SP119

# Black Spot of Strawberry, a disease incited by *Colletotrichum acutatum* (Simmonds)

A Report commissioned by H.D.C.

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March 1991

Contents

Summary

I. C. acutatum is the most important of a group of closely related pathogens affecting strawberry in Europe. Under normal weather conditions lesions on plants are inconspicuous, giving rise to the supposition that infection is "latent", which is incorrect. At temperatures near to the optimum for this sub-tropical fungus (28$^{0}$C) and in the presence of high rainfall or overhead irrigation giving leaf wetness for 15h or longer, overt lesions appear on petioles and stolons. Spores splashed or transferred by hand onto ripe fruit give rise to the typical 'black spot' rotting. Fungicides with clearance for strawberry, for example captan, are not as effective in controlling this phase as prochloraz. None of the treatments can eliminate infection from plants preplanting. Resistance to this whole group of pathogens has been identified in an American breeding programme.

II. Ongoing research programmes were identified in most strawberry growing regions of the world. These focus on screening for resistance (USA), epidemiology (USA and France), fungicidal control (Netherlands and France) diagnosis and race structure (UK) and agronomic factors (USA).

III. Although the pathogen is endemic on a number of hosts in the UK it is unlikely to cause problems to strawberry growers under the current eradication policy. Even if these measures failed it is unlikely that loss to main season crops would be significant but suitable weather conditions do sometimes occur during the late season of everbearers and fungicidal intervention could be needed. It is doubtful if the cost of the eradication policy, including crop destruction orders can be covered by the benefits gained. The pathogen is now widespread in the Dutch plant propagation system, albeit at a low level (0.2%), consequently continuance of the eradication policy is at the expense of access to Frigoplants in large numbers. In that the most urgent problem for the industry is to respond to the challenge posed by late season imports, this is a serious matter. Unfortunately there is little evidence that growers intend to take the necessary steps and consequently the eradication policy can remain with little extra cost. It is recommended that growers should carefully reconsider this position when the matter is reviewed in 1992 but they should not pursue the objective to place C. acutatum on the quarantine list of the EC at this time.

IV. There is an urgent need to simulate the events that would occur if infected Frigoplants were imported to the UK and for this it will be necessary to establish a quarantine site. If undertaken immediately this will provide the information on the behaviour of the pathogen in the all important second season of production in time for all full risk assessment for the 1992 review. In addition it will provide the opportunity to test fungicidal treatments preplanting and during cropping. It is advisable that resistance should be incorporated to the breeding programme for which a screening process is needed coupled with an analysis of the possible race structure of the pathogen.

Recommended action

The industry should urge the policy divisions of MAFF to establish an open research contract immediately and persuade the Plant Health Division of MAFF to licence an isolated field experiment. The task can be handled by ADAS (Wye) in collaboration with Wye College.

## Introduction

Colletotrichum acutatum first made an unwelcome appearance on strawberry plants imported to the UK in 1983 {43}. Since then it has been troublesome to growers both by the restrictions that have been imposed on plant importations from the continent and more directly as a consequence of destruction orders that have been served on infected plantations since 1988.

The objective of the exercise reported here was:-

I. To review the work published on this pathogen from the time it was first described in 1966 {40}.

II. To obtain information relating to ongoing work in laboratories around the world.

III. To assess the likely impact of the disease on UK production both in its current status and in the event that the pathogen was more widely distributed.

IV. To identify research priorities for all potential sponsors based on this information.

A bibliography of the publications on C. acutatum {Annex 1} was compiled using the retrieval systems of CAB and BIOSIS. Throughout this report references to research publications are indicated by the assigned number in this bibliography, and others retrieved by standard search procedures. Where persons have been named directly the information has been obtained by personal communication.

## I. Review of the literature

### A. Taxonomy

(i) C. acutatum belongs to a group of closely related fungi in the class Coelomycetes, several members of which have been recorded on strawberry. These are:-

C. acutatum, Simmonds
C. dematium (Pers ex Fre) Grove
C. fragariae Brooks
C. gloeosporioides (Penz) Penz & Sacc

and which have been associated with disease symptoms variously described as crown rot, wilt, anthreacnose and black spot {42}. The genus differs from Gloeosporium only in the production of setae within the acervulus (Fig. 1) and this, coupled with the very slight differences in spore morphology which distinguish the species within Colletotrichum has led to some confusion in the early literature. For example, the causal organism of black spot in Australia was ascribed to Gloeosporium before Simmonds described the species C. acutatum in 1966 {42}.

(ii) Each of these species is usually encountered in nature in the asexual phase and the names describe the anamorph. The teleomorph (sexual phase) of C. gloeosporioides can be induced in culture and is sometimes encountered in vivo as Glomerella cingulata (Stonem) Spauld & Schrenk. Sexual reproduction in C. acutatum has not been observed.

(iii) In each species conidia are produced in acervuli in beige or pink masses erupting in the centre of lesions. C. acutatum is most readily distinguished by conidial shape, which are fusiform and, unlike C. gloeosporioides, pointed at both ends (Fig. 1). Both of these species have been identified on plants imported in Britain (Cook). In America most reports {e.g.44} ascribe isolates to C. fragariae, and whilst there are slight differences in spore shape with C. Gloeosporioides {Fig. 1} further study might reveal synonomy with the latter species. C. dematium has not been recorded on strawberry in Britain and need not be considered further.

(iv) Isolates of C. acutatum and C. gloeosporioides are both highly variable in culture and consequently colony form is not a dependable means of diagnosis. C. acutatum generally grows more slowly than the others {43}, and some isolates from hardy ornamental species and strawberry from the USA produce a distinctive pink-orange pigment in the medium in contrast to the olive-grey colours produced by C. gloeosporioides {41 & 43}. However isolates of C. acutatum from strawberry in Holland and of the imports from that country intercepted in the UK were dark grey {van Kesteren and Cook}. It is tempting to ascribe these variations to the origin of the strains but that is impossible at this stage.

I.B. Host Range

(i) C. acutatum has been recorded on a wide range of genera of plant hosts (Table 1). This list should not be regarded as exhaustive and others will almost certainly be added. In Holland for example the species has been found in association with disease on Cyclamen and Lobelia in commercial production. It has also been intercepted on plants imported into Britain other than those shown in Table 1. For example Cook has isolated C. acutatum from Caenothus Camelia and Magnolia and although these were of the 'pink' colony form rather than the 'grey' form usually isolated from strawberry he found no difference in pathogenicity between eleven isolates from eight different hosts. Of particular importance in these trials was the demonstration that isolates from Anemone obtained from S.W. England were equally pathogenic to strawberry as those from strawberry.

(ii) One strain has been described as specific, namely C. acutatum f. sp. pinea causing terminal crook disease of Pinus Radiata in New Zealand, Chile and Africa. There is no record that cross-pathogenicity experiments have been performed with this isolate but as it has been found to infect weed species in forest nurseries (10) it is clearly incorrect to have erected a forma speciales at this stage.

It is interesting to note that the centre of origin of P. radiata is California. Whilst C. acutatum has been found on strawberry in that State there are no records for P. Radiata, leaving open for speculation the possibility that the pathogen was transmitted to Australasia by infected seed of pine.

(iii) However there is no hard information available to indicate the location of the origin of C. acutatum, which has now been found in many countries in the world. To the countries formally included in Table 1 Cook would add Costa Rica, Ecuador and Kenya together with most of continental Europe including the Iberian and Italian peninsulars.

(iv) The lack of specialisation of isolates of C. acutatum suggests that many weed species growing in the vicinity of strawberry crops could act as reservoirs of infection. Whilst Smith acknowledges this for S.E. areas of the USA there have been no systematically detailed reports apart from that for P. radiata nurseries (10).

Table 1

Host range and distribution of Colletotrichum acutatum records in C.A.B. files

| Host | Country | Reference |
|---|---|---|
| Anemone | Netherlands | [1][2][11][12] |
| | UK | [3][37] |
| | France | [30][40] |
| | Australia | [48] |
| Apple | UK | [39] |
| Camelia | UK | [9] |
| Capsicum annum | India | [23] |
| Coffee | Africa | [7][8][16][21][22] |
| Cowpea | India | [36] |
| Kiwifruit | New Zealand | [20] |
| Lupin+ | New Zealand | [10] |
| Mango | Australia | [14][15] |
| | China | [25] |
| Olive | China | [27][28] |
| Pawpaw | Australia | [41] |
| Pinus radiata+ | Chile | [35] |
| | New Zealand | [10][18][31][32][33][46][54][55] |
| | Africa | [17][26][38] |
| Ranunculus | Australia | [48] |
| Strawberry | Australia | [35][53][56] |
| | New Zealand | [6][29] |
| | South Africa | [51] |
| | UK | [39][40] |
| | USA | [13][42][43][47] |
| Tamarillo | New Zealand | [19][44][49][50] |
| Tomato | Australia | [41] |
| Tsuga | Canada | [52] |
| Zinnia | India | [24] |
| Vicia sativa+ | New Zealand | [10] |

+ Recorded as C. acutatum f. sp. pinea.

(v) Given the lack of pathogenic specificity, the cryptic nature of infections including seed and the very many species acting as natural hosts it is inevitable that C. acutatum, capable of causing black spot in strawberry, is frequently imported into Britain in spite of the current regulations

I.C. Infection and Colonisation

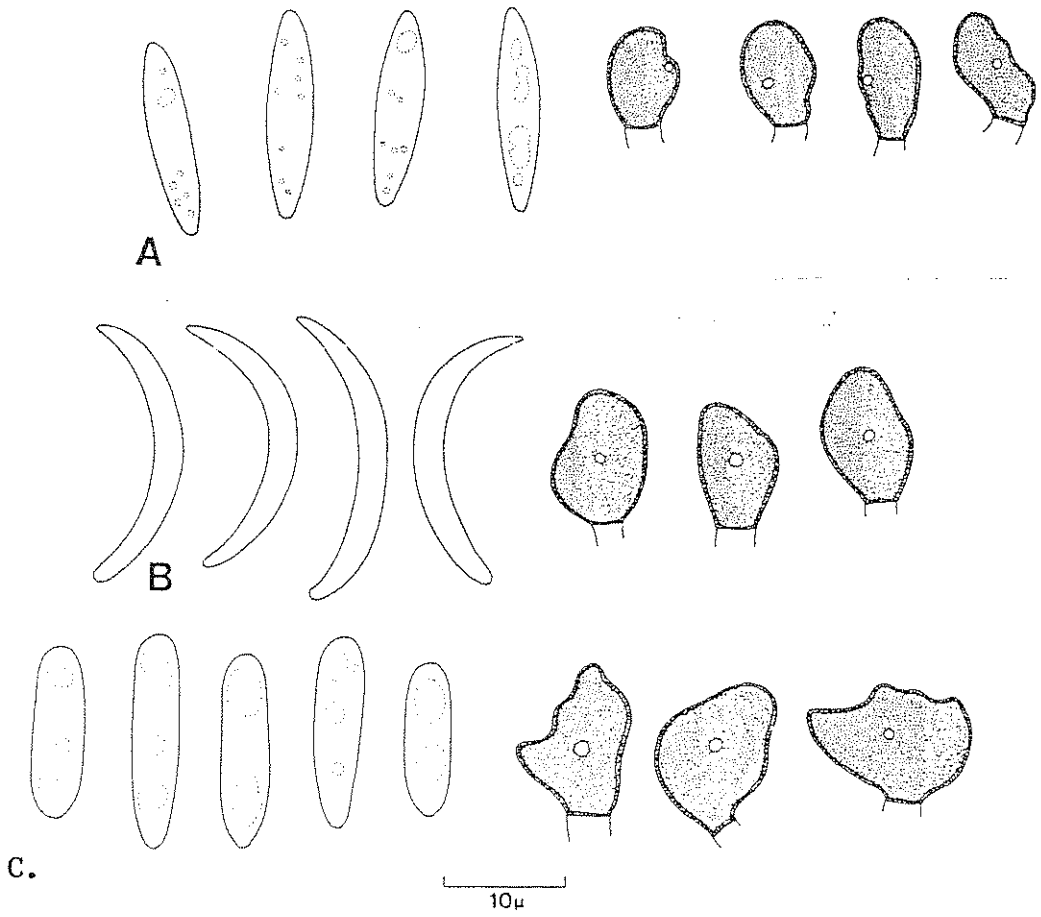
(i) Colletotrichum spp. are capable of infecting the intact surfaces of plants by producing highly developed infection structures called appressoria (Fig. 1). The first stage of germination is the production of a septum within the conidium followed by the emergence of germ tube from one end. When in contact with the host the germ tube stops elongating and swells to form a thick walled structure, the appressorium which is firmly fastened with the cuticle by gummy deposits. From the underside of the appressorium at an unthickened part of the wall a penetration peg is forced through the cuticle. In addition to enabling infection appressoria are also capable of providing a means of survival, the conidia having a relatively short span of viability.

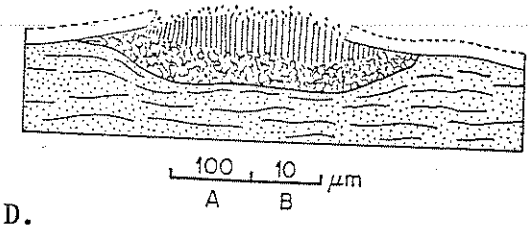
(ii) There are no details of the infection process recorded for C. acutatum, although the various stages of germination and subsequent development have been illustrated (33 and Fig. 1).

(iii) What happens next is a matter of some speculation. Certainly the development of visual symptoms on stems, petioles and unripe fruit is either very slow or the fungus passes into a quiescent phase, which in the literature is erroneously referred to as "latent infection". Cook's unpublished findings suggest that there is colonisation of the surrounding tissues but obviously this is not accompanied by extensive necrosis which would be visible to the eye. Detailed studies by Baileys'group at Long Ashton on C. Cindemathianum infecting Phaseolus vulgaris show that in compatible interactions the first infected cells remain alive for some time indicative of a biotrophic relationship. Only in later stages of disease development do host cells collapse and further extension of the lesions is necrotrophic. Whilst it is unlikely that biotrophy would feature strongly in a non-specific pathogen such as C. acutatum there is the possibility that in the early stages of disease development the fungus does not penetrate cells or trigger extensive cell death.

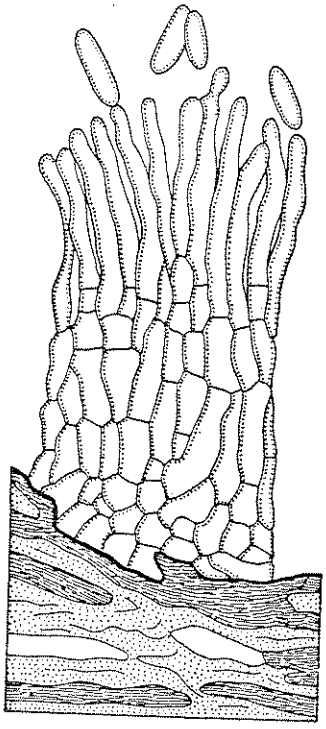
Fig. 1. Conidia and appressoria of A C. acutatum B. C. dermatium C. C. gloeosporioides (from 61 ). D, a generalised section of an appressorium and E. conidial production of C. gloeosporioides (from ). F, gemination and subsequent development of C. acutatum (from 33).

Fig. 1

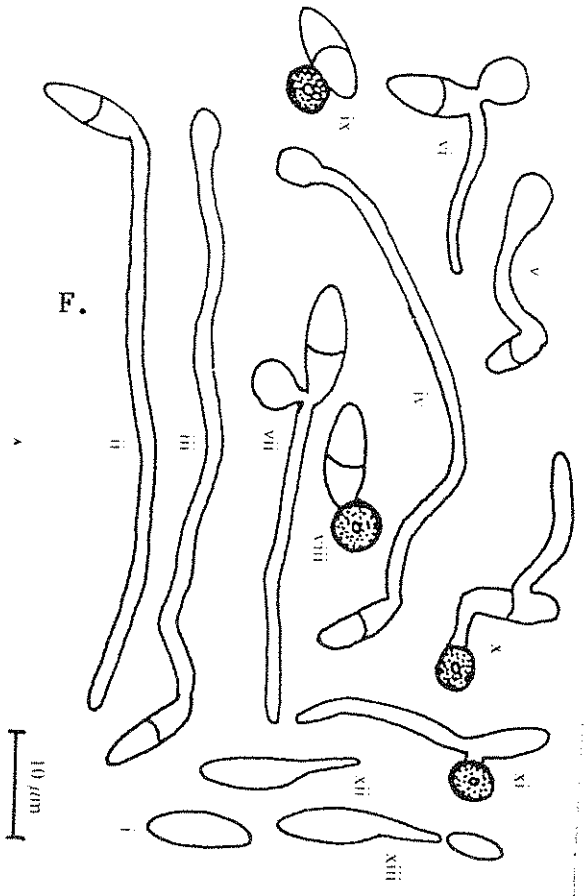



D.



E.




F.

(iv) Cooks' observations suggest that infection of the crowns remains relatively superficial and restricted to the cortex, and C. acutatum is not associated with crown rot per se in contrast to reports for C. fragariae. From these superficial infections conidia are produced in relatively low numbers in the quiescent phase, many fewer than would be expected in a typical acervulus. A substantial part of the surface area can be infected in this way without showing overt necrosis and thus the so-called 'latent phase' is actually an ongoing part of disease development.

(v) Typical anthracnose lesions are most frequently found on petioles and stolons. Here necrotic, water soaked lesions develop which are typical of a necrotrophic interaction leading eventually to the production of acervuli and very large masses of spores. However field observations suggest that the cryptic phase of infection can be present which never leads to typical anthracnose and the events which trigger the transition remain obscure.

(vi) Ripe fruit is highly susceptible and under the right conditions the arrival of the conidium is quickly followed by anthracnose development, or black spot. This is not so for green fruit but there is no information to reveal how the fungus survives the period before fruit maturity or the basis of resistance.

(vii) The pathogen readily colonises moribund tissue such as abscissed bracts and dead leaves and petioles. Thus an infected runner is likely to have fungus present over the surface of the crown and indeed roots, together with a substantial amount of inoculum quiescent in the dried up plant debris. The possibility of systemic infection can not be eliminated totally at this time, but most field observations on the distribution of lesions within plants can be explained by this creeping superficial infection and Cook has found that healthy plantlets can be generated from infected mother plants.

(viii) It is pertinent to note here that Cook has found that the best way to reveal infections is by first killing or weakening the plant with paraquat, suggesting that either C. acutatum is a weak pathogen of strawberry or that this treatment triggers the switch from biotrophic to necrotrophic growth.

## I.D. Epidemiology

(i) The optimum temperature for growth in culture of C. acutatum is higher than normally found for fungal pathogens native in Britain and more like those found in the sub-tropics (Fig. 2). Whilst there is some discrepancy in the observations (13 & 47) the optimum temperature for growth is 25-28$^0$C with a sharp decline above 30$^0$C. In contrast C. gloeosporioides, a pathogen frequently found in the humid tropics, continues to grow well at 32$^0$C.

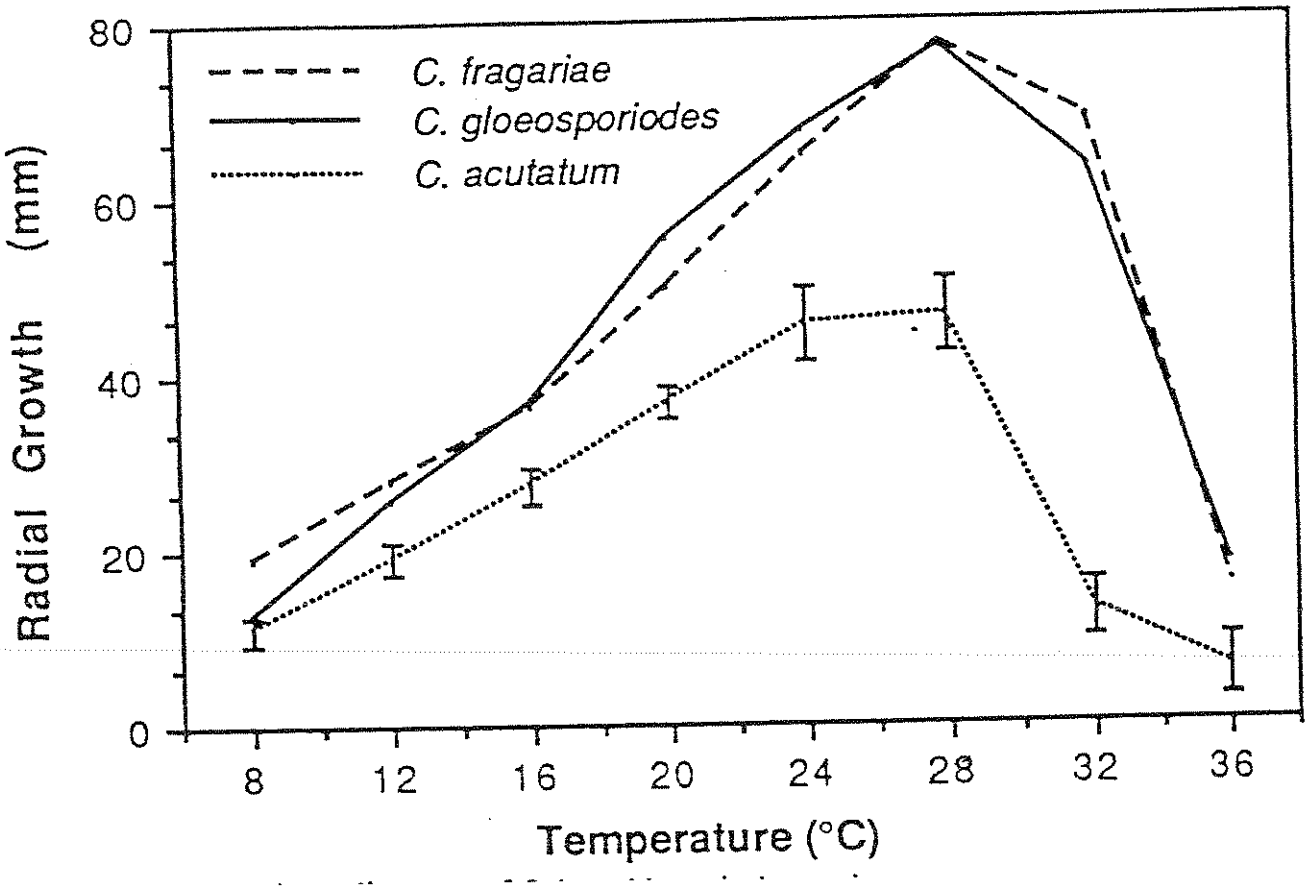
(ii) Of greater interest to the situation in the UK is tolerance to low temperatures. Some isolates do not grow below 12$^0$C (13) and Cook found that at 10$^0$C inoculated ripe fruit took 10 days to produce visible lesions. In most months of the year the pathogen would then be relatively inactive.

(iii) There are two phases in the epidemic that are crucially dependent on the availability of water. The first of these is the production of conidia, especially from colonies in the dead and therefore dry parts of the plant. There is no information on this and consequently the periods of wetness needed for the second phase, germination and infection may greatly underestimate the time required.

(iv) Water is also required for spore dispersal. This is provided in nature by heavy rain, with droplets splashing conidia from the slimy masses in acervuli. Overhead irrigation accurately mimics this, a matter of importance emphasised by most workers. The distance travelled by this means in unit time is obviously less for rain splashed pathogens than for those with airborne propagules. Smith suggests that healthy planting material can be produced 500 feet from an infected crop.

(v) Cook has shown that the slimy masses of spores readily adhere to the hands of pickers and, in experiments, could be transferred to culture medium even after standard washing. It must be anticipated that healthy fruit picked from an infected crop will develop lesions in the marketing chain unless the temperature is held below 10oC.

Fig. 2




Average colony diameter of 5 day old cultures on PDA grown in the dark. (from 42)

(vi) Barkley has found that the incidence of C. acutatum in strawberry in New South Wales has dropped since the drought of 1979-84, further indication of the dependence on water. Less explicable is that there has been a concomitant rise in the incidence of C. gloeosporioides.

(vii) Black spot is then a disease which is likely to be troublesome only under conditions of exceptionally warm hot weather in the UK, conditions which are experienced only in the late season, i.e. August. It explains why fields in which a substantial proportion of the plants carry infection very few berries rotted (Cook & Ebbels), an experience shared by Dutch growers (van Kestener).

(viii) Survival in soil has been recorded for 11 months in Illinois, USA {13} and up to 25 months in New Zealand {32}(Cheah). Debris of a previously infected crop seems to be the main reservoir for non-active chlamydospore-like darkly pigmented mycelium but appressoria formed on soil particles may also play a role {32}. As fumigation eliminates such inoculum there is little information to suggest how important this source of infection could be or how soil type or weather conditions influence survival.

(ix) From the wide host range of C. acutatum it should be possible for infection to be carried over from crop to crop on weeds. This seems to be true for infections of Pinus in nursery beds {10} but the apparent success of eradication in the UK suggests this may not be important for strawberry. Seed transmission in Lobelia and Lupin (van Kesteren) and Zinnia {24} suggests that breeders should take precautions when exchanging germ-plasm.

(x) Smith is convinced that all anthracnose/crown rot outbreaks are associated with infected stock plants and that seems to be the case in the UK and Holland. It is a little difficult to understand why the Dutch have found it impossible to eliminate infection from their propagation system. van Kesteren reported that the earlier practice of washing the roots of lifted plants, which would spread conidia very effectively, has been stopped. Possibly there are other practices which enable the pathogen to persist.

## I.E. Agronomic Factors

The observations by Smith on the effect of nitrogen on disease development are of great importance. She has clearly demonstrated (Fig. 3) that ammonium application at high rates can markedly increase susceptibility to C. fragariae. Assuming the same relationship holds for C. acutatum the very weather conditions which most suit disease development would also accelerate the release of nitrogen from uncapsulated fertiliser and thus lead to increased susceptibility (van Kestener).

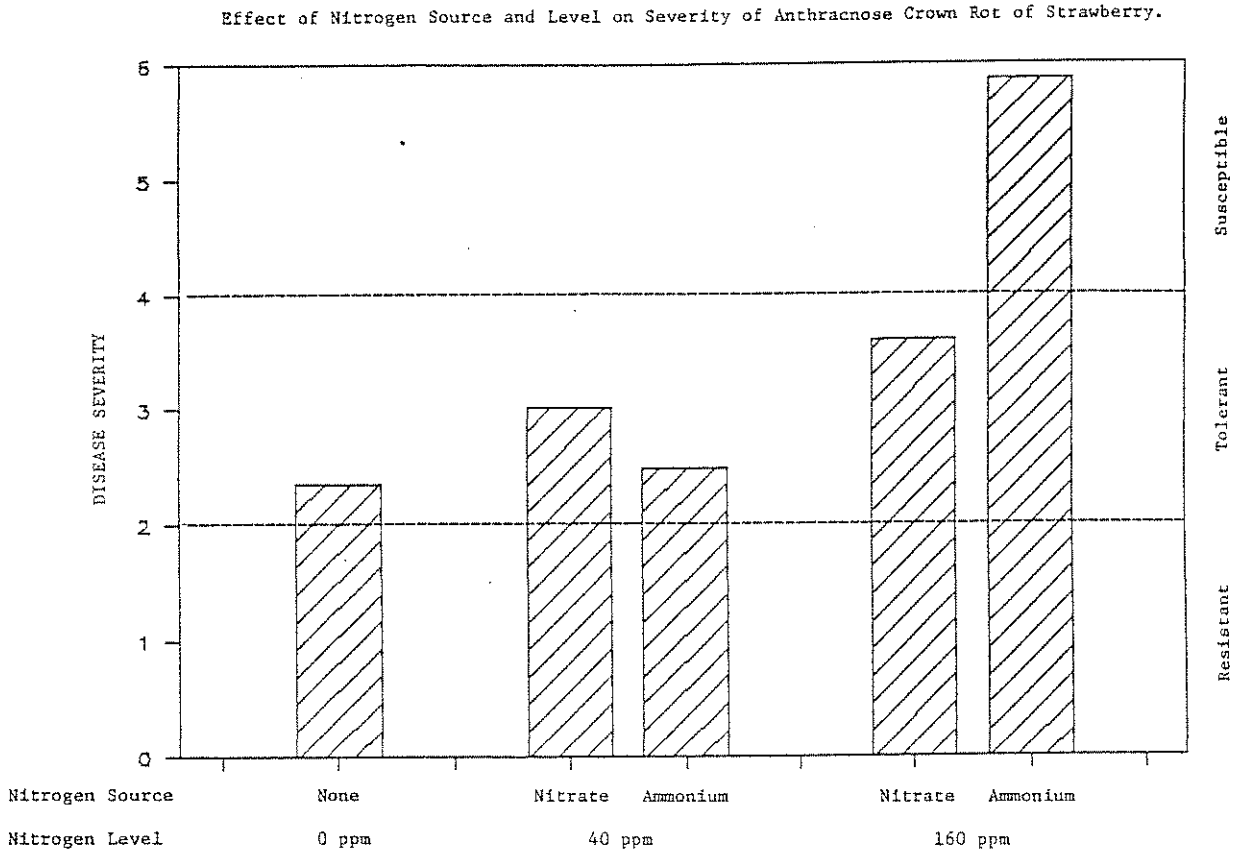
Smith also recommends that in addition to switching to drip irrigation, straw or grass mulches between the polymulch in the row is effective in reducing spread, perhaps as a means of reducing splash.

## I.F. Resistance

Screening for resistance to C. acutatum is taking place in California and to both C. acutatum and C. fragariae in the S.E. States of the U.S.A. Work by Gupton and Smith suggests that inheritance of resistance was similar for both species and conclude that it should be feasible to establish a broad genetic based population resistant to both species. The nature of resistance is not clear, but working with varieties resistant to C. fragariae Millholland {59} it was found that plants became infected but colonisation was restricted to a few cells beneath the infection site which were then surrounded by tannin filled cells.

Table 2 records the reaction of fifty varieties to C. acutatum in experiments undertaken by Winterbottom in California. An understanding of the possible race structure of C. acutatum is crucial to the success of a breeding programme. On the basis of variation in disease severity in certain strawberry cultivars grown in different locations in the States has led to the assumption that races of C. fragariae exist {43} and indeed earlier work {59} separated eight isolates into three races. If resistance to both C. fragariae and C. acutatum is coinherited the existence of race specific (vertical) resistance would be surprising, and the horizontal resistance identified by Smith more likely.

Fig. 3. Effect on N; on C. fragariae, data supplied by Smith.



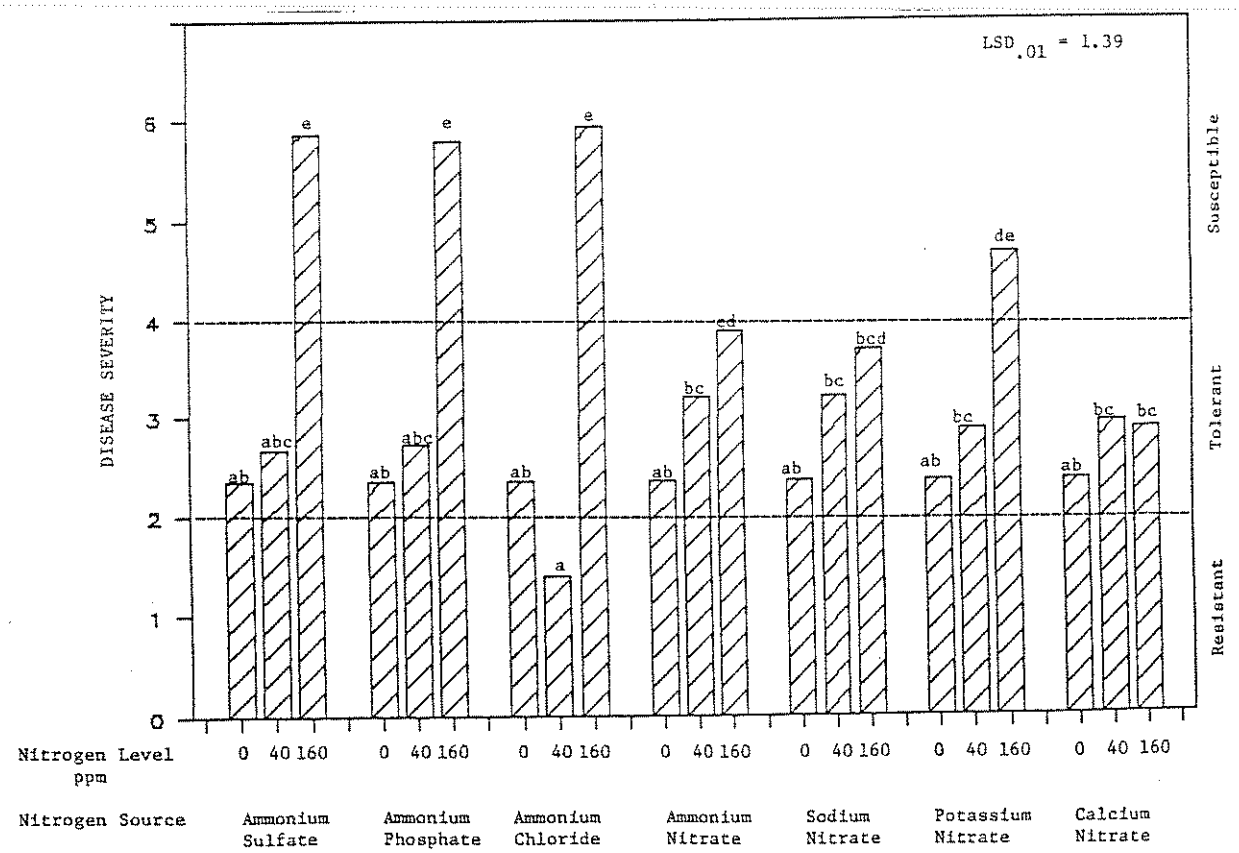



Table 2. Plant reaction of entries to Colletotrichum acutatum 20 days after inoculation with 1.5 x $10^6$ conidial/ml.

| Entry | n [1] | Reaction [2] | Entry | n | Reaction |
|---|---|---|---|---|---|
| 1. Aiko | 9 | R | 26. Solana | 10 | R |
| 2. Aliso | 9 | R | 27. Soquel | 9 | R |
| 3. Aptos | 8 | S | 28. Tahoe | 12 | S |
| 4. Brighton | 9 | S | 29. Tioga | 8 | R |
| 5. Campbell | 9 | R | 30. Torrey | 10 | R |
| 6. Chandler | 9 | R | 31. Toro | 9 | S |
| 7. Cruz | 11 | R | 32. Tufts | 10 | R |
| 8. Donner | 9 | S | 33. Tustin | 9 | S |
| 9. Douglas | 10 | R | 34. Vista | 10 | R |
| 10. Fern | 10 | S | 35. Wiltguard | 8 | R |
| 11. Fresno | 10 | R | 36. Yolo | 12 | S |
| 12. Hecker | 8 | S | 37. C35 | 9 | S |
| 13. Irvine | 8 | S | 38. 83.49-2 | 8 | R |
| 14. Lassen | 10 | R | 39. 37.20-45 | 10 | S |
| 15. Muir | 11 | R | 40. 59.39-1 | 8 | S |
| 16. Mrak | 12 | R | 41. 83.93-6 | 7 | R |
| 17. Oso Grande | 10 | R | 42. Allstar | 10 | R |
| 18. Pajaro | 62 | S | 43. Ozark Beauty | 5 | R |
| 19. Parker | 9 | R | 44. Redchief | 8 | S |
| 20. Salinas | 7 | R | 45. Scott | 9 | R |
| 21. Santana | 6 | S | 46. Surecrop | 10 | S |
| 22. Selva | 13 | R | 47. 39.117-4 | 10 | S |
| 23. Sequoia | 63 | R | 48. 39.82-19 | 6 | S |
| 24. Shasta | 8 | S | 49. 42.8-16 | 10 | S |
| 25. Sierra | 8 | R | 50. 51s1-1 | 7 | R |

1. Number of plants evaluated.
2. R = resistant and S = susceptible. Plants were rated after Smith et al. (1987): 0 = no lesions; 1 = lesion(s) <3 mm; 2 = lesion(s) 3-10 mm not girdling petiole/runner; 3 = lesion(s) >10-20 mm, usually girdling petiole/runner; 4 = lesion(s) >20 mm, usually petiole/runner necrotic; 5 = youngest leaf wilted indicating crown infection; 6 = dead. Plants with a disease severity rating (DSR) on either petiole or runner ≥ 3.0 were rated as susceptible.

Information from Curtiz, Report of the Californian Advisory Board.

## I.G. Fungicidal control

The literature records tests of several fungicides for efficacy against C. acutatum, sometimes with conflicting results, although it must be recalled that these experiments were made with several crops. (Table 3)

Smith reports that none of the fungicides tested to control crown rot and black spot in the field which had label clearance, were wholly effective. In California both C. fragariae and C. acutatum are tolerant to benomyl and only captan had any value. It should be noted that the compounds used for Grey mould such as Rovral and Ronilan had no effect on black spot.

Cook found that benlate/captan mixtures were effective suggesting that benlate tolerance is not yet present in the UK, but this must be anticipated.

Of the unlabelled compounds both Cook and van der Scheer found prochloraz the most effective, and Cook and Smith found the triazole compound propiconazole promising.

None of the fungicides tested were able to eliminate infection and were therefore not effective when applied to plants before planting. Cook has also tested heat treatment in combination with fungicides, which is effective in treating anemone corms. Unfortunately the temperature regimes required appear to be too high for strawberry.

## I.H. Techniques

Cook has evaluated several techniques to reveal cryptic infections on runners, including baiting by inoculation of apple and tomato, of which the latter is more rapid. This approach has been largely replaced by treating sample tissue with paraquat. Lesions with typical pink spore clusters develop on the dying plant material, especially petioles, and the method is obviously much more sensitive than can be achieved by visual inspection.

A selection medium has been developed {3} which enables qualitative and quantitative estimation of inoculum levels in soil. Cooks 2 medium is useful for maintaining cultures in the laboratory {40}.

Table 3

Effect of fungicides on C. acutatum on several hosts recorded in the bibliography of C.A.B.

| Fungicide | Effective | Non Effective |
|---|---|---|
| benlate | [5] | [7] |
| benlate + captan | [6][35] | |
| bitertanol | | [6] |
| captan | [51] | [46] |
| captan + PMC | [46] | [18] |
| + pyridinitril | [46] | |
| captofol | [8][35] | |
| daconil | [35] | |
| dichlofluanid | [6][35][55] | |
| dichlone + oil | | [46] |
| dinocap | | [19] |
| imazilil | [49] | |
| mancozeb | | [19] |
| mezineb | [35] | |
| prochloraz | [50] | |
| procymidone | | [6] |
| thiophanate-methyl | [5] | |
| triadimefon | | [19] |
| triforine | | [19] |

Field inoculations using either conidial sprays or the introduction of infected plants are not always successful. Cook has found it difficult to develop epidemics in polytunnels even with overhead irrigation and maintaining high humidity by closing them at night. van Kestener reports similar difficulties. van der Scheer's fungicide trials are made in high density plantings "seeded" with apple fruit bearing sporulating lesions and this seems to be effective.

Screening for resistance to C. fragariae is done with spray applications with conidia and by puncturing the crown {42}. It is important to note that seedling age is a critical factor as resistance increases with age. The fungicide tests described were done on 7 or 10 day intervals spraying and inevitably close to harvest. The literature has no information on the use of meteorological data as a means of guiding spray application.

## II. Ongoing work in laboratories around the world.

### A. U.K.

(i) Roger Cook at Harpenden is focusing attention on the development of specific diagnostic aids, including monoclonal antibodies. Work on fungicides and epidemiology has ceased.

(ii) Angela Berry at ADAS (Wye) intends to test the efficacy of fungicides and hot water treatment of preplanting materials and the importance of weeds as alternate hosts. She has a licence to handle the pathogen in the greenhouse.

(iii) Dr. Avril Brown at Queens University of Belfast is undertaking an RFLP analysis of the genus Colletotrichum on behalf of the ODA. Many of the isolates included in the experiments are tropical species but C. acutatum has now been included and cultures obtained from many countries.

(iv) Dr. John Bailey's group at Long Ashton is also involved in this ODA project and although it concentrates on Colletotrichum spp that attack legumes or cereals it could lead to the development of a phytogenetic taxonomy of the genus, relevant to C. acutatum.

B. U.S.A.

(i) Barbara Smith, ISDA Mississippi, will continue to conduct fungicide trials for both plant and fruit rot control but intends to devote more time to explore cultural methods of control, particularly phytosanitary procedures in the nursery. She will continue to screen seedlings for resistance as part of the programme led by:

(ii) Gene Galetta, USDA Beltsville, who is coordinating the breeding programme which is examining both C. fragariae and C. acutatum, and includes work in Florida, Louisiana, North Carolina and Arkansas.

(iii) Bob Curtis of California Strawberry Advisory Board is conducting a similar programme more specifically directed to C. acutatum in conjunction with Winterbottom.

(iv) W. Gubler, University of Illinois, is continuing epidemiological studies, especially soil survival.

C. Netherlands

(i) A.A. van Kesteren of the Plant Protection Service and Dr. Noordeloos will continue to monitor the occurrence of the pathogen on a whole range of hosts and are particularly interested in cultural and pathogenic variation.

(ii) van der Scheer, Wilamenadorp is conducting trials on fungicides in the field in conjunction with,

(iii) Henk Nuyten, Breda, where the work is located.

D. France

(i) M. Clerjeau, J.G. Nourrisseau and Beatrice Dénoyés of INRA, Bordeaux, in conjunction with J.P. Morzieres have an ongoing programme which includes several aspects of epidemiology, chemical control and cultivar resistance and variability of the fungus.

E. South Africa

(i) Susan Koch, Stellenbosch, is responsible for some continuing trials on fungicidal control now that work at the Fruit Technology Institute has been concluded.

F. New Zealand

(i) L.H. Cheah, MAFF, has reduced his programme on the disease but intends to continue to undertake field surveys and tests on survival of the pathogen in soil.

G. Australia

(i) Research on the disease has largely ceased but Don Hutton, Maroochy, has a watching brief and,

(ii) Doug Parberry, Melbourne University, continues to include C. acutatum in his studies on appressorial development in the genus.

III. The impact of the disease in the U.K.

A. Endemic or exotic?

Colletotrichum acutatum is no stranger in this island. It has a long history in anemone and is almost certainly present on hardy ornamentals and even annuals imported for planting in gardens across the country. The weather precludes this fact from being obvious in all but commercial anemone production, where it is kept under satisfactory control by hot water/fungicide treatments.

It is impossible to tell how long it has been in the country or how frequent its occurrence, but we must now accept that this fungus is endemic.

B. Cross infection

Artificial inoculation experiments reveal that the fungus can be transmitted to a wide range of hosts, but the key question is how often does this occur in nature. The only experience we have is with strawberry and even in the South West, where anemone and strawberry are grown in the same county there are no recorded instances of cross-infection. Moreover, all the cases of black spot can be traced to the importation of plants which were already infected.

Therefore for strawberry the fact that the pathogen is endemic is possibly irrelevant so long as it is excluded from the propagation system.

C. **Are further outbreaks likely if the eradication policy is maintained?**

The number of reported outbreaks has declined sharply since the adoption of the eradication policy. It is impossible to judge if this is due to a real decline in incidence or a failure to report. Given the financial penalty that growers face if they report black spot it would not be surprising if they were reluctant to reveal the presence of one or two infected berries and it is reasonable to assume that there are crops present in the UK which are infected. Discreet enquiries have confirmed this suspicion.

Could these become the focus for a more general dissemination of the pathogen? Given that pickers move from farm to farm it must be expected that there could be some local movement around such a focus. However this will be important only if in the life of an infected crop the weather conditions resemble the humid subtropics. After two hot dry summers it is unlikely that such spread has been significant.

The contamination of propagating beds from infected cropping fields is a more serious matter. However this is only likely if personnel and machinery are moving between both locations at the appropriate time. It is reassuring that even on farms growing both anemone and strawberry that the difference in timing of the farming operations for these crops has so far precluded cross infection. However, propagators will have to be vigilant if they are to prevent the introduction of the pathogen; so far all beds submitted for certification have been found healthy.

It might then be reasonable to conclude that if the eradication policy is maintained then loss through disease in strawberry production will remain small.

D. **Cost of the eradication policy**

(i) There are two elements of cost that need to be considered; the direct costs arising from the destruction orders that have been served and the plant testing costs and the opportunity costs resulting from the loss of access to plants for out of season production.

(ii) It has not been possible to quantify the costs borne by individuals upon whom destruction orders have been served but they must be considerable. With hindsight it is possible to see that the loss of crop from the approximately 18 holdings destroyed was probably far greater than the entire industry would have suffered even if there had been more widespread infection over the last two exceptionally dry years. There are likely to be further incidents which will add to these costs.

(iii) The opportunity costs are potentially very large but depend on the willingness of the industry to respond to market changes, irrespective of black spot. In the view of many Dutch growers there is a strong probability that East European countries, with their cheap labour, will flood Western Europe with main season fruit. Their response has been to switch production to early and late season crops using newly developed techniques such as waiting-bed plants or Frigoplants. This is reflected in imports to the UK for the months of July and August which rose from 1432 tonnes in 1989 to 2943 tonnes in 1990, a trend likely to be repeated in 1991. According to Nuyten there are now 110ha of protected strawberry in Holland and this continues to expand.

(iv) The NSA has stated that it can meet all of the demands for conventional plants and is gearing up to produce waiting bed plants for the 1992 season on orders placed now (March 1991). So far the industry has shown relatively little interest in attempting to satisfy the demand for late season fruit. In my view this is most unfortunate and carries a threat even to the main season for sales through multiples who tend to look for continuity.

(v) There is some opportunity cost in the current season in which it proved impossible to import something like 1 million Frigoplants as a result of Black spot. This opportunity cost would be intolerable if there was a substantial increase in the numbers wishing to grow such plants in 1992.

E. Consequences of relaxing the eradication policy

(i) There is little prospect of obtaining plants from Holland with no infection, and as the 0.2% tolerance limit judged by eye must underestimate true infection, then access to Frigoplants in 1992 and beyond could only be achieved by relaxing the eradication policy. The consequences of admitting substantial quantities of infected plants are difficult to judge and inevitably rely heavily on Dutch experience.

(ii) The Dutch have a fairly relaxed attitude to Black spot which from their perspective is seen to pose no threat to commercial strawberry production. They feel that suitable weather for an epidemic is so rare that it can be discounted. In addition their strategy of discarding plants after one year's production in the field probably prevents a significant build-up of inoculum. The disease is very unlikely to spread in protected crops produced in "flying pillows", drip fed without overhead irrigation. As the pillow technique is even being extended to outdoor production it is easy to see why they feel that C. acutatum infection is irrelevant.

(iii) With the same production techniques it is equally unlikely that black spot would be a problem in the UK, but the impact on existing practices, particularly that of retaining beds beyond the first year is more difficult to judge. The key question is the likelihood of suitable weather in the main cropping period. As this probably implies the need for periods of more than 15hr of leaf wetness at temperatures of $20^{0}$C or over it is reasonable to assume that the risk is very small. It becomes significantly greater with everbearers in August and for these it could be necessary to use fungicides.

(iv) The inability of the Dutch to keep infection out of their propagation scheme is difficult to explain given that they maintain a 5km quarantine zone around foundation plants and demand 500m separation for the last stages of plant production from cropping beds. It is impossible to judge if the same situation would arise in the NSA scheme, if the eradication policy were relaxed. Certainly there would be a need to separate plant raising and cropping functions even more stringently than at present if general infection was to be prevented. However, it is possible to predict with confidence that the NSA could continue to match the health status of plants produced anywhere else in Europe.

F. Conclusions

(i) Whilst it is axiomatic that all measures should be taken to prevent the entry of exotic pathogens into the UK., the stringency which which these are applied hinges on economic considerations. The industry will wish to reflect on the cost of maintaining the eradication policy when this is reviewed in 1992, especially the consequence to its ability to face up to the challenges of the market after that date.

(ii) On the evidence of the epidemiology, C. acutatum does not seem to pose a significant threat to production in the UK; in this it resembles the fire-blight situation of the 1960/70s, and with that lesson in mind the industry will need to reflect on the cost of issuing destruction orders compared to the direct losses caused by the disease. The industry will also need to assess the chances for success in excluding from strawberry a pathogen which already seems widespread on several indigenous hosts. It would be unfortunate if having put itself to the considerable expense of applying the eradication policy this proved unworkable, as was found with fireblight.

(iii) In my view no further attempt should be made to place C. acutatum on the quarantine list of the EC as this step is scientifically untenable. There is nothing now to be gained from relaxing the existing policy before 1992 although any new outbreaks this season should be considered very carefully before destruction orders are served. With the experience of this and the coming season the industry should be able to make an honest and open appraisal of their position with respect to the future and advise MAFF accordingly.

(iv) I am strongly of the opinion that a viable strawberry industry depends on responding to the opportunities of late season production. It will be surprising if this can be done without importing Dutch plants, which will necessitate some relaxation of the existing eradication policy.

## IV. Research Priorities

1. The decisions which the industry needs to make should be based on hard facts and not supposition. Unfortunately the eradication policy itself has precluded the acquisition of data needed to understand how C. acutatum behaves under UK conditions. This should be rectified as a matter of some urgency and an isolation plot of infected plants established. So far, the Plant Health Branch has refused such a breach of the eradication policy and they are unlikely to agree unless specifically requested to do so by the industry. If the work is done by people and machinery remote from other cropping farms the risk of spread is very small.

   A number of research objectives could be tackled in such a plot.

   (i) To assess the severity of the disease when infected plants are grown under UK conditions of commercial strawberry production.

   (ii) To assess the dissemination of the pathogen to adjacent healthy plants.

   (iii) To estimate the effectiveness of fungicidal treatments applied preplanting on the reduction of inoculum and subsequent disease.

   (iv) To test the efficacy of fungicides to control black spot under field conditions.

   (v) To determine the importance of weeds in the carry over of the pathogen from season to season.

2. The epidemiology of the disease is being studied in France under conditions far more conducive to infection than can be anticipated in the UK. This should be monitored closely by UK research workers to obtain a more accurate measure of the weather patterns for an epidemic. Using this data meteorological records for centres in the UK should be interrogated to determine the frequency of occurrence and consequently measure the risk.

3. Infections on planting material are carried cryptically and work on improving diagnostic procedures being undertaken at Harpenden should be encouraged, especially if these prove to be quicker and cheaper than existing methods.

4. The factors which lead to the transition from cryptic to overt infections are best approached with artificially inoculated plants grown in controlled environments. The objective is to determine those conditions which after infection most rapidly lead to lesion development on stems and petioles and mass sporulation. This study should include a detailed histological investigation on the behaviour of the pathogen under these conditions and seek to establish the basis of resistance which undoubtedly exists.

5. Natural plant resistance would be the most effective way of controlling the disease if the decision was taken to relax the current policy. This will require a screening process, probably adapted from that in use in California, for all existing and intended European varieties. It is important that this work is accompanied by a knowledge of the race structure, and pathogenicity tests should be undertaken on the collection of isolates now held in Belfast for RFLP analysis.

Recommended Action

C. acutatum is a scheduled pathogen under statutory restriction in the UK. As such research work is eligible for funding by that policy division of MAFF responsible for plant health. The industry should urge MAFF to set up an open contract to enable work to begin in the current season.

It will also be necessary to persuade the Plant Health Division to allow an open field experiment with this pathogen, something they have so far refused to sanction. With proper safeguards the asscociated risks are very small and fully warranted by the need to obtain data in support of the decisions that will be made in 1992.

The work can be done most readily by collaboration between ADAS (Wye) and Wye College, where all the appropriate facilities are available, remote from commercial strawberry farms and yet in an appropriate climatological zone.

Acknowledgements

I am indebted to the many research workers around the world who willingly provided much of the information on which this report was based. I also wish to express my gratitude to Mrs. Ann Wakefield for her patience in producing the typescript so expertly.

T R Swinburne

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