven the synergistic effect of chloropicrin mixed with compounds of low fungicidal activity is shown in Fig. 2. The fungicidal action of DCP, DD or EDB is low (columns 8, 9 and 10) but addition of CP increases the fungitoxicity of these compounds particularly in the peat-sand mixture of 75% RMC (columns 12, 13 and 14).

Leeks (*Allium porrum*) can be infected by both nematodes (*Pratylenchus penetrans*) and by fungi (*Fusarium oxysporum*) and control of the nematode markedly decreases incidence of disease. Similar results have been obtained in chicory and potato where the pathogen is *Rhizoctonia*.

There is very little information on the direct effect of sterilants on soil-borne viruses (van Winkel. 1967). The influence of soil fumigation on the degree of soil infestation with Tobacco Mosaic Virus (TMV) is shown in Fig. 3.

It is known that TMV is to some extent inactivated by actinomycetes, soil fungi and bacteria and it seems clear from the results that D-D, chloropicrin and methyl-isothiocyanate in some way interfere with the inactivation process, the most marked effects being seen in the chloropicrin treatments. Methyl bromide on the other hand seems to have little or no effect on the actinomycetes and bacteria and therefore further biological degradation of TMV will occur. Physical heat, however, deactivates TMV completely after 15 minutes when the temperature of treatment is at least 89°C - See also Fig. 3.

NITRIFICATION

The appearance of necrotic symptoms on the root tips and on the edges of leaves in lettuce crops often occurs after soil sterilisation. Higher assimilation of manganese, distortion of the $CO_2 : O_2$ ratios in soil and inhibition of the nitrogen cycle have been given as possible reasons for the necrosis. Ammonifying bacteria are much less susceptible to temperature (lethal level 110° - 120°C) than nitrite-and nitrate-building bacteria (60° - 70°C) and there is, accordingly, a temporary breakdown in nitrification after steaming. The effects on nitrification of steaming and of chemical treatment are compared in Fig. 4. Both water-soluble organic nitrogen and ammonium nitrogen increase after steaming as a result of this differential response of the two groups of bacteria and also because of the denitrification of nitrites and nitrates, especially in the early anaerobic phase. The accumulation of ammonium may be a cause of phytotoxicity. The higher the humus content of the soil, the higher is the amount of water-soluble ammonium and, consequently, the risk of phytotoxicity.

Chemical sterilants, in contrast to steaming, produce little change in organic nitrogen and ammonium nitrogen content; nitrate formation is temporarily inhibited but after a few months the nitrate concentration is higher than in untreated soil.

PLANT GROWTH

Both steaming and chemical sterilisation favour crop growth by increasing nitrate in the soil as well as reducing the number of pathogenic organisms. But some plants react in different ways to steam and chemical sterilisation.

Methyl bromide is particularly damaging to carnations (*Dianthus*) because of the amount of bromide released in the soil but chrysanthemums grow well in methyl bromide treated soil. Chloropicrin tends to be phytotoxic to lettuce but good growth is obtained after fumigation with MIT because of the methylamine produced in the soil. Good growth responses have been obtained from leek, celery and tomato grown in chloropicrin treated soil containing no pathogenic organisms. Dichloropropene also gives favourable results for tomatoes and beans (*Phaseolus vulgaris*). Tomatoes grown in soil treated with CP or DCP give an early yield whereas on those grown in steamed soil, the increased yield comes later in the season. As mentioned above, the N-cycle plays a prominent role in growth responses, as shown by the bluish coloration of chicory grown in steam-sterilised forcing beds.

When used at the right period, DCP gives a good control of Club root, *Plasmodiophora brassicae*, though it has only very limited fungicidal action against soil fungi such as *Rhizoctonia* and *Pythium*. This intracellular obligate parasite can be destroyed as long as only the active parasitising phases are present in roots after harvesting the crop. The fumigation must be done before the natural decomposition of the cabbage roots when resistant resting spores are formed: tillage with a rotary cultivator which breaks up the roots is an advantage. An example of this very effective fumigation is shown in Table I.

TABLE I

Effect of DCP on development of *Plasmodiophora brassicae*

Treatment	Disease Index (Maximum 10)	
	Young plants	Mature plants
Control	3.6	10
DCP 250 ml/m^3	0	0.2

This result opens up new ideas for the use of a soil fumigant, which is primarily a herbicide or a nematicide, for the control of other root infesting fungi. It must, however, be stressed that after such treatments other problems may persist, for example, the non-obligate pathogenic fungi such as *Phoma* spp. which may cause canker of cabbage.

TOXICITY

The dangers to those applying methyl bromide and chloropicrin without following rigorously the instructions for use have been stressed earlier. In practice, 2% chloropicrin is added to methyl bromide but the technique of injecting followed by covering with sheets can still be dangerous even though chloropicrin is present. Moreover there have been several instances when plastic sheets have been improperly dug into the soil resulting in escape of the gases at concentration dangerous to the operators. Very often gas masks have inefficient filters and the practice of operators refilling the filters with their own charcoal is to be condemned because it has been shown that the aeration and sorptive capacity of this charcoal is 3 - 4 times less efficient than the original.

Because there is 2% chloropicrin in commercially applied methyl bromide, users feel safe in the absence of the concentration (1.3 ppm) which causes irritation. Based on the physical properties of the two chemicals making up the methyl bromide/chloropicrin mixture (vapour pressures 1380 mm Hg and 18.3 mm Hg at 20°C and densities 3.78 and 5.68 for methyl bromide and chloropicrin, respectively) the concentration of methyl bromide is always about 100 times greater than that of chloropicrin. Under practical conditions, losses of the order of 2% at a dosage of 75 g/m^2 could give concentrations of 115 ppm of methyl bromide in the atmosphere which would be lethal after a few hours. For this reason operators are at serious risk and we therefore suggest that the present legal safety limit of 2% is insufficient and probably dangerous to health. Because it can rapidly diffuse from soil methyl bromide concentrations may build up to a lethal level before the warning concentration of chloropicrin (1.3 ppm) is reached.

RESIDUES IN PLANTS

In recent years there have been alarming reports of 2,000 to 10,000 ppm of 'bromine' found in some plants estimated in terms of dry weight. But a residue of 10,000 ppm in lettuce corresponds to about 400 ppm (40 mg/100g) estimated on a fresh weight basis.

Medically a daily therapeutic dose is of the order of 3 to 4 grams. Mental or neurological symptoms do not occur until the concentration in the human body fluids exceed 720 mg/l and there is clear physiological evidence (private communication from colleagues at Louvain University) that a continuous daily intake of 700 mg of 'bromine' into the system would not lead to plasma concentrations exceeding the above figure. This corresponds to a 'no-effect level' of 14,000 mg in dry weight of plant, the 'no-effect level' proposed by FAO being 7,000 mg (≡ 100 mg/kg).

Although it is illegal, some contractors still fumigate without due care. But we may conclude that, when done expertly, the 'bromine' residues are only of the order 10 to 20 ppm of the fresh edible product (≡ 10 - 20 mg/kg).

Factors affecting the uptake of bromine are:-

1. the dosage applied,

2. the time of exposure,

3. the ion exchange capacity of the soil,

4. the cultivation practices and the physical condition of the soil.

Insufficient knowledge about soil characteristics and poor control of parasite at normal dosages of 50 to 75 g/m^2 often leads the contractor to increase the rate of application to 100 or 125 mg/m^2. If diffusion in soil is poor, the concentration of methyl bromide in the upper 10 cm of soil can range from 5 to 100 g Br/m^2.

Attempts to improve results by a prolonged covering of the soil are to be deplored, at least when edible crops are to be grown, for the increased retention in the case of MB leads to greater bromine residues. The latter may be reduced by flooding the soil or by increasing the chlorine anion concentration of the soil or by growing a non-edible crop.

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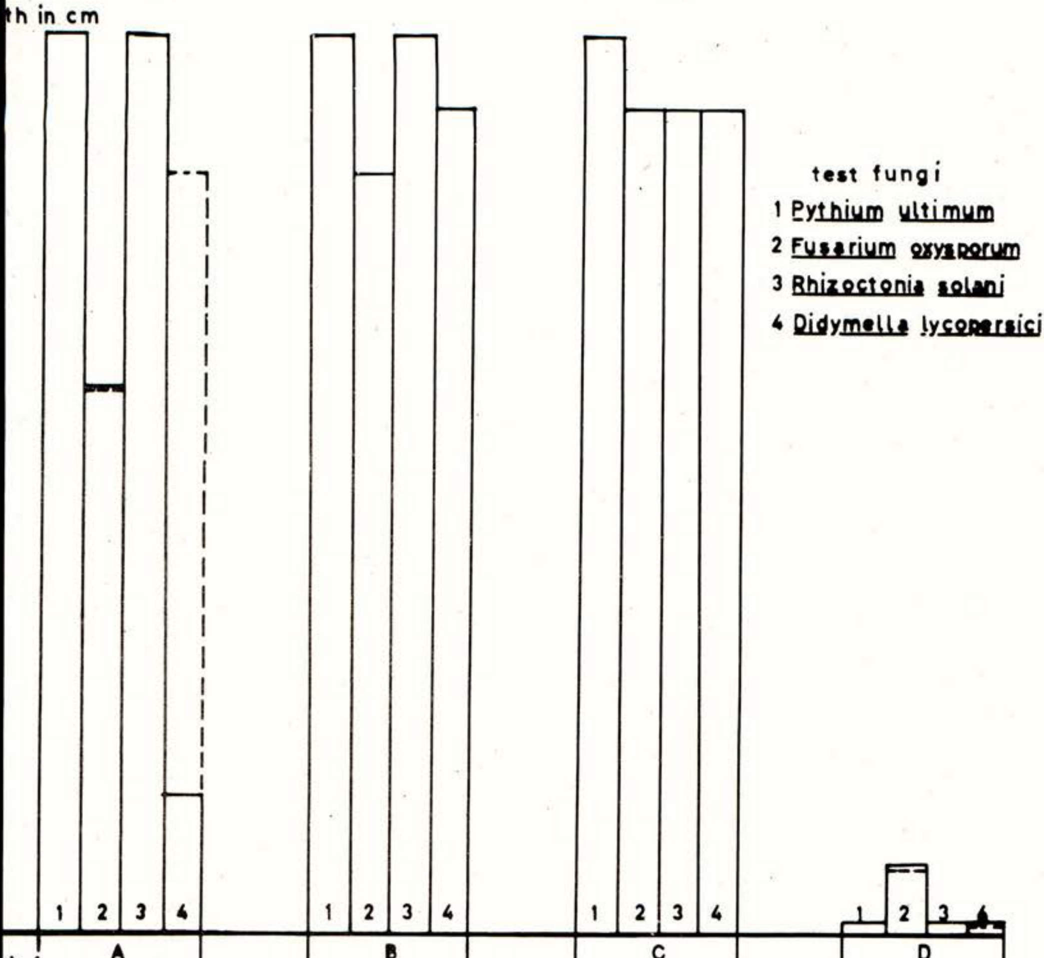
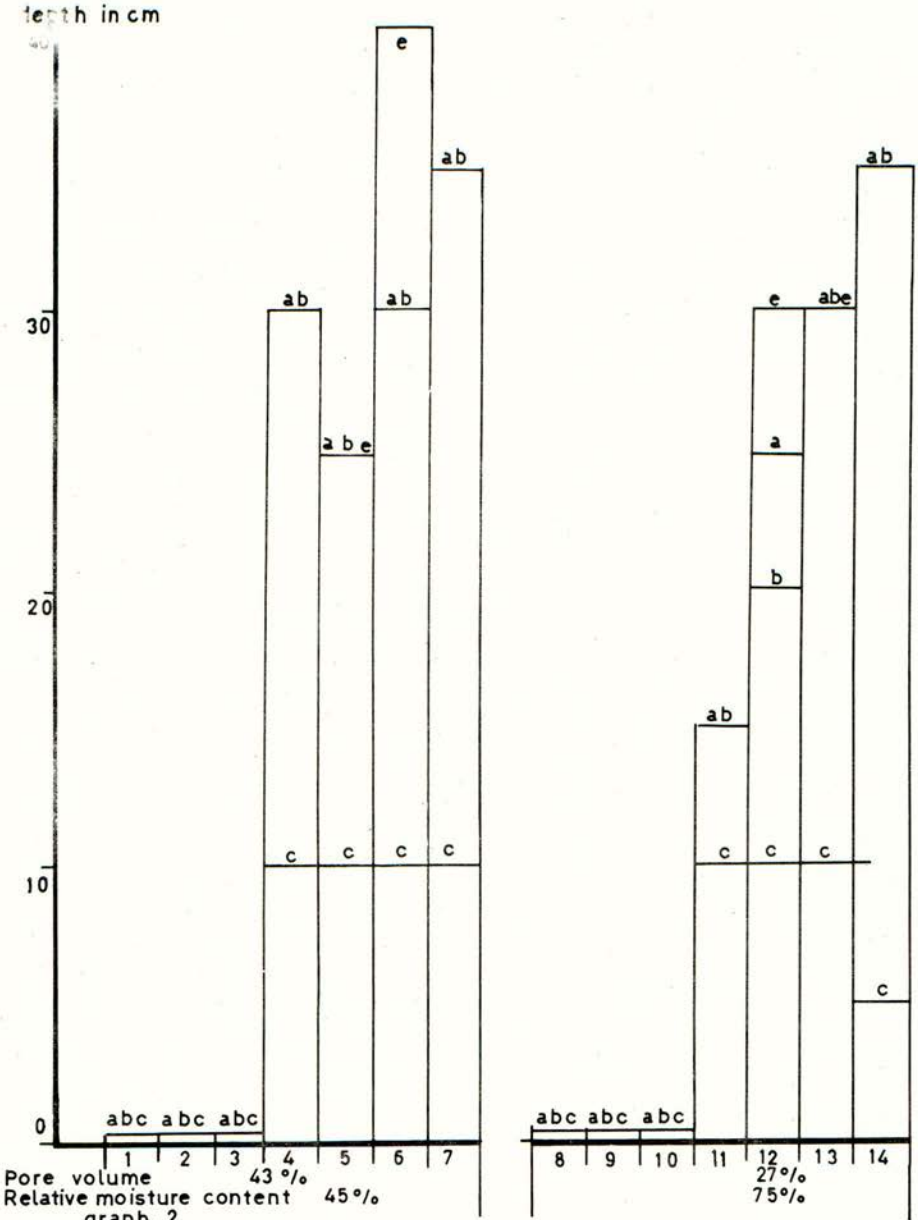


h. 1

omparative fungicidal effect of methyl romide at various depths in sandy loam soil

Sandy loam	A	Relative moisture content	(RMC) 45 °/.	Pore volume (PV)	48 °/.
	B	" " "	45 °/.	" "	51°/.
	C	" " "	75 °/.	" "	16,4°/.
	D	" " "	75 °/.	" "	9,7 °/.

——4 days contact
----7 days contact
B & D: 25 °/. peat by volume
temp: 20° C



graph. 2

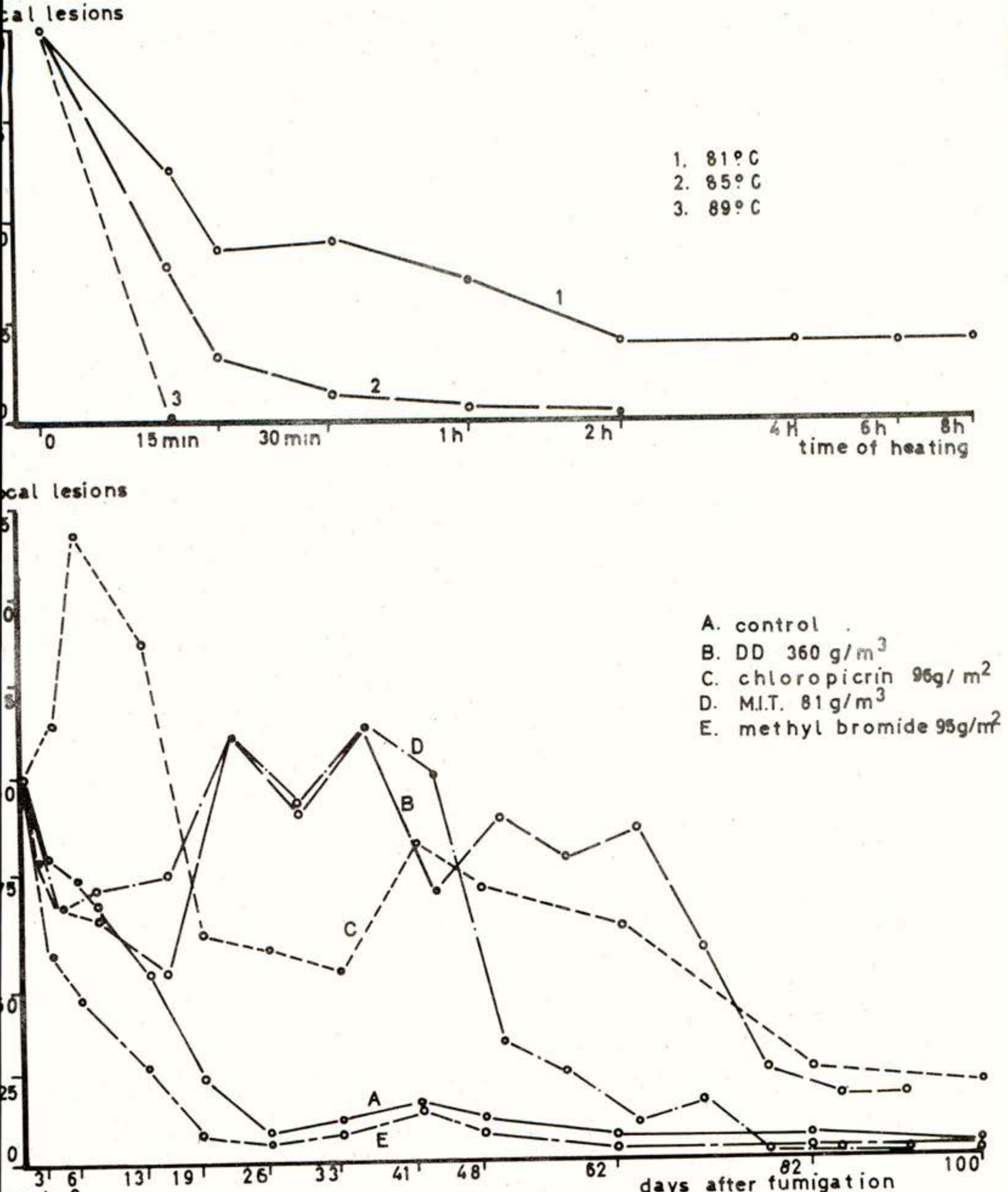
Comparative fungicidal spread of fumigants in peat-sand mixture (60-40% by volume)

fumigants

1, 8	1,3 D	92% AI	20 ml/m^2
2, 9	DD	53% AI	38 ml/m^2
3, 10	EDB	50% AI	20 ml/m^2
4, 11	CP	97% AI	10 ml/m^2
5, 12	1,3 D + CP		20 ml + 10 ml/m^2
6, 13	DD + CP		38 ml + 10 ml/m^2
7, 14	EDB + CP		20 ml + 10 ml/m^2

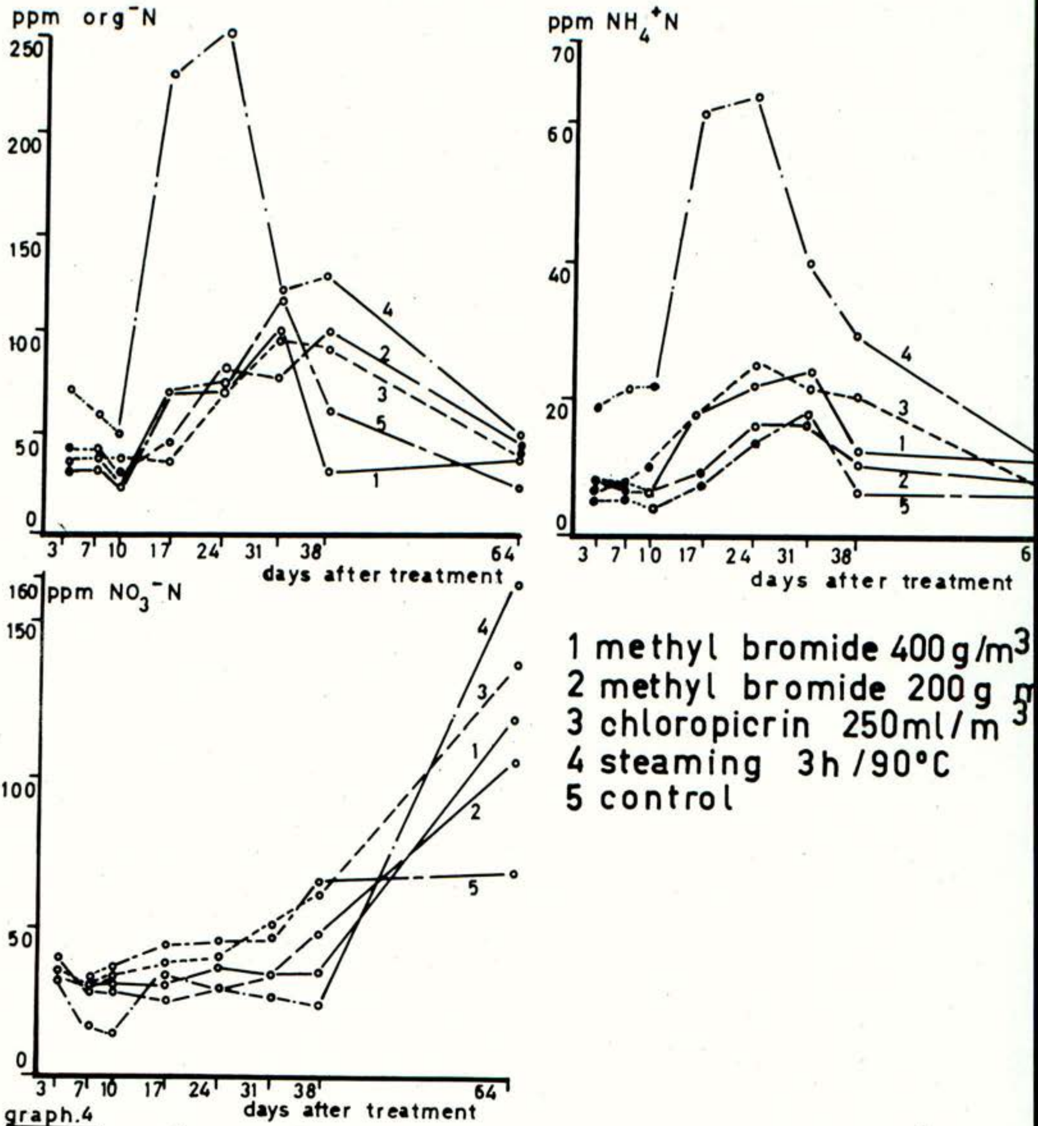
test fungi

a *Botrytis cinerea*
b *Fusarium oxysporum*
c *Trichoderma viride*
e *Verticillium albo-atrum*



raph. 3

Effect of physical and chemical soil-disinfestation on concentration of TMV



graph.4

Evaluation of the amount of Org⁻N, NH_4^+N and NO_3^-N in a disinfested sandy loam soil

(org. matter: 7,1 %; pH: 6,7; RMC: 65% and temp: 20°C)