Session 5
Potatoes and Bulbs

Chairman and
Session Organiser G A HIDE

USE OF SEED TREATMENTS IN THE INTEGRATED CONTROL OF POTATO TUBER DISEASES

S. J. WALE

Scottish Agricultural College, 581 King Street, Aberdeen, AB9 1UD

ABSTRACT

Fungicide treatment of seed potatoes is an important integral part of a strategy for control of tuber diseases. It must be considered through all stages of seed multiplication. Choice of fungicide and correct timing of application depend on an assessment of disease risk. This risk can be assessed from a thorough knowledge of storage diseases but requires to be interpreted in a practical context.

INTRODUCTION

Whilst the ware grower converts the seed he buys to a saleable crop in one season, seed growers have to multiply a stock up over several seasons. In doing so there is the potential each year for ingress of disease both in the field and during storage. For a grower to produce healthy seed suitable for top quality ware production, he has to adopt an appropriate strategy to minimise or prevent tuber disease from the initial multiplication (VTSC) to the point of sale.

Seed tuber fungicide treatment is only one element in any strategy, for it must be integrated with husbandry techniques. Whilst the use of a fungicide treatment requires planning from the start of seed multiplication, flexibility is also needed to cope with changing disease risks and practical problems that arise each season. The choice of fungicide, time of application and method of application are all extremely important for successful control of seed tuber diseases.

The range of diseases which can affect tuber health in Great Britain is wide. In this paper consideration will be given primarily to storage fungal diseases for which fungicide seed tuber treatments are available (gangrene - *Phoma foveata*; dry rot - *Fusarium solani var. coeruleum*; skin spot - *Polyscytalum pustulans*; silver scurf - *Helminthosporium solani*; black dot - *Colletotrichum coccodes* and black scurf - *Rhizoctonia solani*).

For an effective disease control strategy to be developed, a knowledge of the life cycle and epidemiology of each pathogen is crucial. Tuber storage diseases have been reviewed by a number of authors (Boyd, 1972; Hide & Lapwood, 1992). In this paper essential features of each of the fungal storage diseases listed above are reviewed and the husbandry factors that reduce them are summarised in Table 1. Thereafter, the use of seed treatments in the integrated control of disease will be discussed.

ESSENTIAL FEATURES OF THE BIOLOGY OF STORAGE DISEASES

Silver Scurf

During seed multiplication the main source of inoculum is the seed tuber, soil-borne contamination being considered a minor source of the fungus. *H. solani* is easily detected in dirt and dust in potato stores (Hide, 1992) and initial contamination of stocks derived from mini-tubers or VT clones is likely to occur in store.

Infection of progeny tubers can occur pre-harvest and/or post-harvest. Pre-harvest infection is probably dependant on suitable conditions for spread and infection. In general, early harvest results in limited pre-harvest infection (Hide, 1992). Infection can occur in the crucial period immediately post-harvest when air humidity and temperatures can be high and moisture may be present on tuber surfaces. Infection can continue during storage, given relatively high temperatures and humidity. The concept of 'dry-curing' has been introduced as a method of minimising early post-harvest infection by maintaining unfavourable conditions for infection (Hide & Boorer, 1991).

Pre-harvest infection can result in symptoms already being expressed at harvest, but usually symptom expression follows a period of storage. Expression can be delayed, or minimised, by holding tubers at constant low temperatures (eg $<4^{o}C$) (see Table 3) but after a period of cool storage, once tubers are placed in a warm environment, symptoms can rapidly develop.

Skin spot

Skin spot is a 'latent' disease, symptoms developing several months after infection has occurred. At harvest it is not possible to visually assess the extent of infection. Like silver scurf, the main source of inoculum is probably the seed tuber although inoculum has been found capable of surviving in soil. During multiplication from pathogen-free material, VT clones or mini-tubers, limited soil-borne inoculum may be responsible for initial infection of stocks. However, viable spores of *P. pustulans* are readily detectable in store dust (Carnegie *et al.*, 1978) and contamination of stocks during storage is probably the major method responsible for ingress of the pathogen (Carnegie & Cameron, 1987).

Inoculum of *P. pustulans* can multiply after planting as the fungus invades stem bases, roots and stolons and sporulates readily from these lesions. This explains why correlation between contamination of daughter tubers and that on seed tubers can be poor. Before harvest tuber infection, usually of eyes, is possible but the majority of infection occurs at or after harvest. Infection is very dependent on environmental conditions. Prolonged low temperatures ($4^{o}C$) and high humidity, prolonging tuber dampness, lead to extensive infection. Dry curing minimises infection. There is potential for infection throughout storage if suitable conditions for infection occur, hence tubers in refrigerated stores with temperatures as low as 1-$2^{o}C$ may be at greater risk.

Early harvest of seed crops reduces the incidence of infection. This is due to less opportunity for pre-harvest infection in the soil, a lower inoculum build up on the harvested tubers and conditions more consistently suitable for rapid drying of tubers after lifting.

Dry rot

In Scotland, dry rot has been reported and observed more frequently in recent years. This might be a consequence of widespread use of 2 amino-butane which does not control this disease, a series of dry seasons or a general move to earlier lifting. Of the pathogens associated with dry rot, *F. solani var. coeruleum* is most prevalent in Scotland. *F. sulphureum* and *F. avenaceum* are rarely isolated.

Inoculum is both soil-borne (Carnegie & Cameron, 1990) and carried on the seed tuber. Initial contamination of early generations of seed may come from the soil, or from store dust (Carnegie, 1992). Infection is dependent on damage to tubers, either directly through physical wounding during handling or indirectly through lesions of other pest and diseases (eg. slugs, common and powdery scab, gangrene). The greater the damage and/or the higher the inoculum, the greater the risk of infection.

In store, symptoms develop after a latent period. Frequently, symptoms develop after grading in January to March, implying that the most important period of infection follows damage on the grading line. However, trials by Carnegie *et al.* (1986) indicate that fungicide treatment into store gives the greatest control of dry rot. This implies that lesions inflicted at harvest are most important. Lesions may remain latent until the stimulus provided by movement during grading encourage symptom expression. However, infection through wounds inflicted at grading can occur.

Black dot

Black dot is not a common disease on Scottish seed potatoes, although the similarity in appearance to silver scurf may have resulted in it being overlooked. Major factors contributing to a lower incidence in seed are probably the enforced 5 year minimum interval between seed potato crops and generally earlier harvest. Low levels of inoculum on seed and relatively limited soil inoculum appear to result in a limited build up of the disease during multiplication. Dry curing reduces the incidence and severity of black dot especially when used in association with early harvest. Irrigation tends to increase the disease but this is unusual on seed crops in Scotland.

Gangrene

Soil-borne *P. foveata* is unlikely to be a source of inoculum for seed potato crops (Carnegie & Cameron, 1990). Diseased tubers or tubers contaminated from dust and dirt in the store (Carnegie & Cameron, 1987) are the principal sources of inoculum. The fungus develops on stems after senescence or chemical desiccation. Spores from these infected stems and from rotted mother tubers contaminate progeny tubers. This contamination increases the later tubers are havested. Infection is dependent on wounding, and may thus occur at any time tubers are handled. The disease exhibits a long latent period and symptoms following infection at harvest may not develop for several months. Sometimes grading is the stimulus for the latent infection to develop. Curing, after damage has been inflicted, can reduce infection. Conditions that are unfavourable for wound healing thus favour the disease.

Black scurf

Although some post-harvest development can occur most infection occurs pre-harvest. As resting structures, the black sclerotia of *R. solani* are found only on the tuber surface and do not usually affect the seed tuber in store. Once sprouting has begun and if conditions favour growth of mycelum, infection of sprout initials can occur. Eyes are rarely killed by the fungus and secondary sprouts can develop. Invasion of eyes can continue after planting. Infection of established stems can occur resulting in stem canker symptoms. Fungicide treatment prior to planting can limit infection of sprouts and subsequent development of black scurf on progeny tubers. However, soil-borne inoculúm is not controlled by seed tuber treatments and black scurf can develop on progeny tubers from this source.

Table 1. Summary of husbandry factors that reduce (+) tuber fungal storage disease

Husbandry factor	Gangrene	Skin spot	Dry rot	Silver scurf	Black dot	Black scurf
Cultivar resistance	+	+*	+*	+*	+*	+*
High seed tuber health	+	+	+	+	+	+
Early haulm destruction and lifting	+	+	+/-	+	+	+
Good skin set	+	-	+	-	-	-
Minimising damage	+	-	+	-	-	-
Dry curing	+	+	+	+	+	-
Minimising condensation during storage	+/-	+	+/-	+	+/-	-
Use of fungicide seed treatments at:						
harvest	+	+	+	+	-	-
grading	+/-	+	+/-	+	-	+
pre-planting	-	+	-	+	-	+
Store, box and machinery hygiene	+	+	+	+	+	-
Grading warm tubers	+	-	+	-	-	-

+* disease resistance ratings not recorded but cultivar differences exist

DISCUSSION

The need for and choice of fungicide treatment(s) during storage each year requires a risk analysis. Routine treatment will be needed if:
a) there is a high disease risk for a particular cultivar
b) there is a prevalent disease problem on the farm
c) there were significant disease levels on the seed planted

d) there is a disease which would influence marketability, even at low levels

Other factors need to be considered. These include: seasonal or husbandry factors that could increase the risk of disease, such as late harvesting; the practical potential for fungicide application and the likely effectiveness and risk of resistance following application. If the disease risk is perceived as low and good husbandry is followed, routine fungicide use is not necessary.

Fungicide seed treatments constitute an important element of seed production but their use should be considered in relation to husbandry and the time of application before selecting the fungicide to use.

Husbandry practices and their relation to fungicide use

Fungicides are not substitutes for good husbandry, indeed they work most effectively only in conjunction with good husbandry practices. Hide (1992) demonstrated that for the surface blemish diseases, silver scurf and black dot, not only were there significant individual effects on infection by seed treatment (applied prior to planting) and husbandry factors such as harvest date and dry curing but also significant interactions between factors. Thus, for example, the effect of curing was greater in earlier harvested crops.

Evidence from studies on almost all storage diseases demonstrate that early haulm destruction and early harvest minimises disease risk. This is because lower levels of inoculum are present on harvested tubers. The later the harvest, the greater the inoculum and the higher the disease pressure. Consequently, the task facing a seed treatment in a later harvest is much greater.

There are associated practical reasons why a late harvest increases the risk of disease. Soils are often wetter as the autumn proceeds and more earth adheres to the tubers during harvesting. This decreases the efficacy of fungicide treatment either by spray applications or as a fumigant. Also, with later harvests, soil and tuber temperatures have fallen with dual risks of increased tuber damage and slower wound healing.

Dry curing is another factor that can have a major influence on most tuber storage diseases. Keeping tubers dry during the early phase of storage is essential if infection is to be minimised at this critical time. Early lifting usually ensures tubers are above 10^{o}C entering store and wound healing, so essential to prevent gangrene and dry rot, proceeds rapidly. At temperatures above 10^{o}C there is usually no need to permit tuber temperatures to rise for curing. Rather, curing will proceed sufficiently fast even where ventilation to dry the tubers and maintain dry conditions is applied continuously. When tubers are lifted later in cooler conditions, not only is wound healing slower but drying is less efficient because the moisture holding capacity of the air is lower.

Rapid drying of tubers entering store, particularly when they are wet, has been complicated by the move by seed growers from bulk to box storage. In the latter it is less easy to pass air positively past all tubers. Of the many ventilation systems available, few have the potential to pass air through boxes and achieve very rapid drying of tubers.

Infection by *H. solani*, *P. pustulans* and *C. coccodes* can occur throughout storage provided conditions are suitable for infection. When the tuber temperature has fallen to that desired for long term storage (3-4^{o}C), the effect of moisture is less important. The aim, however, must be to continue to minimise condensation through judicious ventilation. The impact of the microclimate around tubers on disease development is poorly understood and deserves further investigation.

Store, box and machinery hygiene is a little studied area of potato production. Confirmation that store dust harbours spores of many fungal pathogens indicates a potential for rapid contamination of healthy stocks. A move to positive ventilation and maintenance of dry conditions throughout storage has resulted in dust becoming a major problem, particularly during grading. The benefits of thorough cleaning of stores and boxes are uncertain but removal of as much dust as possible should reduce tuber contamination. Regular cleaning of the grading line is also important but often difficult to achieve. There have been no studies on the spread of fungal spores on grading lines. The value of disinfectants to clean grading lines, stores or boxes has not been evaluated.

Fungicide timing

At harvest. For all diseases that develop in store, infection can occur at or shortly after harvest. Therefore, this is probably the most crucial time for fungicide application to control them. Carnegie *et al.* (1986) demonstrated that thiabendazole was less effective against gangrene, skin spot and dry rot the later it was applied after harvest. Even if infection occurs later in storage, the presence of fungicide on the tuber surface from application immediately post-harvest would limit it. However, despite the importance of harvest treatments, there are practical difficulties for growers applying fungicides at this time.

There are several opportunities to apply spray fungicides. The first one is on the harvester at the point where they tumble into a hopper. However, treatment on the harvester has rarely proved effective. Another opportunity comes if tubers are split dressed or pre-cleaned before storage and a final opportunity is when they pass up an elevator in store before placing in boxes. The current, widely adopted, practice of lifting straight into boxes minimises handling but restricts the opportunity for these last two options. The restriction imposed on many fungicides, that they can only be applied to seed tubers, has resulted in an increase in the practice of split grading into store. Into store separators are expensive but do present a clear opportunity for seed-size tubers to be treated with fungicide and additionally offer practical advantages to rid tubers of excess soil and reduce the proportion of lifted tubers that need to be stored as seed. However, there is the disadvantage that extra handling increases damage thereby increasing the risk of invasion by wound pathogens. When lifting in wet conditions the use of into store separators can be totally impractical.

At grading. Effective fungicide treatment at grading is far easier to achieve because fungicide can be targeted at seed to be sold rather than all the crop, soil contamination on the tuber surface has been removed and roller tables provide an even supply of tubers for efficient fungicide spray applications. Fungicide treatment at grading will only have limited effect on disease initiated at harvest. But because grading can result in wounding of tubers, fungicide applications at this time will reduce any subsequent invasion by wound pathogens. However, treatment at grading should be primarily intended for reduction of inoculum on seed to minimise spread to progeny tubers after planting.

Conditions at grading can play an important role in the risk of infection by fungal wound pathogens. When tubers are graded at temperatures close to 3-4^{o}C, damage will be greater than if they are warmed prior to grading. The curing of wounds is also slower. However, whilst warming prior to grading is a desirable objective it can be difficult to achieve.

Pre Planting. Fungicide treatment just prior to planting is also intended to reduce inoculum and spread to progeny tubers. Most of the fungicides used at this time are dusts applied to seed in the hopper of a planter. Recently, application of fungicides in a spray applied to tubers as they are collected by the planter cups has been investigated.

Choice of fungicide

Of the fungicide options available (Table 2), experience would indicate that 2-aminobutane is the most consistently effective fungicide against gangrene and skin spot. Trials support this contention (Graham *et al.*; 1981). This is not due to greater efficacy but to the fact that, by fumigation, the fungicide is usually better distributed over and absorbed into the surface of tubers (Malone, 1986). 2-aminobutane does have a restricted spectrum of activity. In particular, it does not control dry rot and where this disease is present or a variety is susceptible an additional treatment or alternative fungicide is advisable.

Those fungicides that control *R. solani* alone are generally not applied into store, although provided only the seed fraction is treated and tubers are free from soil effective control of tuber-borne inoculum is still possible. Of those combinations of fungicides where one component controls *R. solani*, there is also a presumption against applications at or soon after harvest for the same reasons.

Of those fungicides that control diseases that develop in store, thiabendazole is the cheapest option. For application into store, because it has approval for seed and ware, there is no requirement to split grade at harvest. However, the use of thiabendazole alone results in resistant strains of *H. solani* (Hide *et al.*, 1988; Burgess *et al.*, 1993), and to a lesser extent of *P. pustulans* (Carnegie & Cameron, 1992) developing. Thus the use of this fungicide is not advised at any time during seed multiplication. Where this strategy is followed ware growers should be able to use thiabendazole, their only fungicide option into store, without the risk of exacerbating infection by these two pathogens.

For varieties where silver scurf does not affect the marketability of the final crop and where skin spot resistance is high, the option to use thiabendazole would seem valid. However, because store dust can readily contaminate other varieties in a store the spread of resistant isolates to varieties where this disease is of greater importance could be rapid and is clearly undesirable.

There is, therefore, a presumption in favour of into store treatment using 2-aminobutane, imazalil alone or imazalil in combination with thiabendazole. The effect of the fungicide mixture on development of isolates of *H. solani* or *P. pustulans* resistant to thiabendazole is not

Table 2. Seed potato fungicide tuber treatments

Active ingredient(s)	Product	Formulation[1]	How applied	For use on		Application timing			Relative disease control - good (++) or moderate (+)						
				Seed	Ware	Har	Gra	Pre	GAN	SSP	DRO	SSC	BDO	SCA	BSC
2-aminobutane	CSC 2-aminobutane	SL	Fumigant	+	–	+	–	–	++	++	–	+	–	–	–
thiabendazole	Storite Clear Liquid	SL	Spray	+	+	+	+	–	++	++2	++3	++2	–	–	–
	Storite Flowable	SL	Spray	+	+	+	+	–	++	++2	++3	++2	–	–	–
	Tecto Dust	DP	Dust	+	+	+	–	+	++	++2	++3	++2	–	++	+
thiabendazole + imazalil	Extratect Flowable	SC	Spray	+	–	+	+	–	++	++	++	++	–	+	–
	Seedtect	DP	Dust	+	–	–	–	+	–	++	–	++	–	++	+
imazalil	Fungazil 100SL	SL	Spray	+	–	+	+	–	++	++	++	++	–	–	–
iprodione	Rovral WP	WP	Spray	+	–	–	+	+	–	–	–	–	–	++	++
tolclofos-methyl	Rizolex Flowable	FS	Spray	+	–	+	+	–	–	–	–	–	–	+	++
	Rizolex	DP	Dust	+	–	–	–	+	–	–	–	–	–	+	++
pencycuron	Monceren Flowable	FS	Spray	+	–	+	+	–	–	–	–	–	–	+	++
	Monceren DS	DP	Dust	+	–	–	–	+	–	–	–	–	–	+	++
pencycuron + imazalil	Monceren IM	DP	Dust	+	–	–	–	+	–	–	–	++	–	+	++

1) SL-Soluble concentrate, DP-Dustable powder, SC-Suspension concentrate, WP- Wettable powder, FS-Flowable concentrate

2) Insenstive strains have been detected 3) Insensitive strains of *F. sulphureum* have been detected

4) GAN-Grangrene, SSP-Skin spot, DRO-Dry rot, SSC-Silver scurf, BDO-Black Dot, SCA-Stem canker, BSC-Black scurf

clear. Limited evidence (Burgess *et al.*, 1993) has suggested that the mixture does not encourage resistance although this is still under investigation.

A delay in emergence has been recorded with a number of fungicide treatments, especially dusts applied pre-planting. Such effects are usually transient. However, where two fungicide applications are made, then the liklihood of delayed emergence is increased (Table 3). This effect occurs relatively infrequently and in a strategy trial in progress by SAC where sequences of fungicide treatments are being compared over several years, no major delays in emergence using treatments into store and at grading have been recorded. The benefits or otherwise of sequential fungicide treatments over the passage of several years of seed multiplication and the effect on production of a ware crop are not yet fully understood.

Table 3. SAC Potato Fungicide Strategy trial 1989-91: Effect of fungicide treatments at harvest, grading and pre-planting alone or in combination on emergence and silver scurf development on the subsequent crop stored at 4°C or 8°C for six months. Aberdeenshire.

Treatment			**Emergence (%)**		**S. scurf - April 91 (% surface area)**	
Harvest	**Grading**	**Pre-planting**	**5/6/90**	**25/6/90**	**4°C**	**8°C**
Nil	Nil	Nil	48.0	95.5	6.6	25.2
TBZ+Im	Nil	Nil	36.5	96.0	2.6	12.6
TBZ+Im	Nil	T-Methyl	18.5	98.0	1.3	4.5
Nil	TBZ+Im	Nil	46.5	98.5	4.1	11.5
Nil	TBZ+Im	T-methyl	18.5	94.5	5.9	19.8
S.E.D.			6.41	1.96	1.49	6.11

TBZ+Im - Thiabendazole + Imazalil; T-methyl - Tolclofos-methyl

CONCLUDING REMARKS

In general, the more years of multiplication there are the more likely inoculum has built up and the greater the risk of fungal storage disease. Surveys of seed stocks have shown that the percentage of tubers contaminated by *P. foveata* and *P. pustulans* was greater in lower grade stocks than for VTSC (Carnegie, 1992). This was not true for *H. solani* where contamination was similar at all grades. Every effort to minimise inoculum build up is needed, therefore, throughout seed multiplication. Thus during multiplication of VTSC fungicide treatment each year is recommended. The potential for rapid contamination by *H. solani* has encouraged VTSC growers to keep each years production in separate stores and to mainatain high hygiene standards.

To consistently produce high quality, high health status seed potatoes, attention to detail is important. In particular this will mean early haulm destruction and lifting but the financial returns must be guaranteed for a crop which is intended primarily for seed. Otherwise the grower will be tempted to leave the crop to bulk up and produce a ware fraction. Such a 'dual purpose' crop presents a greater disease risk and difficulties for selection and application of fungicide seed treatments. In the future, more rational use of seed treatments will come when rapid means of measuring inoculum levels on harvested tubers are possible and risk assessments rely less on judgement.

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POTATO TREATMENT: GETTING IT OUT OF YOUR SYSTEM

THE WORK OF THE BCPC POTATO TREATER GROUP

G.H. INGRAM (Convener) and members of the Group

c/o Rhône-Poulenc Agriculture, Fyfield Road, Ongar, Essex CM5 0HW.

SUMMARY

The BCPC Potato Treater Group was conceived about 3 years ago, and since its birth has gathered together representatives of a wide range of disciplines, who have an interest in potatoes. This interest is primarily concerned with optimizing the application of agrochemicals to seed or ware potatoes with various agrochemical products and mechanical techniques.

To this end, a series of information sheets and guidelines have been produced covering different aspects of treatment such as:-

Calibration of equipment (No. 1)
Roller table design improvement (No. 2)
Tuber disease control factors (No. 3)
Roller table efficacy (No. 4)
Tuber treatability scores (No. 5)
Disease assessment guidelines (No. 6)
Residues and deposit analyses guidelines (No. 7)

Liaison between the Group and training organisations, ATB and NPTC, has resulted in a new module PA12 for the treatment of crops on conveyor systems.

To encourage standardization and improvement in the interpretation of results of trials, etc. guidelines have been issued for the recording of both disease incidence/severity and levels of product deposits.

Future projects include:-

- the significance of surface soiling of tubers
- application volumes, the facts and myths
- improved treater systems and tuber feed systems
- information on products available and use

INTRODUCTION

The BCPC Seed Treatment Working Party has an interest in the treatment of potatoes, particularly seed tubers, and has published "Guidelines for the effective and safe treatment of potatoes" (Scott, 1990). It has long been recognised that potato treatment was overall rather "hit and miss", with each component working well, but normally unco-ordinated, resulting in widely varying quality of treatment and tuber deposit levels.

Approximately three years ago various interested parties, representing the main sectors of the potato industry, set up the BCPC Potato Treater Group in consultation with their own sectors of the industry. The BCPC Seed Treatment Working Party acted as the umbrella organization. The core Group is composed of:-

A.C. Cunnington	Sutton Bridge Expt. Stn.	representing	Potato trials/testing
P.A. Dover	ADAS (Secretary)	"	ADAS
G.A. Hide	Rothamsted Expt. Station	"	Research Organizations
R.T. Hubbard	Team Sprayers	"	Sprayer Manufacturers
G.H. Ingram	Rhône-Poulenc (Convener)	"	British Agrochemical Association
D.C. McRae	S.C.A.E.	"	Scottish Agricultural College
J.A. Nightingale	Dalgety Produce	"	National Assn. of Seed Potato Merchants
R.M.J. Storey	Potato Marketing Board	"	Potato Marketing Board
W.R. Threapleton	Golden Wonder	"	Potato Processors Assn.
A. Toon	Peal Engineering	"	Agricultural Engineers

From time to time, specialists are co-opted as required for specific skills, e.g. members of the disciplines represented.

The objectives of the Group can basically be summarized as "getting the best performance out of tuber treatment systems", such as :-

- Enhance the standards of potato treatment (initially wet liquid systems).
- Draw on the experience of all sectors of the "Potato" industry, to establish their needs and target objectives for future work.
- Promote educational material for plant operators, growers, seedsmen and merchants, etc.
- Optimize the use of the systems currently available.

- *Stimulate* investigations into the detailed problems of potato treatment and novel systems.
- Enhance the safety to operators and the environment, when using potato treaters.

It is not the objective of the Group to specifically recommend one product or one piece of equipment, but to give guidance for the optimum utilisation of products and equipment to the benefit of the industry as a whole.

THE WORK OF THE GROUP

The Group is involved in many aspects of potato treatment and, having identified factors which have a significant impact on the efficacy/application of products, produce information sheets. These have been given wide circulation at potato demonstrations, in newsletters and via various company information distribution channels.

Calibration

This was one of the first areas in which the Group had an impact. It was recognised that growers and seed houses did not necessarily match equipment calibrations and several misconceptions abounded. Typical problems were:-

- incomplete coverage of the roller table by tubers.
- arbitrary adjustment of spray pressure with different table loadings.
- inaccurate calibration of tables and sprayers omitting go-down time, box changing and using average hourly or daily work rates.

Coupling these problems easily led to over 50% reductions from target doses. Information Sheet No. 1 was issued on calibration of systems.

Tuber Size Implications

Work commissioned with Scottish Centre for Agricultural Engineering, by joint funding from industry sources, quantified the large variation in tuber surface areas due to tuber size, and the variations of tuber numbers, tuber weight and tuber volume for a range of sizes across the major UK varieties. Once the mechanical application problems are resolved, then dose rate versus tuber surface area relationships can be examined, and these may impact on product recommendations, and application volumes.

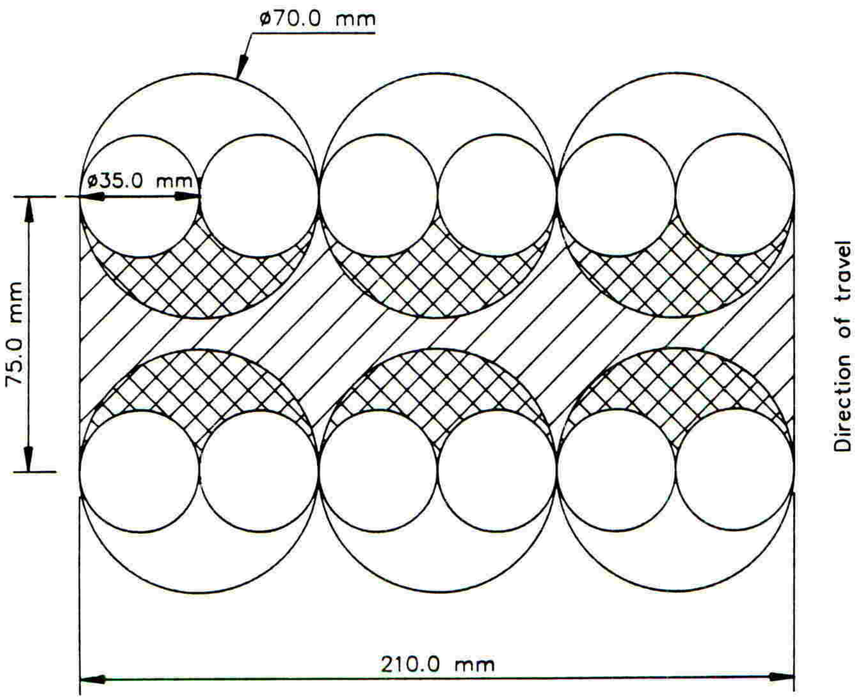
Another aspect of grading was examined, using video techniques by Writtle College. These investigations clearly showed that tubers within a narrow size band greatly improved rotation on roller tables, otherwise movement was disrupted resulting in uneven spray coverage. In addition it was found that one misshapen tuber caused abnormal movement or indeed no movement in a large area around it, out of all proportion to the tuber itself.

Thus a general conclusion was that for optimum spray deposit, even graded, well shaped tubers were necessary. A key to improve roller table efficacy was drawn up by Writtle College, and can be used to give a % score which indicates the optimization of tuber presentation to sprays. This is presented as Information Sheet No. 4.

The general conclusion was that for optimum treatment conditions evenly graded crops with no misshapen tubers gave the best chance of improving product targeting, dose implication being a subject of further debate.

Roller Tables

Under the auspices of the Group, SCAE have been investigating the potential for enhancing tuber movement on roller tables by table design, and have concluded that for treatment of seed grade tubers a treatment table that is purpose designed for such crops should be considered (Information Sheet No. 2). This would feature smaller rollers than typically used on closer centres, as shown in the diagram, which improves coverage of the tables by tubers, thus reducing the amount of product lost onto rollers. An example of the concept was produced for the Group by Peal Engineering for a recent demonstration and attracted considerable attention and several tables for "seed" treatment have now been commercially produced. The potential for lost (or off target) spray can be very high, as shown in the following diagram.



The space occupied by two sizes of potatoes (spherical shape) on rollers at 75mm pitch

7-27% of spray falling on the shaded area is wasted when spraying 70mm potatoes, depending on tuber shape. 53-63% of spray falling on the shaded area plus cross hatched area is wasted when spraying 35mm potatoes of various shapes.

In the future it is proposed to look at roller surfaces to ensure rotation even when the tubers are wet or soiled; at present smooth rollers acting like skid pans with the tubers turning unevenly, or not at all. This work would also look at the impact of tuber cleanliness on tuber rotation.

Spray Timing and Disease Development

It is important to optimize application timing for the highest level of disease control. The Group's disease specialist has drawn up Information Sheet No. 3 to aid growers, advisors, and others in selecting the best treatment timing for the target diseases on their seed tubers.

As a further aid, particularly for advisory and education purposes, the specialist has drawn up a series of disease life cycles which will shortly be available through the Group. These detail the life cycles for the major tuber diseases and will improve the understanding of potato workers for improved control measures and the importance of coverage and timeliness.

Tuber Descriptive Score

It was agreed by several areas of the industry that a means of categorising tuber condition would be advantageous. Reference to the suitability for spraying or for storage and as a means of long term reference for trials or seed lots, would assist in upgrading standards in both trials and commercial situations and in the interpretation of levels of control (or failure). Accordingly a score system has been defined by the Group's advisors and issued as Information Sheet No. 5. The key is described as follows, and can be expressed as a unique 3 digit number.

Condition of Tubers

Tubers should be assessed for each of the following factors:

A.	**Surface Moisture**	**B.**	**Soil Thickness***	**C.**	**Soil Cover %**
0	Dry	0	Clean (washed)	0	< 5
1	Damp	1	Thin	1	5-10
2	Moist	2	Medium	2	10-25
3	Wet	3	Thick	3	> 25

* A thin soil layer is one which should be penetrated by fungicide.

Treatability score	Optimal	0 or 1	in all factors
	Acceptable	2 (or lower)	in any factor
	Inadvisable	3	in any factor

A score of 110 would be ideal for treatment, etc. whereas 233 would be unacceptable for any use.

Operator and System Safety

This is an area of concern to the industry as a whole. It was found operators need to be qualified only for treatment of the seed crop, whereas considerable quantities of ware crop is treated for direct public consumption.

The ware industry representatives on the Group considered that for obvious reasons staff need the same or higher standard of qualifications .

Discussions took place with training representatives and as a result of the Group's detailed collaboration with the National Proficiency Test Council, a test module has been agreed within the Scheme, specifically for crop treatment on conveyor systems. This will be issued as module PA12.

Concern over anomalous requirements for various sectors of the industry, and in various regulations such as labelling, has prompted the Group to take these up with Pesticide Safety Directorate and these are currently ongoing.

Standardization of Terms and Methods

It soon became apparent that there was considerable variation in terminologies and methodologies within the potato industry, for both commercial and technical aspects. The Group has therefore undertaken a consolidation of the various details, including disease assessment, product deposits and product residues. This has been done in close consultation with the appropriate sectors of the industry and regulatory authorities.

As a result, two guidelines have been issued which it is hoped will result in improved standardization. These are available from the Group as:-

- Guidelines for the assessment of potato tuber diseases.
  These detail the assessment of flesh and skin diseases by using the most widely accepted methods and include expression of data, sample sizes and sample preparation.

- Definition of objectives and methodology for the analysis of agrochemical products on tubers.
  These highlight the difference between chemical deposits and chemical residues. They detail aspects of the sample preparation and selection that are required for these two different objectives.

It is hoped that these harmonizing exercises will improve exchange of data and information, and will minimize confusion caused by a multiplicity of terms.

OTHER GROUP INITIATED PROJECTS

Tuber Soiling

An area that has stimulated considerable discussion, with little hard fact, is the significance of soiling of tubers. We are encouraging some research projects into the real importance of loose skin, soil and dust in the retention (or not as the case may be) of products on the tubers, with reference to both seed and ware crops. The work aims to quantify the problem and look for solutions and simultaneously dispelling some myths.

It is currently thought that this could be a major source of loss of product post-treatment during storage and handling.

Volume of Application

There is a trend towards using medium volumes, e.g. 0.75-1.0 L/T for spraying. Over the years there have been several trends, e.g. high volume 3-5 L/T to get total coverage, medium volume 1.5-2.5 L/T for good coverage, 0.05-0.1 L/T as a concentrate spray for ease of use, minimum refilling and minimum tuber wetting. There have been many comments regarding the inducing of rots by high spray volumes and the merits of coverage and deposit levels. However, there is little real data to support or refute the various hypotheses.

Therefore the Group has encouraged and supported moves to elucidate the problem in research projects, one of which is being carried out by the Potato Marketing Board.

Treater Feed Systems

It is recognised that even and regular tuber flow onto the treatment table is important to optimize (a) tuber flow, (b) treatment quality and (c) economical use of products. Work is needed to develop the "feed-on" systems.

Improved Treatment Systems

The Group is keen to encourage collaboration between companies in different disciplines, and to develop systems of treatment that will bring together the optimum means of presenting a product to a potato. As such we have facilitated communication in some areas, resulting in improved treatment systems and novel approaches to the market in terms of specialist application equipment and treatment lines.

THE FUTURE

The Group is keen to stimulate work in many different disciplines that will generally improve the standards of potato treatment.

We welcome feed-back from the Industry on their current problems, areas which need research, and indeed the success of the current lines of communication.

It must be remembered that we are self-funding, and much of the information is derived from projects set up as a direct result of either a general support request, or because a college or company has the necessary facilities available. Therefore we would welcome any proposals for future projects, offers of assistance in carrying these out, and for future information sheets, their production and circulation (which currently stands at approximately 4,000 per issue, indicating good uptake).

ACKNOWLEDGEMENTS

The author wishes to thank the other members of the Group for their ideas, inspirations and support in the wide-ranging activities of the Group. The advice and suggestions from others in the Potato Industry is also acknowledged.

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GREEN-CROP-HARVESTING, A MECHANICAL HAULM DESTRUCTION METHOD WITH POTENTIAL FOR DISEASE CONTROL OF TUBER PATHOGENS IN POTATO

P.H.J.F. VAN DEN BOOGERT, P. KASTELEIN, A.J.G. LUTTIKHOLT

DLO-Research Institute for Plant Protection (IPO-DLO), P.O. Box 9060
NL-6700 GW Wageningen, The Netherlands

ABSTRACT

Green-crop-harvesting (GCH) is a recently developed mechanical potato haulm destruction method that helps to adequately prevent virus transmission to the progeny tubers. It provides excellent healing conditions for tuber skin damage, reduces many important tuber diseases, and provides an opportunity to control diseases on the progeny tubers in soil. Recent data on biocontrol of black scurf (*Rhizoctonia solani*) and soft rot and black leg (*Erwinia* spp.) in GCH are presented. A miniaturized model system of GCH was used to screen antagonists and their compatibility with fungicides for broad disease control. Control of black scurf was improved in GCH by application of the mycoparasite *Verticillium biguttatum*. *Erwinia* spp. also were effectively controlled by fungal and bacterial antagonists. *V. biguttatum* is tolerant of Oomycete-specific fungicides and several potential antagonists of *Erwinia* spp, so mixtures of microbial and chemical agents could be used for broad disease control in GCH.

INTRODUCTION

To prevent virus infection, Dutch growers of seed potato crops use to kill the foliage shortly after mass flights of virus-transmitting aphids begin. Simultaneously with mechanical harvesting of seed tubers, chemical and mechanical haulm killing became a standard procedure to prevent transmission of virus and *Phytophthora infestans* to the tubers. The current method to kill green potato haulms is to pulverize the foliage and then either pull the haulms or spray them with a herbicide. Black scurf caused by *Rhizoctonia solani* is an important problem in seed potato production and is strongly promoted by chemical haulm destruction and, to a lesser extent, haulm pulling (Dijst *et al.*, 1986). Tuber exudates and volatile compounds from decaying plant parts favour black scurf formation (Dijst, 1990), so the release of tuber-derived exudates should be prevented and decaying plant parts should not accumulate near tubers. A method that brings about a spatial separation between tubers and the remaining plant parts combines haulm destruction and black scurf prevention. Research on harvest methods and prevention of black scurf has led to green-crop-harvesting (GCH) which involves the following (Bouwman *et al.*, 1990):

1. removal of potato haulms by cutting off at soil level or by pulling;
2. digging up the progeny tubers;
3. placing the tubers back on a new soil bed;
4. covering them with soil to obtain new ridges for an *in situ* maturation period.

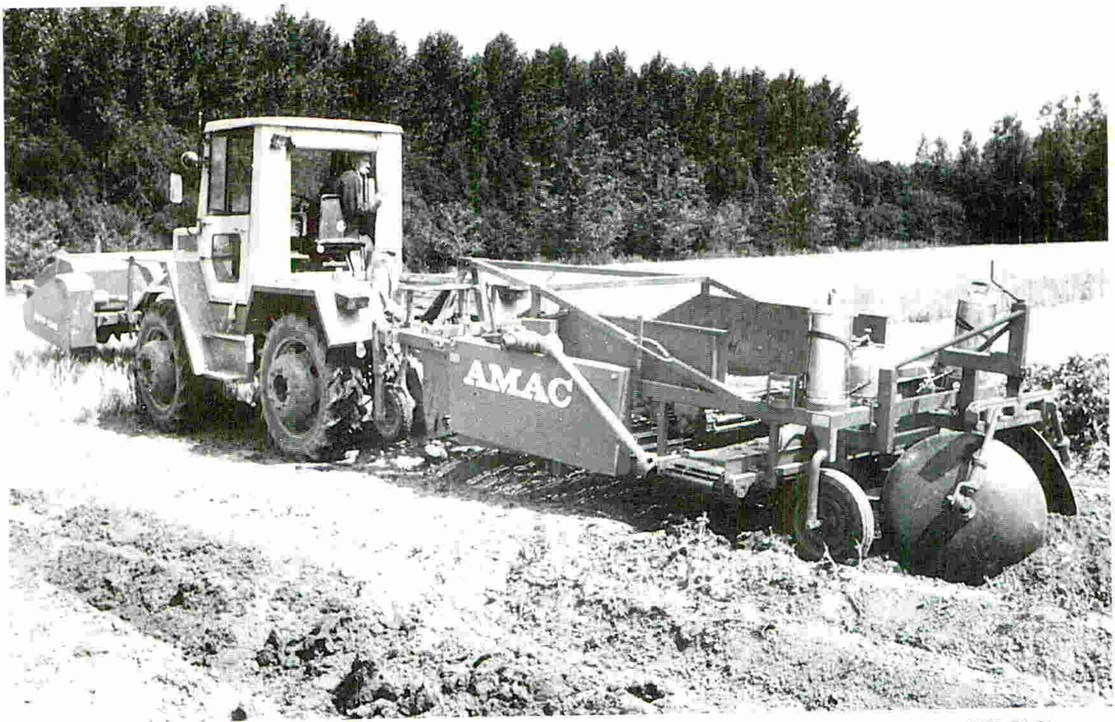

Photo courtesy supplied by Ir. A. Bouman (IMAG-DLO) and Dr. L. J. Turkensteen (IPO-DLO)

FIG. 1. Green-crop-harvesting equipment: haulm stripper in the front; tuber lifter in the middle; roto discs to built new GCH-ridges. The two containers on the back of the lifter serve to treat the tubers with antagonists and/or fungicides.

GCH is an effective haulm destruction method (Mulder *et al.*, 1992) and the specially designed diggers provide an acceptably low level of skin damage (Bouwman *et al.*, 1990) so that the incidence of some important tuber diseases compared favourably with that following chemical haulm destruction (Table 1).

TABLE 1. Effect of green-crop-harvesting (GCH) on potato tuber disease incidence compared with chemical haulm destruction (CHD) methods (Mulder *et al.*, 1992).

Tuber disease (pathogen)	Effect of GCH on disease incidence compared with CHD
Black scurf (*Rhizoctonia solani*)	decrease
Gangrene (*Phoma exigua* var. *foveata*)	decrease
Silver scurf (*Helminthosporium solani*)	indifferent
Soft rot and black leg (*Erwinia* spp.)	indifferent
Tuber late blight (*Phytophthora infestans*)	indifferent/slight increase*

* after haulm stripping/after haulm pulling, respectively.

GCH also provides the opportunity to apply control agents directly to progeny tubers after the first lifting between steps 2 and 3. For successful introduction of antagonists in GCH, the control agents must be proven to be i) effective against the target pathogen *in situ*, ii) compatible with other co-applied chemical and biological control agents for broad disease control, and iii) mass-producible at economic rates. To further reduce the dependency on chemical control agents recent research has been aimed at i) isolating and screening of antagonists for effectiveness against potato tuber pathogens *in situ* during GCH and ii) testing for compatibility with chemical control agents for broad disease control. In this review we concentrate on recent data obtained with antagonists of *R. solani* and *Erwinia* spp.

GREEN-CROP-HARVESTING AND CONTROL OF BLACK SCURF

A miniaturized model system for GCH

A bioassay had to be developed to screen potential antagonists for their suppressive properties under realistic GCH conditions. From *in situ* observations in the GCH ridges the components to be recognized as necessary are: immature progeny tubers and (diseased) potato plant parts. These may be mimiced in a miniaturized system for GCH ridges - the mini tuber system (MTS). The MTS consists of plastic containers (12 cm diam; 11 cm height) filled with 250 g natural soil and 20 mini potato tubers sandwiched between two layers of soil. Mini tubers (1 cm diam) were obtained from *in vitro* propagated potato plants (cv Bintje) grown in pots filled with compost-perlite mixture for 6 weeks. At two-week intervals mini tubers were harvested to provide uniformly sized and physiologically young tubers throughout the year. The amount of plant fragments and densities of test organisms (*R. solani* and antagonists) applied either to soil or on mini tubers were adjusted according to the experimental need. Each treatment was replicated 4 times. Soil moisture content was adjusted to and kept at 50 % water holding capacity.

Requirements for black scurf development in MTS

Below-ground plant parts left in the GCH-ridges and colonized saprophytically are thought to be the main inoculum source of facultative pathogens, including *R. solani*. The effects of plant residues on black scurf development were studied extensively in MTS. For this, mini tubers were incubated in soil amended with 1% (w/w) pulverized potato plant parts. Perlite-borne sclerotia of *R. solani* were mixed into the soil at a density of 500 particles kg^{-1}. Black scurf development on the tubers was periodically assessed and its amount was expressed as a sclerotium index (SI; 0-100). The SI was calculated as follows.

$$SI = 25(1N_1+2N_{2\text{-}5}+3N_{6\text{-}10}+4N_{>10})/N_{tot},$$

in which $N_{1,2\text{-}5,6\text{-}10,>10}$ = Number of tubers with 1, 2-5, 6-10 and > 10 sclerotia per tuber;

N_{tot} = total number of tubers

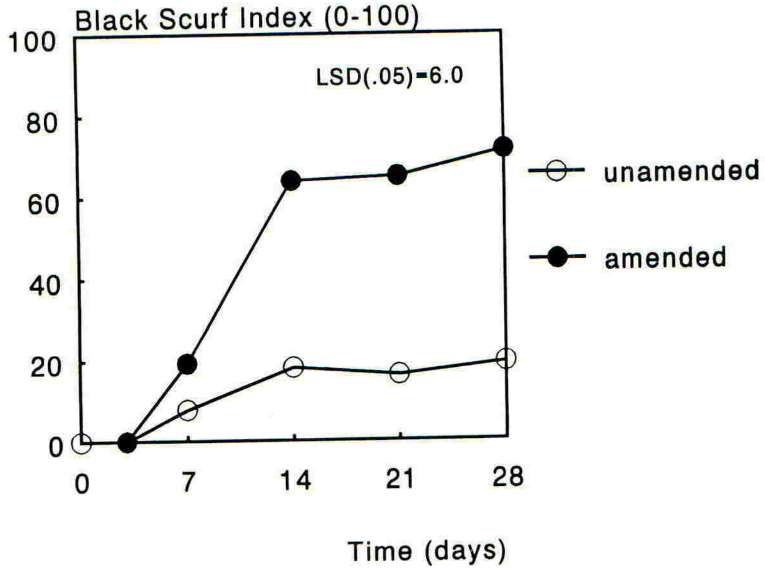

FIG. 2. Development of black scurf (*R. solani*) on mini tubers in soil unamended or amended with potato plant fragments.

Black scurf development was strongly enhanced in the presence of potato plant fragments (Fig. 2). This development of black scurf is essentially similar to that on potato tubers in the field after chemical or mechanical haulm destruction (Mulder & Roosjen, 1984). There was a linear correlation between the amount of plant residue added to soil and black scurf development in MTS. Pieces of stolon or stem added to soil caused stimulation of black scurf whilst other plant parts, such as roots or leaves caused little or no stimulation. Stem pieces from different potato cultivars gave similar black scurf responses; stem pieces from other plants caused no black scurf response (wheat), slight stimulation (peas) or marked stimulation (tomato) similar to potato. Thus, both the concentration of plant material and its source influence black scurf development on potato tubers. In the practice of GCH, part of the below-ground plant material remains present in the newly built GCH-ridges, especially after haulm stripping, so additional control measures are needed to suppress black scurf on the progeny tubers.

Screening of fungal antagonists of *R. solani.*

In an exploratory study on *R. solani*-suppressive soils, attention was drawn to mycoparasitic fungi as possible biocontrol agents of black scurf. *Verticillium biguttatum* proved to be the most effective one following seed tuber inoculation; other mycoparasites such as *Trichoderma* spp., *Gliocladium* spp. and *Hormiactis* *fimicola* were less effective (Van den Boogert & Jager, 1984). Although *V. biguttatum* has potential for practical application as a seed tuber inoculant (Jager *et al.*, 1991), its relatively high minimum temperature (> 13°C) limits its feasibility for use in Dutch conditions. However, at the time of GCH (last two weeks of July), the soil temperature is more favourable to *V. biguttatum* than the temperature at planting time. Some of the mycoparasites in the IPO-DLO collection, including *V. biguttatum* M73, were assayed for potential to control black scurf in MTS. For this, the mini tubers were dipped into conidial suspensions (10^7 conidia ml^{-1} water) following a two-week incubation period in soil amended with potato plant fragments.

TABLE 2. Effect of tuber inoculation with different antagonistic fungi on black scurf incidence as assayed in MTS after 14 days of tuber maturation.

Fungal inoculant	Black scurf index (0-100)
none	81.1 a
+ *V. biguttatum* (M73)	34.1 b
+ *Trichoderma* sp. (IVT-10)	85.8 a
+ *T. viride* (IPO-1811)	86.4 a
+ *T. harzianum* (IPO-1812)	89.5 a
+ *Gliocladium roseum* (IPO-1813)	80.6 a
+ *G. nigrovirens* (IPO-1815)	89.6 a
+ *G. roseum* (IPO-M171)	82.7 a

Data followed by the same letter are not significantly different at P=0.01

Tuber-inoculation with spores of *V. biguttatum* significantly reduced the black scurf incidence, whereas no other tested mycoparasite did so (Table 2). When individual sclerotia of *R. solani* from the *V. biguttatum* treated series were checked for viability by plating onto water agar they did not yield hyphae of *R. solani*, whilst sclerotia from the *Trichoderma* or *Gliocladium* series were still viable. The data from MTS thus provided evidence of the antagonistic potential of *V. biguttatum* under experimental conditions.

Dosage-response of *Verticillium biguttatum* on black scurf

The most feasible option for applying control agents in GCH is by spraying the progeny tubers. From a practical and economic point of view, 400 l spray liquid ha^{-1} is the upper limit for current spray equipment. Dosage-response tests were designed accordingly. Preliminary experiments on the efficiency of the spray equipment on GCH machines showed that about 10% of the spray liquid was deposited onto the tubers. Apart from any loss to the air the rest contacted the soil and might thus indirectly affect the tubers. Technical improvements in the spray methodology would seem worthwhile. To find out at what spore density of *V. biguttatum* effectively suppresses black scurf under GCH conditions, dosage-response experiments were done in MTS and in the field. For this purpose, tubers were either dipped into a spore suspension for MTS or sprayed with a spore suspension in GCH. The field experiments were laid out in a randomized block design with 4 replications. Per plot (20 x3 m) 100 tubers were rated for black scurf infestation.

TABLE 3. Dosage-response of *V. biguttatum* on black scurf in MTS and in the field after 14 and 20 days of tuber maturation, respectively.

Concentration of *V. biguttatum* spores (ml-1; equivalent of 400 l ha^{-1})	Black scurf index	
	MTS	Field
0	73 ab	24.2 a
$3.2x10^4$	70 ab	17.9 a
$1.6x10^5$	80 a	43.9 b
$0.8x10^6$	65 b	25.3 a
$4.0x10^6$	46 c	7.9 cd
$2.0x10^7$	33 d	2.2 d

Data followed by the same letter(s) in each column are not significantly different P = 0.05

A concentration of $4.0x10^6$ spores ml^{-1} in 400 l ha^{-1} gave significant and worthwhile control of black scurf in MTS as well as in the field (Table 3). For current field experiments 400 l suspension liquid (tap water) with a spore density of $1.0x10^7$ spores ml^{-1} are normally used. Spores of *V. biguttatum* can be cultured on common mycological agar media and to produce $4x10^{12}$ spores for application to 1 ha, a surface grown culture equivalent to 12 m^2 is required; there is need to develop the technology for inoculum production.

Compatibility of *V. biguttatum* with chemical control agents

When potato foliage was infected by *P. infestans*, haulm pulling led to a higher incidence of tuber blight (Mulder *et al.*, 1992). No increase of tuber attack was observed after application of chlorothalonil, mancozeb or cymoxanil at a recommended dosage for foliar application in GCH (Mulder *et al.*, 1992). However, these compounds might be incompatible with *V. biguttatum* in broad disease control. We investigated this in MTS and in the field. Potato tubers were treated with spores of *V. biguttatum* and the chemical components in mixed suspensions. Mini tubers used for MTS were dipped into the spore suspension and tubers used for field experiments were sprayed with suspension. Dosages of spores and fungicides were adjusted to equivalents of $4x10^{12}$ spores ha^{-1} and the recommended chemical dosage for foliage application in 400 l water (Table 4).

TABLE 4. Effect of tuber inoculation with *V. biguttatum* alone and with chemical control agents used for tuber late blight control on the incidence of black scurf (*R. solani*) in MTS and in the field after 14 and 20 days tuber maturation, respectively.

Tuber treatment (commercial product; a.i. kg ha^{-1}	Black scurf index	
	MTS	Field
Water (400 l)	50 a	29.3 a
V. biguttatum ($4x10^{12}$ spores in 400 l water)	28 b	17.2 b
+ cymoxanil (a.i.; 0.20)	32 bc	18.8 b
+ propamocarb (Previcur; 1.44)	34 bc	17.6 b
+ thiabendazole (Lyrotect; 1.00)	35 bc	18.0 b
+ fluazinam (Shirlan; 0.20)	43 ac	nt
+ chlorothalonil (Daconil; 1.50)	44 ac	28.1 a

Data followed by the same letter(s) in each column are not significantly different at P=0.05
a.i. = active ingredient
nt = not tested

The Oomycete-specific fungicides cymoxanil and propamocarb did not affect the antagonistic action of *V. biguttatum*. In combination with the broad-spectrum fungicides chlorothalonil or fluazinam, the antagonistic action of *V. biguttatum* was completely suppressed. Nevertheless, the broad-spectrum fungicide thiabendazole, currently used to control fusarium dry rot and silver scurf in storage, appeared to be compatible with *V. biguttatum*.

GREEN-CROP-HARVESTING AND CONTROL OF BACTERIAL DISEASES

Requirements of bacterial diseases

GCH involves the lifting of immature tubers, which are prone to damage. As skin wounds are avenues of entry for soft-rot *Erwinia* spp., it was expected that GCH would lead to a considerable increase in bacterial infection. Therefore, field experiments were done on the effect of the current chemical method of killing green potato haulm on infestation of progeny tubers with *Erwinia carotovora* subsp. *atroseptica* (Eca) and *E. chrysanthemi* (Ech). The experiments involved seed potato crops with or without supplementary inoculum of bacteria. Inoculum consisted of tubers that had been induced to rot by strains Eca (IPO-161) or Ech (IPO-502) and then buried in the ridges after pulverization of the foliage. Non-inoculated tubers were used in plots without enhanced contamination. Infestation of tubers with Eca and Ech was assessed by semi-selective isolation from peel extracts and immunofluorescence colony staining (IFC; Van Vuurde & Roozen, 1990). With IFC, the bacterial colonies in agar isolation plates were stained with FITC-conjugated antibodies raised against strains of Eca or Ech to enumerate the *Erwinia* colonies. During the 1990 and 1991 growing seasons GCH did not lead to marked increase in infestation with Eca or Ech.

Fungal and bacterial antagonists of *Erwinia* spp.

When the mycoparasitic fungi *G. roseum* (IPO-1813) and *T. harzianum* (IPO-1812) were used to control dry rot (*Fusarium sulphureum)* a remarkable reduction of tuber soft rot by *Erwinia* was observed (Mulder *et al.*, 1992). This observation led to exploratory field trials on the control of Ech (trial 1) and Eca (trial 2) in potato crops with mixtures (400 l ha^{-1}) of *Trichoderma* spp. (10^9 spores ml^{-1} in trial 1 or 10^6 spores ml^{-1} in trial 2) or *Gliocladium* spp. (10^8 spores ml^{-1}) or fluorescent *Pseudomonas* spp. (10^9 cells ml^{-1} in trial 1 or 10^{10} cells ml^{-1} in trial 2). Tubers were harvested after two and seven weeks after haulm destruction in trial 1 and 2, respectively (Table 5).

TABLE 5. Effect of tuber inoculation with fungal and bacterial antagonists on the numbers of *Erwinia chrysanthemi* (Ech in trial 1) and *E. carotovora* subsp. *atroseptica* (Eca in trial 2) on potato peel after a two-week tuber maturation period in GCH ridges.

Inoculant	*Erwinia* count (log10 ml^{-1} peel extract)	
	Ech	Eca
None	1.13 a	0.00 a
Erwinia spp. (Ech in trial 1; Eca in trial 2)	2.71 b	1.68 a
+ *Pseudomonas* spp. (WCS 358;IPO-a,b)	1.00 a	1.78 a
+ *Trichoderma* spp. (IVT-10;IPO-1811,1812)	1.43 a	0.46 a
+ *Gliocladium* spp. (IPO-1813, 1815)	1.42 a	nd

Data followed by the same letter in each column are not significantly different at
P = 0.05
nd = not determined

In trial 1 all three groups of antagonists prevented the colonisation of Ech from inoculated tubers to progeny tubers. However, trial 2 failed to show significant differences among experimental treatments. Apparently the antagonistic interactions are very specific or are influenced by site variables. It should be noted that antagonistic organisms in these trials were not selected for specific antagonism against either Eca or Ech, so the success in trial 1 holds promise for control of pathogenic *Erwinia* spp. by microbial antagonism. Currently, antagonists of *Erwinia* spp. are being isolated and screened for effectiveness and compatibility with *V. biguttatum* in MTS. So far, most of the organisms applied in trials for the control of Eca and Ech are fully compatible with *V. biguttatum* as assayed in MTS. Hence, future MTS and field experiments may show whether mixtures of antagonists can control both bacterial diseases and black scurf.

CONCLUDING REMARKS

MTS is a helpful tool in screening for antagonists under realistic conditions of GCH. *Verticillium biguttatum* is a promising biological control agent of black scurf in seed potatoes and, since it is a specific antagonist of *R. solani* (Van den Boogert *et al.*, 1989), additional means are needed for broad spectrum disease control. Some Oomycete-specific fungicides were shown to be compatible with *V. biguttatum* and in fields with high risk of tuber blight, mixtures of these with *V. biguttatum* could be applied in GCH to prevent tuber blight and black scurf on progeny tubers. In addition, a promising outlook was established for biological control of bacterial diseases with fungal and bacterial antagonists. The obligately mycoparasitic nature of *V. biguttatum* appears to ensure that it is compatible with a variety of bacterial and fungal antagonists. One of the most challenging ways to promote biological control is the development of mixtures of antagonists that control an array of plant pathogens under different environmental circumstances.

Green-crop-harvesting is an acceptable alternative to the current chemical haulm destruction method and, if it can be integrated with the use of microbial antagonists to control tuber diseases, it will satisfy the increasing demands for reduction of agrochemical inputs in agriculture.

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FUNGAL AND NEMATODE PATHOGENS OF NARCISSUS: CURRENT PROGRESS AND FUTURE PROSPECTS FOR DISEASE CONTROL

C. A. LINFIELD

Plant Pathology and Weed Science Department, Horticulture Research International, Wellesbourne, Warwick, CV35 9EF, UK.

ABSTRACT

The major limiting factor for the increased export of ornamental bulbs from the United Kingdom is disease control. *Narcissus*, the most important ornamental bulb crop in the U.K. is susceptible to several diseases whose control would offer increased export opportunity. Control of these may be achieved by modification of crop husbandry practices, chemical control and the use of field resistant cultivars. Fungicide insensitivity is an increasing problem especially in the control of *Fusarium oxysporum* f.sp. *narcissi* and *Penicillium* spp. Future opportunities for disease control lie in maximising control by crop husbandry practices, the use of alternative chemicals, biological and integrated control, pest and disease forecasting systems and the use of resistant and indexed stocks.

INTRODUCTION

The United Kingdom ornamental bulb and corm industry is dominated by one species; the daffodil. The United Kingdom is the world's largest producer of daffodils with current production at 4,000 ha per annum (Table 1). This area probably accounts for over half of the world *Narcissus* production. The U.K. has a good export trade in *Narcissus* currently valued at £4 M. The large-bulbed *Narcissus* cultivars are suited to mechanised handling of high planting densities on large farms where cultivation is compatible with cereal and potato growing. This has done much to aid the success of the crop in the U.K. As the *Narcissus* crop has increased in the U.K., so the tulip crop has declined from 360 ha in 1982 to 111 ha in 1992 (Table 1). The species making up the remainder of the 194 ha of field-grown flower bulbs in the U.K. in 1991 mainly comprise iris, anemone, lily and gladiolus. The concepts applied to *Narcissus* disease control are equally applicable to minor bulb crops and they are not considered separately here. Diseases are one of the major limiting factors to bulb production and consideration of their control is essential for cost effective management. The development in recent years of the export trade in bulbs and bulb flowers has emphasised the importance of good disease control. Bulb diseases can be controlled or their effect on quality and yield minimised in several ways; the modification of crop husbandry practices to limit disease development, use of disease resistant or tolerant cultivars, elimination or reduction of the pathogen at source and the use of fungicides/nematicides or other control agents.

Specific environmental conditions often favour development of bulb diseases and in some cases crop husbandry practices can do much to eliminate or aggravate the situation. For example, depth of planting and time of planting and lifting can influence disease incidence. Careful handling of bulbs, thus reducing wounding and bruising, prevents invasion by opportunistic fungi. In store, humidity and temperature regimes can be optimised to minimise disease progression.

Daffodil cultivars vary in their susceptibility to basal rot, some are highly resistant while the most commonly grown cultivars are very susceptible. All cultivars seem to be highly susceptible to neck rot. Many factors influence the choice of cultivar grown and the most resistant are not always the most suitable. In recent years, virus-free stocks have been released to the industry and a programme of breeding for resistance to *Fusarium oxysporum* f.sp. *narcissi* is in progress.

Elimination of the pathogen at source or reduction of inoculum level provides a further approach to control. Fungi such as *Fusarium* are able to survive in the soil for many years and soil sterilisation of hectares of daffodil fields is not practical or cost effective. However, rotations of six to seven years can reduce the inoculum level. Many bulb diseases are carried on the outside of the bulb and the planting of good pathogen-free stocks will do much to reduce disease development during the growing season. Removing affected plants during the growing period will also limit the build up of diseases in a stock.

Fungicides may be used on bulbs as protectants and or eradicants and, in some instances, provide the only effective method of disease control. They are most commonly used as foliar sprays and bulb dips. Insensitivity to fungicides is a problem which has increased in recent years. Under selection from fungicide use, insensitive variants will over a period of time, begin to account for a greater proportion of the fungal population, thus resulting in ineffective disease control. In particular, insensitive strains of *Penicillium*, *Botrytis* and *Fusarium* are increasingly a cause for concern. Recently, there have been several studies on the potential use of biological control agents (BCAS) for control of bulb diseases.

Table 1. Total areas (ha) of field-grown bulbs and allied crops in England and Wales*

	Calendar Year									
Bulb crop	1982	1983	1984	1985	1986	1987	1988**	1989	1990	1991
Narcissus	3675	3505	3616	4013	3721	3814	4047	3826	3961	3972
Tulip	360	368	282	269	235	193	190	166	127	111
Iris	56	48	36	36	31	28	26	24	32	20
Anemone	150	39	39	45	40	36	31	30	27	18
Others	109	125	155	153	155	153	157	157	157	156
Total	4350	4085	4128	4516	4182	4224	4451	4203	4304	4277

* Source: MAFF Basic Horticultural Statistics for the United Kingdom, July 1993.

** ADAS interpolations due to cancellation of October 1987 census.

FOLIAR DISEASES

The most serious foliar disease "smoulder", caused by *Botrytis narcissicola*, is currently controlled by regular sprays with MBC fungicides, dicarboximide fungicide or chlorothalonil. In years when "leaf scorch", caused by *Stagonospora curtisii*, is also a problem dithiocarbamate fungicides can be incorporated in the control programme. In the first year of a two year crop, spray programmes continue after flowering; in the second year sprays are targeted in the early part of the growing season to avoid prolonged green leaf retention. Strains of *Botrytis* insensitive to MBC fungicides are now common and strains insensitive to dicarboximide fungicides and chlorothalonil have also been reported. No cultivars are resistant to these two diseases. By avoiding the planting of infected bulbs and removing affected plants, the level of infection within a crop can be reduced.

BASAL ROT AND EELWORM

Basal rot, caused by the fungus *Fusarium oxysporum* f.sp. *narcissi*, continues to be the most serious problem faced by the bulb industry. The correct management of bulbs in the dry bulb phase is of crucial importance for the maintenance of disease free stocks.

The basal rot pathogen occurs in most soils where *Narcissus* have been grown and, although the fungus is specific to this host, it has also been recorded in soils where cultivated *Narcissus* have never been previously grown. The fungus produces three types of spores: micro-conidia, macro-conidia and chlamydospores. It is the latter that enable the fungus to survive for many years in soil and on the outside of bulbs.

Root infection and disease development are closely related to temperature. The fungus is active over the range 5° - 35°C but with an optimum for activity at 25°C. Bulb to bulb spread of the disease in soil is favoured by the high planting densities currently used. Studies on fenland soils demonstrated the distance the fungus can spread in a field. Healthy bulbs were planted, touching or at a distance of 10, or 20 cm from infected bulbs. By the end of the first season 60% of the bulbs which were in direct contact with infected bulbs were rotting. At 10 cm distance 27% of bulbs were infected, and at 20 cm distance 6% of the bulbs were infected, which was a similar incidence to infection in control plots.

Complete control of basal rot is difficult to achieve mainly because of the ability of the fungus to survive in soil for prolonged periods. However, it is possible through a combination of cultural and chemical measures to significantly reduce the level of disease in a stock. Rotation should be as long as possible, preferably 8-10 years. Bulbs should be lifted and dried early to avoid exposure to warm soil temperatures. Careful handling of bulbs and removal of diseased bulbs in the field and during lifting will reduce potential sources of inoculum. Bulbs should be stored at temperatures not exceeding 17°C before planting to reduce in-store spread of the pathogen. Planting depths of 12-15 cm are favourable to shallower planting as this avoids the warm late summer/autumn soils.

The chemical control of basal rot is closely connected to that of the stem and bulb nematode (*Ditylenchus dipsaci*). Unlike the basal rot pathogen this pest also attacks tulips, gladioli and snowdrop. Soil and debris cleaned from bulbs are the primary source of infection. Debris from a stock of bulbs with 11% infestation yielded 210,000 nematodes per 1000 bulbs (Hesling, 1967). Of the major cultivars grown none are highly resistant. As with basal rot, control involves rigorous inspection, correct rotation, removal of affected plants and chemical treatment.

Hot water treatment (HWT) at 44.4°C for 3 h is the only method of controlling the stem nematode. The addition of 0.5% formalin ensures that free swimming nematodes are also killed and additionally kills spores of *Fusarium* thus preventing bulb to bulb contamination in the tank. The addition of a benzimidazole fungicide to the HWT tank offers some protection against *Fusarium* infection after planting. When HWT is carried out within 10 days of lifting disease control is considerably improved, however this practice often causes flower damage in the first year unless bulbs are pre-warmed.

Providing a stock is not infested with eelworm a cold formalin dip within 48 h of lifting can greatly reduce the level of disease. More effective but also more expensive dips in benzimidazole fungicides can be utilised at this stage.

In recent years it has been shown that control is further improved by using a double-fungicide treatment i.e. a post-lifting dip in either formalin or thiabendazole plus a pre-planting dip with thiabendazole in the HWT. When applied annually, disease levels in a stock were substantially reduced. However in a conventional biennial crop it could take up to six years to achieve the 1% disease level required for export.

Approval has recently been granted for an alternative treatment using prochloraz (as Sportak 45) either in the HWT tank or as a cold dip with or without the addition of captan. Alternating this treatment with thiabendazole may offer some protection against the build up of fungicide insensitive populations of *Fusarium* and *Penicillium* sp.

ALTERNATIVES TO FORMALDEHYDE

Formaldehyde vapour is an irritant and, whilst the vapour levels near HWT tanks are within safety limits, working conditions in these areas are often unpleasant. Doubts about the mammalian toxicity of formalin have been raised in the USA and Germany, and stricter control on its production and use are being considered in these countries (Zell, 1984; Pearce, 1984). Because of these considerations, and the fact that formaldehyde fails to control *F. oxysporum* totally, alternatives have been sought. The aim of the tests was to assess the efficacy of compounds in killing *F. oxysporum* chlamydospores, and to determine whether they were phytotoxic to *Narcissus* bulbs (Linfield, 1991).

Compounds were tested at 44.4°C for up to 3 h (Table 2). At rates of 0.25% active ingredient and above, a glutaraldehyde formulation (Cidex) killed all spores within 160 min. Peratol, a hydrogen peroxide and peracetic acid-containing formulation, gave 100% kill after 80 min at a concentration of 0.5%. A thiabendazole formulation (Storite Clear Liquid) killed all chlamydospores, but would not be expected to exert an effect on the stem and bulb nematode. Decon 90 failed to control the fungus adequately. Formaldehyde (as 0.5% formalin) gave good, but less than complete control.

TABLE 2. Effect of chemicals on the survival (%) of chlamydospores of *Fusarium oxysporum* f.sp. *narcissi* at 44.4°C.

Time (min)	Concentration (%) of chemical							
	formalin		Cidex		Peratol		Decon	
	0.5	2.5	0.05	0.5	0.5	1.3	1.0	10
10	3.19	2.74	1.13	0.10	1.59	0.07	81	32
20	0.11	0.08	0.80	0.08	0.68	0.0	81	22
40	0.06	0.05	0.59	0.01	0.45	0.0	68	14
80	0.05	0.03	0.42	0.01	0.0	0.0	57	12
160	0.01	0.01	0.33	0.0	0.0	0.0	52	10
320	0.01	0.01	0.02	0.0	0.0	0.0	53	3

All the products were tested for their effect on the flower development of *Narcissus* cvs. St. Keverne, Golden Harvest, Ice Follies and Carlton. Bulbs had HWT at 44.4°C for 3 h in a solution containing 0.5 or 2.5% formalin. After treatment during the first week of August, bulbs were dried and planted in mid-September. The treatment was repeated, with formalin being replaced by the test products at the rates shown in Table 2. The 2.5% formalin treatment led to flower malformation and corkiness of the bulb base plate. The other four chemicals tested had no adverse effect on flower quality and yield. Further work is in progress to determine the effect of these four chemicals on the stem and bulb eelworm, and their ability to control the fungus in an infested stock. Undoubtedly one of the main factors will be their relative cost compared with formalin.

NECK ROT

In recent years neck rot has increasingly become a cause of narcissus bulbs failing export inspections. Neck rot starts at the top of the bulb in the old scape and surrounding tissues. After harvest the tissue becomes progressively rotten and typically chocolate brown in colour if the infection is caused by *Fusarium oxysporum* f.sp. *narcissi*. In other cases a gingery rot of much slower progression is observed, caused by *Penicillium hirsutum*. In some instances, a non-spreading form of neck rot is seen, caused by physical damage or non-invasive pathogens. In a survey of crop husbandry practices conducted over several years (Linfield, 1990) it was found that "top bashing" tripled the percentage rejection when compared with standard flailing. The time between flailing and lifting can also be important, with an increase in neck rot the longer the bulbs are left in the ground.

Experiments have shown that moisture is a pre-requisite for *Fusarium* infection to take place (Table 3). Application of a fungicide at flailing greatly reduces disease incidence. Practically this is difficult and a dip or spray within two days of flailing would probably suffice. *Penicillium* neck rot has been little investigated although the disease has greatly increased in recent years. This fungus is frequently seen in large quantities on otherwise healthy bulb stocks and its prevalence seems to be linked with increased fungicide insensitivity.

TABLE 3. Effect of flailing-off leaves, inoculation with *Fusarium oxysporum* f.sp. *narcissi* and fungicide treatment on the development of *Narcissus* neck rot.

Treatment Flower stalk	 Inoculated with	% Neck Rot
Left uncut	Untreated	0
Cut	Water	5.1
Cut	*Fusarium* spores*	27.4
Cut	*Fusarium* spores + thiabendazole** after 48 h	8.6
Cut	Thiabendazole + *Fusarium* spores after 48 h	8.0
Cut	Thiabendazole	1.2

* Spore suspension (1 x 10^6) applied as 2.5ml/bulb
** Applied as 1.0ml/bulb of 5ml/l Storite Clear

HOST RESISTANCE

The use of disease indexed or disease resistant stocks is an effective way of controlling disease development especially when combined with other control measures. For the fungal foliar pathogens there are few sources of resistance and the removal of diseased plants together with chemical control is essential.

About 20 viruses are known to infect *Narcissus* although many are not common. The most damaging viruses are aphid borne: narcissus yellow stripe (NYSV), narcissus degeneration virus (NDV) and narcissus white streak virus (NWSV). Yields can be seriously reduced by virus infection; 10-35% has been recorded in stocks affected with NYSV and NWSV (Asjes, 1990). Propagation schemes of virus-tested material offer an excellent opportunity for the improved health of bulb stocks. Virus-tested (VT) stocks of over 30 *Narcissus* cultivars have been produced and many of these have been released to the U.K. industry (Brunt, 1985). In Scotland, VT bulb production and certification schemes are also in place (Rankin, 1986). One problem is the rate at which virus-free bulbs become re-infected, but the wider use of VT stocks to achieve increased yield and flower quality and a reduction in export rejection is in the long term interest of the grower.

Among *Narcissus* cultivars and species there is considerable variation in susceptibility to basal rot; many of the most commonly grown commercial cultivars are very susceptible but are grown for other qualities. Significant reduction of the disease in the long term will be best achieved by growing cultivars resistant to *Fusarium*. In other crops, resistance to

Fusarium oxysporum has been found amongst the wild relatives, and this is also the case with *Narcissus* (Linfield, 1992). When species were screened for resistance to the pathogen it was found that accessions were either wholly resistant (bulbs remaining uninfected), partially resistant (a variable portion of the bulbs infected) or susceptible (all the bulbs infected). *N. pseudonarcissus*, the species from which many of the cultivars are derived was susceptible. Those species found to be resistant are now being used as parents in a breeding programme at Horticulture Research International. Progeny from these crosses will be tested to determine the heritability of the resistance. In addition, cultivars with tolerance of the disease, observed in the field i.e. St Keverne, are being crossed with large-yellow trumpet types to produce Division 1 bulbs with resistance to basal rot. In trials, continuous variation of percentage bulb survival between progenies suggests a polygenic mode of inheritance; there is no evidence of maternal inheritance. Parental general combining ability is highly significant and accounts for much of the difference in survival between progenies (Bowes *et al.*, 1992). By its nature this type of selection programme is long term, a period of 5-7 years is required to progress from seed production to the production of a bulb that will flower. Similar selection programmes are underway in Holland for resistance to *Fusarium* of tulips, gladioli and lily (van Eijk & Eikelboom, 1983; Straathof *et al.*, 1993).

MACROPROPAGATION

The slow rate of multiplication of *Narcissus* can be enhanced by the use of the chipping technique. Bulbs are divided into a number of wedge-shaped longitudinal segments, normally 8-16 from each bulb. These propagules (chips), on incubation in a suitable moist substrate, produce adventitious bulbils from the abaxial scale surface close to the junction with the base plate. *Narcissus* bulbils grow to flowering size in three to four years, and the rate of bulb multiplication is greatly increased. Such a method of enhanced multiplication is important for the propagation of virus-tested, disease resistant and other stocks. Whilst on a small scale results have been satisfactory, commercial exploitation of the technique has shown the need for adequate disinfection of chipped tissues and there have been reports of benomyl-insensitive strains of fungi associated with *Narcissus* tissue.

The major fungal pathogens in large scale chipping have been *Rhizopus* spp., largely due to the heat generated when large volumes of vermiculite are wetted. This can be avoided by ensuring the vermiculite is cool before chip incubation. Commonly found fungi on bulbs include *Penicillium* spp. *Trichoderma* spp. and *F. oxysporum* f.sp. *narcissi*. Control of all fungi in chipping is important because saprophytes otherwise become established and invade through cut surfaces to compete with the developing bulb for available nutrients. The most effective fungicide for use during chipping was captafol until its withdrawal in 1990. Since then a wide range of compounds have been tested. This included a systemic fungicide effective against benzimidazole-insensitive strains of *Penicillium*, but which was phytotoxic to the bulbils. Other fungicides tested include thiram, chlorothalonil, thiabendazole and captan.

Whilst all these fungicides gave some benefit over no-treatment, only captan proved to be as effective as captafol on the numbers and weights of bulbils produced. Combining captan with other broad-spectrum fungicides may further enhance yield and disease control.

After bulbil formation a pre-planting dip in 1% captan or 1% zineb/maneb plus a systemic compound has been found to improve skin quality, counteract basal rot and often results in higher yields.

INSENSITIVITY TO FUNGICIDES

Insensitivity to fungicides has become an increasing problem in bulb production in recent years. Forms of a fungus insensitive to one fungicide are usually also insensitive to related fungicides with the same mode of action. In some instances isolates have been found that are insensitive to fungicides belonging to more than one type . Benzimidazole insensitive isolates of *Penicillium* from *Narcissus* have been found extensively in the UK, and in Holland resistant forms have been obtained from lily and iris. Benzimidazole insensitive strains of *F. oxysporum* f.sp. *gladioli* (fusarium yellows of gladiolus) have been found in Holland and recently insensitive strains of *F. oxysporum* f.sp. *narcissi* to the related fungicide thiabendazole have also been discovered.

The use of fungicide mixtures may reduce the build up of insensitive strains and a benomyl/mancozeb mixture has given good results in trials (ADAS, 1986).

BIOLOGICAL CONTROL

Biological control of *F. oxysporum* formae speciales has proved successful (Locke *et al.*, 1985; Sneh *et al.*, 1985). The potential for integrated or biological control of basal rot was reported by Langerak (1977) who found no colonisation by *F. oxysporum* f.sp. *narcissi* in the rhizosphere of fungicide treated bulbs when the fungicide levels decreased to non-toxic levels. Roots were colonised by *Trichoderma* spp. and *Penicillium* spp. The same fungi inhibited growth of the pathogen *in vitro* and *in vivo*, so enhancing the control provided by fungicides alone. Beale & Pitt (1990) identified several soil- and bulb-borne micro-organisms antagonistic to the pathogen, some of which were tolerant to thiabendazole.

In pot trials, *Minimedusa polyspora* and a *Streptomyces* sp. reduced the incidence of disease by over 50%. In a 1-year field trial these antagonists and *Trichoderma viridae* reduced infection and increased bulb yields. The integrated use of *T. viridae* with thiabendazole gave bulb yields significantly greater than either *T. viridae* or thiabendazole alone whilst the integrated use of *M. polyspora* and thiabendazole resulted in significantly greater flower numbers and significantly fewer infected bulbs than either treatment alone. Further work has indicated that in some years the antagonists are adversely affected by environmental conditions in the field and their ability to be effective in a 2-year crop remains to be established.

A formulation of *Streptomyces griseoviridis* (Mycostop), already available in several countries, has been shown in trials in the UK to be effective against *Fusarium* in cyclamen. Its ability to control basal rot in *Narcissus* is currently being evaluated. Initial results indicate that the organism effectively reduces the incidence of infection over a 1-year *period.*

There is clearly potential for the biological and integrated control of *F. oxysporum* f.sp. *narcissi*. To establish the full potential of antagonists, efficacy tests over a 2-year period are required. Antagonists that are ecologically suited to the rhizosphere of bulbs are more likely to be successful over this time period, and more effective at excluding the pathogen from its niche. Compatibility with pesticides used in bulb production must be considered.

FUTURE PROSPECTS

Future disease control in bulbs will be dependant on good crop husbandry practices, the availability of effective control agents and disease resistant stocks. The production of *Narcissus* as an annual crop, instead of employing the normal biennial system, has been shown to significantly reduce basal rot and increase the effectiveness of fungicidal control measures. A fundamental change such as this may be worthwhile where a susceptible cultivar is grown for export or where small expensive stocks are grown. Availability of an alternative to formalin, for use in the HWT system, that gives total control of *Fusarium* and is effective against eelworm is still required. In addition to *Fusarium* and eelworm control such a chemical needs to be compatible with other fungicides used in bulb dips, of low cost, usable in early HWT without causing flower damage and easy to dispose of without the risk of environmental damage.

Virus-tested and indexed stocks are currently available in small quantities; their continued use and maintenance will do much to reduce the spread of virus infection. Breeding for resistance to *F. oxysporum* f.sp. *narcissi* is in progress and flowering size bulbs are now available. Release of material to the industry and its subsequent multiplication will provide further opportunities for improvement of stocks. With an increased concern over the continued large scale use of pesticides, biological and integrated control continues to offer an attractive alternative. Several micro-organisms have been identified as antagonists of *Fusarium* and their ability to control diseases in a biennial crop should be assessed. Much will depend on appropriate formulation and their ability to survive a range of environmental conditions over several seasons.

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THE USE OF IPRODIONE AND IMAZALIL FOR DISEASE CONTROL OF SEED POTATO TUBERS.

D. A. JAMES, S. HIGGINBOTHAM.

Rhône-Poulenc Agriculture Limited, Fyfield Road, Ongar, Essex, CM5 OHW

ABSTRACT

Iprodione and imazalil have been extensively used in the UK and in Europe for the control of most seed-borne diseases of potato tubers, when applied prior to planting. The use of new formulations suitable for the latest application equipment is described. Benefits of iprodione for optimising tuber grade are considered.

INTRODUCTION

Seed potatoes in store are vulnerable to a range of seed-borne diseases which can affect both the vigour of the seed, as well as the quality of progeny potatoes. These diseases include silver scurf (*Helminthosporium solani*), skin spot (*Polyscylatum pustulans*), dry rot (*Fusarium* spp.), gangrene (*Phoma foveata*). In addition black scurf and stem canker (*Rhizoctonia solani*) causes problems in the growing crop. Increasingly, seed potatoes are treated with a fungicide during storage to inhibit the growth of these pathogens in store and to prevent the infection of progeny (Hide & Cayley, 1981; Hide *et al.*, 1987).

In 1976 imazalil developed by Janssen Pharmaceutica, was found to be active against silver scurf, skin spot, gangrene and dry rot (Cayley *et al.*, 1981; Cayley *et al.*, 1983), giving a viable alternative to thiabendazole, with which some resistance problems were occurring (Hide *et al.*, 1988). Imazalil was launched in the UK as an emulsifiable concentrate by Rhône-Poulenc during 1988 and an improved aqueous concentrate formulation is currently marketed as FUNGAZIL 100 SL.

Iprodione was discovered in 1971 by Rhône-Poulenc, and is active in potatoes against *Rhizoctonia solani* (Cayley & Hide, 1980; Hide & Cayley, 1982; Hide & Sandison, 1985). This disease can reduce yields by affecting foliar development and by pruning stolons, reducing tuber numbers. Also it can reduce the quality of potato skin by development of black clusters of sclerotia. Traditionally, treatments have been made prior to planting to control the disease on the mother tuber and reduce the infection of the daughter tubers. However, the disease does develop mycelia in store (personal communication by Dr. S. J. Wale) and there is a case for eliminating the disease in store as well as control in the field. The benefits of this treatment for optimising target grade production have only recently been fully realised (Hardwick & Bevis, 1987). Wettable powder formulations such as Rovral WP have drawbacks in terms of handling particularly with the new ULV/LV potato treatment equipment, where there less agitation; a ready to use product is preferred. Thus a more suitable 500g /l flowable formulation of iprodione, EXP80038 has been developed. The use of imazalil and iprodione together controls all major seed-borne potato diseases, in store and post-planting.

MATERIALS AND METHODS

Formulations used;

Active ingredient	g A.I./t	Product	Application Rate
Imazalil	10	Fungazil 100 SL	100 ml/t
Iprodione	100	EXP80038	200 ml/t
Thiabendazole	40.5	Storite Flowable	90 ml/t *
Tolclofos-methyl	125	Rizolex Flowable	250 ml/t

* used as a dip only

Dip tests

Treatment

Tubers were treated by immersing them in fungicide suspensions for five minutes. Commercial formulations were made up in water to produce the required concentrations of active ingredient.

Gangrene (*Phoma foveata*)

P.foveata was cultured in 2% malt extract solution and after ten weeks the cultures were macerated and diluted with soil and water to give slurries of two inoculum levels, Pentland Crown tubers were immersed in the soil slurry, allowed to dry overnight and then given four cut and crush wounds. After fungicide treatment the tubers were stored as three replicates of fifty tubers at 5 C.

Black scurf and stem canker (*Rhizoctonia solani*)

In one test King Edward tubers with black scurf were treated with fungicides and slices of tissue bearing sclerotia incubated at 15 C. In a second test, ten moderately infected tubers of each of three varieties (Wilja, Maris Peer and Pentland Dell) were washed and then treated with fungicide. After drying , tubers were potted in a peat/sand compost and incubated at 15 C until emergence. The degree of stem canker infection was recorded after four weeks on a 0-4 scale.

Skin spot (*Polyscytalum pustulans*)

Three replicates of ten King Edward tubers affected by skin spot were fungicide treated, and dried before potting in a peat/sand compost. Pots were incubated at 15 C until emergence and then grown on for a further nine weeks. Stem base infection was recorded on a 0-3 scale.

Silver scurf (*Helminthosporium solani*)

Three replicates of twenty severely affected (>30% cover) Maris Piper tubers were washed and treated. After drying the tubers were incubated at 15 C for six weeks when *H. solani* conidia were collected by washing and centrifuging. Numbers of conidia were counted using a haemocytometer. In a second test, tubers with discrete silver scurf lesions were treated and three replicates of ten dry tubers were stored at 10 C in sealed plastic bags. The increase in lesion diameter was measured.

Field Trials

Two trials each using the same two seed stocks, Maris Piper and Pentland Squire, were carried out during 1990/1, Both stocks were infected with black scurf and silver scurf, Pentland Squire was more severely infected. In 1991/2 a third experiment was carried out on a stock of Désirée with a very low level of black scurf infection. Treatments were varied between sites and all trials were in the Edinburgh area.

Application was carried out using electrostatically charged ULV equipment (Microstat) with a total spray volume of 900 ml per tonne of seed, and treatments were applied over a roller table at a throughput of 4 tonnes per hour. Seed was stored under controlled temperature during the winter, and tubers were generally at "eyes open" to early chitting at treatment. Treated tubers were stored pre-planting under the normal conditions.. The seed was planted as randomised block field trials with four replicates and the husbandry of the trials was as recommended for local conditions. Numbers of stolons and numbers pruned were assessed and were scored as slight (1-33% stem affected), moderate (34-66%) or severe (>67%) and the results expressed as an index.

$$\text{Index} = \frac{(1 \times \%\ \text{slight stems}) + (2 \times \%\ \text{moderate stems}) + (3 \times \%\ \text{severe stems})}{100}$$

At harvest, yields in each grade were taken and samples of fifty tubers were assessed for skin disease as occurrence (% tubers infected) and severity (% tuber surface area infected). These assessments were repeated after six months storage at 4°C and 8°C .

RESULTS

Dip tests

All treatments except iprodione gave good control of gangrene and reduced dry rot incidence. (Table 1)

TABLE 1. Incidence of disease on wounded tubers immersed in solutions of different chemicals (% wounds infected after 12 weeks)

Treatment	gAI/litre	P.foveta (1)		F.solani (2)		F.sulphureum (2)	
		Low	High	Low	High	Low	High
Untreated		65	58	35	72	20	28
Iprodione	18	4	27	34	67	24	34
Imazalil + Iprodione	2 + 14	0	3	0.3	3	2	2
	3 + 21	0	0	1	2	2	2
Imazalil	2	1	2	1	4	0	1
Thiabendazole	2	0	2	0	2	0	0

(1) Assessed after 12 weeks. (2) Assessed after 8 weeks.

R.solani sclerotia germination and hyphal growth were significantly decreased with iprodione. Other active ingredients were less effective. Iprodione treatment prevented development of stem canker. Stem base browning caused by *Polyscylatum pustulans* was reduced by imazalil and in its mixtures with iprodione (Table 2).

TABLE 2. The effect of different chemicals on seed-borne diseases

Chemical	g.AI/litre	R.solani (%) Germination	Stem canker	P.pustulans (%) stems
Untreated		65	29	47
Iprodione	18	2	0	23
Imazalil Iprodione	2 + 14	0	0	2
	3 + 21	0	0	0
Imazalil	2	34	30	2
Thiabendazole	2	19	12	15

Both imazalil and iprodione greatly reduced conidial production by . Imazalil with or without iprodione had the greatest effect in reducing the increase in lesion size. Thiabendazole was ineffective (Table 3).

TABLE 3. Number of *Helminthosporium solani* conidia following fungicide treatment and increase in lesion size, 10 weeks after treatment.

Chemical	AI/litre	Number (x 10^4)	% increase
Untreated		187.7	55
Iprodione	18	17.7	27
Imazalil + Iprodione	2 + 14	13.9	24
	3 + 21	6.3	17
Imazalil	2	7.3	10
Thiabendazole	2	157.0	48

Field Trials

Stem canker was greatly decrease by iprodione and tolclofos methy in both cultivars. However with Pentland Squire stolon pruning was not proportionally decreased (Table 4).

TABLE 4. Stem canker development in growing crops, July 1991

Treatment	Timing Autumn	Spring	Pentland Squire stem canker Index	% stolon Pruning	Maris Piper stem canker Index	% stolen Pruning
Untreated			34.3	36	8.3	25.3
Tolclofos methyl		x	1.3	20	0	0
Iprodione		x	1.0	27	1.3	0
Imazalil +	x		4.3	15		
Iprodione		x				

The largest yield of Pentland Squire tubers was achieved by the combination treatment of imazalil applied in the autumn, followed by iprodione applied in spring, this was achieved by a marked increase in the yield of seed grade tubers. In Maris Piper, total yield was not affected but yields of tubers 35-55mm were significantly increased (Table 5).

TABLE 5. Yield of tubers (t/ha)

Treatment	Timing		Pentland Squire			Maris Piper		
	Autumn	Spring	Total Yield	Yield 35-55mm	Yield >55mm	Total Yield	Yield 35-55mm	Yield >55mm
Untreated			48.8	8.2	40.0	41.0	17.6	22.8
Tolclofos methyl		x	48.7	10.5	37.7	45.7	21	21.2
Iprodione		x	48.5	11.6	36.6	43.1	24.3	17.7
Imazalil	x		50.4	9.6	40.3			
Imazalil +	x		52.6	14.7	37.7			
Iprodione		x						

After harvest and on removal from long term storage, iprodione treatments had significantly fewer tubers with black scurf compared with untreated. Fewest affected tubers were from seed treated with imazalil in the autumn and with iprodione at chitting (Table 6).

TABLE 6. Assessment of black scurf before and after long term storage (4°C)

Treatment	Timing		Pentland Square		Maris Piper	
	Autumn 1990	Spring 1991	In store Oct. 1991	Out store April 1992	In store Oct. 1991	Out store April 1992
Untreated			32 (1.2)	26 (1.1)	17 (0.8)	8 (0.4)
iprodione		x	13 (0.6)	5 (0.3)	2 (0.1)	0 (0)
imazalil +	x		6 (0.3)	6 (0.4)		
iprodione		x				

Treating seed with iprodione increased total yield and yield of 35-55mm but decreased the yield of large tubers (Table 7).

TABLE 7. Yield of Tubers (t/ha)

Treatment	Timing		Desirée		
	Atumn	Spring	Total Yield	Yield 35-55	Yield >55mm
Untreated			43.3	28.5	14.4
imazalil	x		42.0	24.9	16.0
iprodione		x	45.5	31.5	13.4

After storage silver scurf was decreased by treating seed with imazalil although iprodione also had a useful effect. The severity of skin spot was reduced by imazalil. (Table 8).

TABLE 8. Silver scurf and skin spot after long term storage (4°C), May 1993

Treatment	Timing		Desirée	
	Autumn 1991	Spring 1992	% tubers infected skin spot	(% severity) silver scurf
Untreated			72 (11.7)	36 (12.6)
imazalil	x		59 (7.8)	16 (2.5)
iprodione		x	61 (11.2)	23 (5.1)

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A COMPARISON OF TECHNIQUES AND DEVELOPMENTS IN THE APPLICATION OF PENCYCURON FORMULATIONS TO SEED POTATOES

A.C. ROLLETT, D.M. ROBERTS, D.B. MORRIS

Bayer plc, Crop Protection Business Group, Elm Farm Development Station, Great Green, Thurston, Bury St. Edmunds, Suffolk, IP31 3SJ

ABSTRACT

Pencycuron was successfully applied to potato tubers using a wide range of application techniques in tests carried out from 1988 to 1993. Pre-planting treatments made with the flowable formulation using roller table applicators achieved efficiences in the range 40-70 % of target dose. Scope for obtaining the higher levels was illustrated where improved target area, electrostatic charging or higher water volumes were used. Treatments applied at planting using dry powder formulations gave efficiences of 45-60 % of target dose but tended to be more variable. The use of dispenser systems for both formulation types at planting gave comparable results and offered significant practical benefits.

INTRODUCTION

The fungicide pencycuron has shown particular activity against black scurf (*Rhizoctonia solani*) on potatoes and trials commenced in the UK during 1985 with dry seed treatment (DS) and suspension concentrate formulations. The techniques used before 1988 were described by Rollett *et al.* (1988) and biological results reported by Adam & Malcom (1988).

During 1988, work commenced with the application of the flowable seed treatment (FS) formulation of pencycuron using commercial in store equipment.

This paper reports on the efficiency, in terms of chemical loading, of the various application techniques from 73 tests carried out between 1988 and 1993. In addition to comparing existing equipment some modifications have been tested including dispenser systems for use at planting.

MATERIALS AND METHODS

All tests were carried out with seed potatoes, mostly graded 35-55 mm, and with the pencycuron formulations given in Table 1.

TABLE 1. Formulation details and application rates.

Trade name	Active ingredient	Formulation	Rate of Use
Monceren® DS	pencycuron	12.5 % DS	200 g/100 kg seed
Monceren® flowable	pencycuron	250 g/l FS	60 ml/100 kg seed

Pre-planting application

Pencycuron FS was applied by various applicators (Table 2) mounted over standard inspection roller tables with a roller pitch of *c*. 70 mm. Some work was also done using a table with a narrow roller pitch of 60 mm to improve the target area (Fig. 1). The roller tables were fully loaded and the applicator output and roller speed were adjusted to achieve the required dose.

TABLE 2. Pre planting application techniques.

Applicator	Atomiser	Volume l/t
Fischer	Single spinning disc	0.6
Mantis LK250	Twin spinning disc	0.6
Microstat	Single 'charged' spinning disc	0.6
Mistral	Twin fluid sonic nozzle	2 - 3
Hydraulic	Hollow cone 65-80°	2 - 3

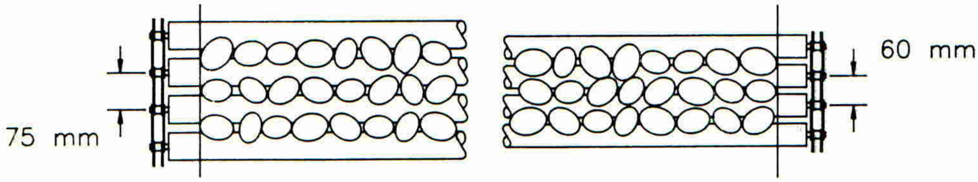


FIG 1. Effect of roller pitch on potato target area.

At planting application

Tests were performed using various makes of cup feed automatic planters and a Cramer Minor was used for much of the initial work.

Pencycuron DS was applied in the planter hopper by the standard layering technique using 1, 2 or 3 chemical layers during filling with potatoes (Fig. 2). A simulation of this technique as used in trials was achieved by treating tubers in a polythene bag (Rollett *et al*., 1985).

On-planter dispensers, including a powder applicator and a liquid applicator, metered chemical dose to the tuber pick-up area (Fig. 2). The liquid applicator dispensed pencycuron FS at the standard rate in volumes of 8-13 l/t through 65-80° cone nozzles.

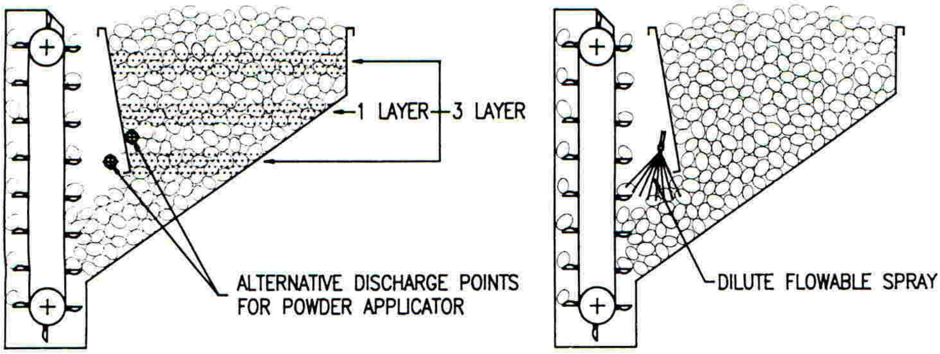


FIG 2. On-planter application positions.

Tuber sampling and analysis

Tubers were usually sampled systematically when the equipment had reached a steady state either from the treatment table or the planter cups to give 5 lots of 5 or by sampling 10 tubers from the treated bulk. They were placed individually or in fives in polythene bags and frozen prior to analysis.

Chemical loading analysis was based on the extraction of the Ceres red dyestuff, present in both formulations at a standard rate, from frozen tubers with dichloromethane. Absorption of the extract was determined at a wavelength of *c.* 500 nm using a Compur mini photometer. From the extract volume, weight of the tuber and photometer reading the tuber loadings were calculated.

RESULTS

A summary of the tuber loading results obtained from the tests conducted with the different application methods is given in Table 3. This data gives the total number of tubers analysed and the overall mean loading expressed as a percentage of the target dose.

The distribution of loadings on individual tubers is shown in Table 4 following an analysis of the data according to Tukey (1977). The median value of the data is similar to the overall mean value and 50 percent of the results lie within the box.

The results were obtained from different numbers of tests on different seed lots and at different times therefore they should be interpreted with care.

Biological data were obtained from some of the treated potatoes but this has not been included in this report. In general differences between treatments were small which reflects on the high activity of pencycuron against black scurf.

TABLE 3. Tuber pencycuron loading results.

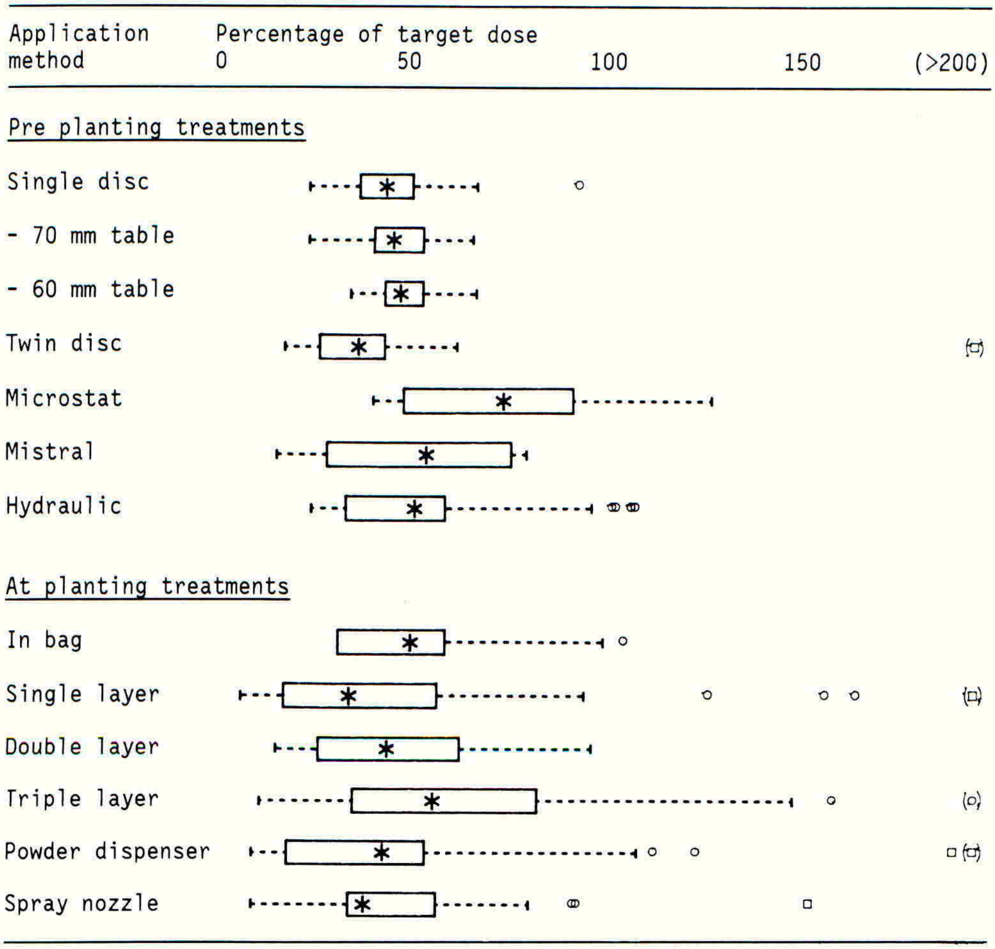
Application method	No. of tests	No. of tubers Total	Individual	Mean % target dose
Pre planting treatments				
Single disc	12	165	90	44
- 70 mm table	1	30	15	43
- 60 mm table	1	30	15	47
Twin disc	2	35	20	40
Microstat	6	150	20	72
Mistral	2	51	10	57
Hydraulic	6	105	30	58
At planting treatments				
In bag	2	49	49	55
Single layer	3	75	75	46
Double layer	3	75	30	47
Triple layer	6	150	105	65
Powder dispenser	10	243	98	43
Spray nozzle	21	590	65	48

DISCUSSION

All results were obtained from carefully supervised tests and therefore the overall achievement of a tuber loading of 40-70 % of target dose was considered high. In practice tuber treatment loadings would often be expected to be lower depending on uniformity and cleanliness of seed and operation of the equipment.

Roller table applicators depend on the table being fully and evenly filled with potatoes, however with a 75 mm pitch roller only *c.* 40 % of the sprayed area is covered with tubers (Anon, 1992). The target area can theoretically be increased by 20 % using rollers with a reduced pitch (Fig. 1). A preliminary test comparing two tables with different roller pitches and using a spinning disc applicator showed a small improvement from 43 to 47 % of target dose. Further developments on the feeding and distribution of tubers on roller tables are being pursued.

TABLE 4. Distribution of tuber pencycuron loadings from individual tuber samples - Tukey analysis.



* - median value, box - 50 % of value, ○ - outlier value, □ - extreme value

Spinning disc applicators are widely used for application on roller tables as they use undiluted product and give even distribution across the table and therefore tuber surfaces. Very consistent results were obtained in the 40-50 % of target range. Losses tended to occur due to a build-up of soil on the rollers and some excessively overloaded tubers were found when the product collected along the table edge.

The use of electrostatic charging vastly improved deposition of chemical (72 %) but increased variability. The reliability of this method in practice is a problem due to the difficulty in maintaining an even charge distribution. Higher water volumes using hydraulic or Mistral applicators also improved chemical loading (57-58 %). Dilution resulted in a more complete cover of the tuber surface and reduced losses on the rollers as the greater moisture allowed secondary redistribution.

Applications at planting have the advantage that tubers are treated as they are planted and consequently chemical losses prior to planting are eliminated. Furthermore any of the applied chemical not carried on the seed tuber can be incorporated close to the tubers in the furrow. Tuber loadings may therefore underestimate the effective dose.

Powder formulations can be effectively distributed in the planter hopper using the layering technique with more layers tending to give better tuber loadings (61 % of target). This compared well with the "in bag" experimental technique (55 % of target).

On-planter dispenser systems are likely to be restricted to planters with cup feed spacing mechanisms since a certain amount of movement of the tubers in the pick-up area is necessary to give even distribution of chemical on the tuber surfaces. Both powder and liquid applicators gave tuber loadings comparable to other techniques, 46-51 % of target, whilst saving the operator time and reducing chemical exposure.

The scope for improving tuber chemical loadings by improved roller table treatment arrangements have been demonstrated and this could result in improved product performance or lower application rates. On-planter application techniques may not be improved so easily but dispenser systems offer significant practical benefits.

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CHEMICAL SEED TREATMENT FOR FUNGAL DISEASE CONTROL IN PROGENY TUBERS

A.C. CUNNINGTON

Potato Marketing Board, Experimental Station, Sutton Bridge, Spalding, Lincs. PE12 9YB.

ABSTRACT

Seed potatoes were sprayed with a range of fungicidal treatments immediately after harvest and/or before traying up for sprouting using hydraulic or electrostatic applicators.
Imazalil treatment resulted in some delays in the emergence of crops but this did not result in any effect on saleable yield (i.e. 45-85mm fraction).
At harvest, silver scurf incidence on the progeny was reduced by treating with fungicides containing either imazalil or prochloraz-manganese complex. Development of the disease during subsequent storage of the progeny was suppressed but not prevented by the treatments in comparison with the untreated control.

INTRODUCTION

There has in recent years been an increasing need to address the problems of skin blemish diseases, notably silver scurf (*Helminthosporium solani*) and skin spot (*Polyscytalum pustulans*), with an integrated control strategy (Hide, 1992). Such a strategy would include measures like the choice of clean seed, early harvesting of the crop and the use of dry curing in store. A further area in which control of these diseases can be addressed is that of chemical seed treatment.

However, the use of fungicides for the control of silver scurf, in particular, has been hampered by the development of resistance by the pathogen to one of the key products used, thiabendazole (TBZ) (Hide *et al.*, 1988) and by a lack of new products to use as alternatives to TBZ or the specialist applied 2-aminobutane.

This trial, started in 1988, was designed to evaluate the use of some new chemical treatments which are either under development or have been recently introduced to the commercial market and to look at their effects on disease levels at harvest and, subsequently, after about six months' storage of the progeny crop grown from the treated seed.

EXPERIMENTAL DETAILS

The treatments used in the trial are detailed in Table 1. Chemicals were applied using hydraulic sprayers fitted with hollow cone nozzles except in year 3 when a Microstat electrostatic machine was used. Volumes applied were 2 l/t and 720 ml/t with the hydraulic and Microstat respectively. In each year, untreated tubers were included as controls.

Treated seed was chitted prior to planting in late March/April each year at two sites. One site (i.e. grower) was used throughout the three years of the trial (site A). The other site was at a different location in each season (sites B, C and D in 1989, 1990 and 1991 respectively).

Locations and soil types for each of the sites were: Site A.Cambs., peaty clay loam; Site B, Lincs., medium silt; Site C, Cambs., silty clay loam; Site D, Cambs., clay loam over chalk.

TABLE 1. Chemical treatments employed and application dates

Year / seed stock / treatment no. /chemical	Application date	
Year 1 (crop year 1989): Maris Piper SE2		
1. Prochloraz Mn / tolclofos-methyl	November 1988	(at lifting [L])
	January 1989	(pre-chitting [PC])
2. Imazalil [a] + iprodione [b]	November 1988	[L]
	January 1989	[PC]
3. Imazalil / thiabendazole [d]	November 1988	[L]
	January 1989	[PC]
Year 2 (crop year 1990): Maris Piper SE1		
1. Prochloraz Mn / tolclofos-methyl	September 1989	
2. Imazalil [c]	September 1989 + January 1990	
3. Imazalil / thiabendazole [d]	September 1989 + January 1990	
Year 3 (crop year 1991): Maris Piper SE1		
1. Prochloraz Mn / tolclofos-methyl	November 1990	
2. Imazalil [c]	November 1990 + January 1991	
3. Imazalil / thiabendazole [d]	November 1990 + January 1991	

a: Fungaflor C, b: Rovral, c: Fungazil (Rhône Poulenc Agriculture) d: Extratect (MSD Agvet)
January applications made at Sutton Bridge Experimental Station; all others carried out in Scotland at seed source. Untreated control = Treatment 4.

Emergence assessments (1990, 1991 only) were made on the growing crop. Crops were grown to the normal commercial practice of each grower and harvested using standard commercial equipment on the following dates:

	1989	1990	1991
Site A	18 October	25 October	8 October
Site B/C/D	8 October (B)	19 October (C)	7 October (D)

Yield measurements were made on each crop at harvest at Sites A, C & D. At site B (year 1) yield could not be accurately measured as only part of each of the 0.2 ha plots was harvested for storage at Sutton Bridge Experimental Station.

Prior to storage, disease incidence was assessed on 6 x 10kg samples taken from each treatment. Crops were then cured at 10-12°C for 7-14 days and then the temperature decreased to 5-6°C. Storage was undertaken in a commercial box store and a further 6 x 10kg samples per treatment were placed in nets within the one-tonne boxes. Two nets were placed in each of the three boxes stored. The store was unloaded after 6-7 months and assessments made on the netted samples of quality and disease incidence.

Disease was assessed on a rating scale according to the surface area affected. Grades were <2%, 2-10%, 10-25% and over 25% and the rating was calculated using the mid-points of each category (1,6, 17.5 and 62.5 respectively) to give a mean incidence ranging from 0 to 62.5. Tests in year 3 also included assessments on additional sub-samples for pre-pack quality on a 1-5 scale where 1 represented top quality and 4 poorest quality suitable for pre-packing. A score of 5 was unacceptable.

RESULTS

Chemical deposition data are summarised in Table 2. Target rates for a single application were: prochloraz Mn 50g/t; tolclofos-methyl 125g/t; imazalil 10g/t; iprodione 100g/t and thiabendazole 40g/t.

Emergence data (Table 3) showed that treatments 2 and 3 caused delay in emergence; both treatments were applied twice to seed. In 1991, when dormancy had broken early, this resulted in additional sprout damage compared with treatments 1 and 4. Tubers with 20, 53, 56 and 12% damaged sprouts were recorded on 15 February for treatments 1 to 4, respectively.

TABLE 2. Chemical deposits on seed (mg/kg detected)

Year /treatment	Prochloraz Mn	Tolclofos-methyl	Imazalil	Iprodione	TBZ
1989					
1 L	4.8	17.9	-	-	-
2 L	-	-	2.2	12.0	-
3 L	-	-	4.3	-	19.6
1 PC	na	-	-	-	na
2 PC	-	-	5.0	-	-
3 PC	-	-	na	-	na
4 +	-	-	nd	-	-
1990					
1	1.2	2.0	-	-	-
2 (x2)	-	-	3.1	-	-
3 (x2)	-	-	1.3	-	8.8
4 +	-	-	-	-	-
1991					
1	1.9	8.9	-	-	-
2 (x2)	-	-	21	-	-
3 (x2)	-	-	25	-	77
4 +	-	-	0.1	-	-

– = not tested; nd = not detected; + = untreated control; na = not available; x2 = two applications.

Effects of the chemicals on yield, however, were not always consistent with these early effects on sprouting and emergence. Yield data for site A for the three seasons (Fig. 1) showed that the effects of treatments on the total yield and the proportion of ware size potatoes varied although, in each year, treatment 2 gave a slightly lower yield than the untreated control. Also, with the exception of treatment 1 in year 1, no seed treatment increased total yield compared with the control; the proportion of ware size tubers was sometimes increased. At sites C and D, there were no trends in the yield of the saleable ware (45-85mm) fraction (Fig. 2).

TABLE 3. Plant emergence (%) ++

Year	Treatment	Site A	Site C	Site D
1990	1	91	72	-
	2	70	51	-
	3	82	60	-
	4	95	79	-
1991	1	93	-	100
	2	100	-	96
	3	87	-	87
	4	100	-	97

++assessed by minimum of 3 x 25 plant counts per treatment on the following dates:
1990: Site A, 24 May; Site C, 25 May. 1991: Site A, 11 June; Site D, 12 June

The primary objective of applying seed treatments was to control silver scurf. However, in two of the three years, silver scurf levels were generally low and only in 1990 was the incidence of the disease greater than trace level. Significant effects of treatments on silver scurf were detected in both 1990 and 1991 but the effects were inconsistent between sites (Table 4). In 1990, each of the three chemicals significantly reduced silver scurf compared with the control at site C, but not at site A. In 1991, a similar significant response was measured at site A but not site D although there were no differences between chemicals. Similarly, there was no significant effect on pre-pack out-turn (Table 5) in 1991 when the incidence of other fungal diseases was negligible at intake; this had also occurred in the two previous seasons.

After storage, progeny tubers of untreated seed usually had the highest incidence of the disease (Table 4). There was a significantly greater amount of silver scurf than in the imazalil treatment in all three seasons (mean data) and all treatments had a significantly better pre-pack score after storage in 1991/92 than untreated (Table 5). Throughout the three years, levels of other fungal diseases were low so that no effects of the seed treatments on black scurf, skin spot and black dot were determined.

TABLE 4. Silver scurf mean incidence (rating) at intake & after storage

Year /treatment		Intake			After storage		
1989/90		Site A	Site B	Mean	Site A	Site B	Mean
1 L		1.0	1.0	1.0	2.6	6.0	4.3
2 L		1.0	1.1	1.1	5.4	6.8	6.1
3 L		1.0	1.0	1.0	3.2	6.1	4.7
1 PC		1.0	1.0	1.0	5.6	6.6	6.1
2 PC		1.0	1.0	1.0	6.3	6.3	6.3
3 PC		1.0	1.1	1.0	6.2	8.7	7.5
4		1.0	1.0	1.0	5.2	10.4	7.8
sig		ns	ns	ns	***	**	**
LSD	P<0.05				1.8	2.4	1.5
	P<0.01				2.5	3.3	2.0
	P<0.001				2.6		
1990/91		Site A	Site C	Mean	Site A	Site C	Mean
1		9.2	2.7	6.0	41.5	9.6	25.6
2		9.5	3.4	6.4	28.6	11.8	20.2
3		16.1	2.4	9.2	36.4	8.6	22.5
4		14.4	8.4	11.4	47.9	15.7	31.8
sig		ns	**	*	*	ns	*
LSD	P<0.05		2.6	3.5	12.8		6.9
	P<0.01		3.8				
1991/92		Site A	Site D	Mean	Site A	Site D	Mean
1		0.1	1.2	-	5.9	4.8	5.3
2		0.2	0.1	0.2	2.7	2.4	2.5
3		0.1	0.0	0.1	0.3	1.3	0.8
4		1.5	1.2	1.3	9.1	9.9	9.5
sig		***	ns	**	**	***	***
LSD	P<0.05	0.6		0.7	4.8	2.7	2.6
	P<0.01	0.8		0.9	6.7	3.8	3.5
	P<0.001	1.2				5.3	4.7

Fig 1 Saleable yield (t/ha) 45-85mm : Site A

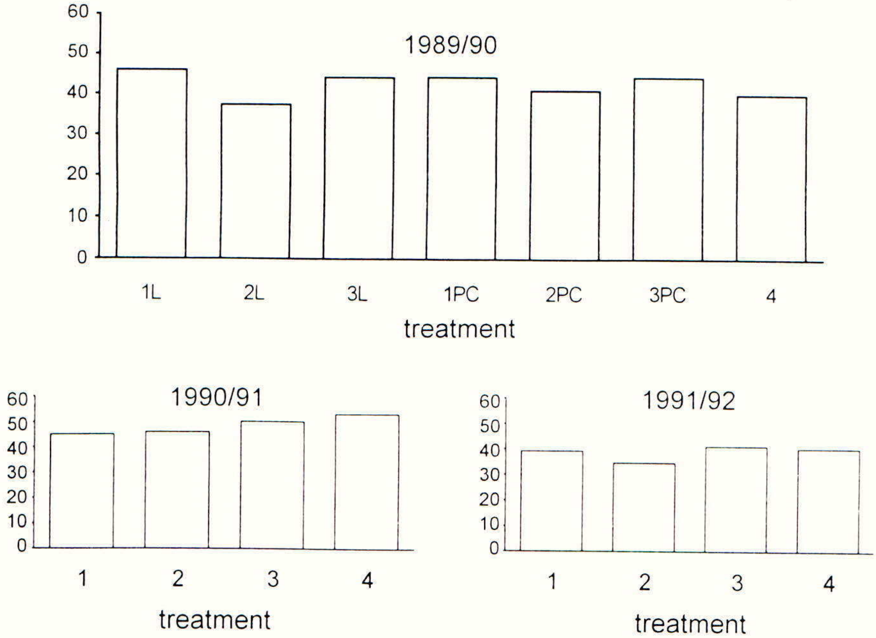

Fig 2 Saleable yield (t/ha) 45-85mm : other sites

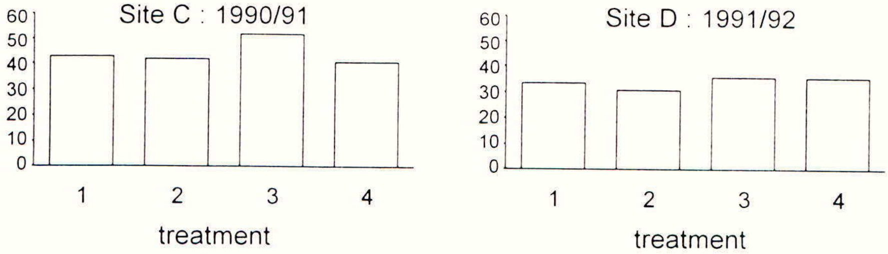

TABLE 5. Pre-pack out-turn, 1991/92 mean data (2 sites)

		Intake	After storage
Prochloraz Mn / tolclofos-methyl		2.9	2.8
Imazalil		2.9	2.8
Imazalil / TBZ		2.9	2.7
Untreated		2.8	3.1
sig		ns	**
LSD	P<0.05		0.17
	P<0.01		0.23

DISCUSSION

The use of seed treatment chemicals in this trial had slight detrimental effects on crop emergence and on yield. This could be attributable to either a phytotoxic effect of the active ingredient imazalil or, more probably, to the double application of the two treatments which caused more physical damage to the sprouts, as confirmed in 1991. Effects on yield were most marked with treatment 2, imazalil, and especially in 1989/90 where its use with iprodione resulted in a high proportion of small tubers (<45mm) in the harvest sample. Iprodione has been shown to increase the yield of seed sized tubers (Oxley & Bowen, 1993).

The major objective of the chemical treatments was silver scurf control. Total suppression of the disease was not achieved but a lower level was generally observed where chemical treatments were used, although differences between the treatments were very variable.However, chemical deposit data suggest that a principal factor was the chemical application process. Sometimes deposits were not high enough to expect good disease control. But, in 1990/91, when a high percentage of the chemical treatment was deposited on the seed, results showed a highly significant response although the incidence of silver scurf at intake was low.

Despite application difficulties which have been shown to be largely attributable to machine design rather than operation (Anon, 1992), it is apparent that all three products used in this work were effective against silver scurf on progeny tubers at harvest. Some were less successful in preventing silver scurf development during subsequent storage but this was not unexpected since the presence of any inoculum, either on the progeny crop or from adjacent stored crops could provide a source of infection. Because of this risk of cross-contamination, results after storage should be treated with caution but are a realistic illustration of the situation likely to be encountered in commercial storage.

The chemical seed treatments tested, exhibited good disease control characteristics, particularly with regard to silver scurf, but problems with application probably limited their success. Although the chemicals did not prevent disease development during storage of the progeny, their relative effects seen at intake were generally still evident after storage. Some benefits of seed treatment were therefore carried through to the stored ware crop, which will be sold for consumption.

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CONTROL OF GANGRENE, DRY ROT, SKIN SPOT AND SILVER SCURF ON STORED SEED POTATO TUBERS BY IMIDAZOLE AND PHENYLPYRROLE COMPOUNDS

S. F. CARNEGIE, A. M. CAMERON, D. A. LINDSAY

Scottish Agricultural Science Agency (SASA), East Craigs, Craigs Road, Edinburgh, EH12 8NJ

ABSTRACT

The efficacy of imidazole and phenylpyrrole fungicides in controlling storage diseases of potato tubers was compared with an established fungicide treatment, 2-aminobutane applied as a gas. In the trial incorporating 3 stocks, the fungicides were applied using an electrostatic sprayer. Best control of gangrene and skin spot was achieved with 2-aminobutane or with a formulated mixture of thiabendazole and imazalil. This mixture gave complete control of dry rot caused by Fusarium solani var. coeruleum while fenpiclonil and a mixture of prochloraz and tolclofos-methyl also gave good control. The largest reductions in silver scurf were achieved following applications of fenpiclonil or the mixture of thiabendazole and imazalil.

INTRODUCTION

Storage diseases are a major problem for seed growers who are aiming to present their customers with blemish-free tubers. The most important are two latent diseases: gangrene, a fungal rot, caused by Phoma foveata and skin spot, caused by Polyscytalum pustulans, affecting both viability of eyes and skin appearance. Dry rot (Fusarium solani var. coeruleum) can cause severe rotting of tubers after grading late in the storage season leading to blanking and uneven emergence in the field. Silver scurf (Helminthosporium solani) has become increasingly important for the ware grower marketing washed, pre-packed tubers and this has increasingly led to requests for seed tubers with minimal infections of the pathogen.

Until 1991 the main fungicides used in Scotland to control storage diseases of potato were 2-aminobutane (2-AB) applied as a gas and thiabendazole (TBZ) applied as a spray. While gangrene and skin spot are controlled by 2-AB, the fungicide only reduces silver scurf and does not control dry rot (Graham et al., 1973). Its approval, as a fungicide under the Control of Pesticides Regulations 1986, is now limited to seed, making its usage less attractive to growers who have to separate seed and ware before applying the fungicide. TBZ can be applied to both seed and ware crops; however isolates of P.pustulans and H.solani resistant to TBZ have been found in Scottish seed tubers (Hide et al., 1988; Carnegie & Cameron, 1992). Treating tubers bearing resistant isolates with TBZ is likely to result in poor disease control (Hall & Hide 1992; Carnegie, 1992).

Alternative fungicides are being developed and some of these have recently gained full commercial approval for use on potato tubers (imazalil) or are likely to do so in the near future (prochloraz, fenpiclonil). However, in field trials with these fungicides, the predominant disease has been silver scurf followed by skin spot with only a few reports of rot diseases (Cayley et al., 1983; Oxley et al., 1990; Burgess et al., 1993). This paper reports the results of a trial made in 1992-93 to determine the efficacy of these fungicides applied after harvest to tubers of three stocks selected to produce a range of diseases.

MATERIALS AND METHODS

In 1992 seed tubers of a stock (stock 1) of cv. Pentland Squire classified Super Elite 1 were obtained from a farm in Perthshire where dry rot had occurred the previous year. The tubers were machine harvested on 27 September, sized over riddles and one tonne of the 35-55 mm fraction was delivered to East Craigs on 29 September. Tubers were clean and dry and spray applications were made on the day of delivery.

Tubers of cv. Pentland Squire were also produced at SASA Gogarbank Farm by planting seed from two stocks. In stock 2 most tubers bore gangrene lesions and were sparsely affected by skin spot. From stock 3 in which skin spot was common, tubers for planting were mixed in the ratio of two tubers bearing dry rot lesions to one rot-free. Tubers were planted on 6 May and haulm killed by applying diquat dibromide (Reglone, ICI) on 24 August. Tubers were harvested on 7 October by single row digger into 0.25 tonne boxes and spray applications made on the same day. Tubers were damp with soil adhering.

The fungicides tested were imazalil (Fungazil 100SL, Embetec), thiabendazole + imazalil (Extratect, Merck Sharp & Dohme Ltd), prochloraz manganese chloride complex + tolclofos-methyl (Sporgon 50 + Rizolex Flowable, Schering), fenpiclonil (proposed name Gambit, Ciba Geigy) and 2-aminobutane (Chemical Spraying Co Ltd). The first four fungicide formulations were applied as sprays using an electrostatic sprayer (Microstat, Horstine Farmery Ltd) on a roller table with a throughput of 5 tonnes/hr. The intended application rates (mg AI/kg) were 40 TBZ, 10 imazalil, 50 prochloraz, 124 tolclofos-methyl and 50 fenpiclonil. The fumigations with 2-AB were made on 14 October (stock 1) and 30 October (stocks 2 and 3) using a 1 tonne capacity chamber and a dosage rate of 200mg/kg. For each treatment there were 4 replicate batches, each of 80 tubers. Each batch was kept in a numbered net bag in a 0.25 tonne box.

On 7 January tubers were passed over a reciprocating riddle, rots counted and removed, and remaining tubers stored until a final assessment of rots was made in late March. The identity of the pathogens causing rots was confirmed by placing a small sample of pieces of tissue from edge of rots on 2% malt agar. Fifty tubers from each replicate were washed and assessed for % surface area affected by skin spot and silver scurf (Carnegie et al., 1994).

Tubers for fungicide deposit analysis were stored at 4°C and tests made on a representative sample of opposite quarters from at least 5 unwashed tubers. Deposits of 2-AB were extracted by steam distillation and determined by hplc using fluorescence detection as described by Hunter & Lindsay (1981), except that automated on-line derivatisation with orthophalaldehyde was used. TBZ, prochloraz and tolclofos-methyl deposits were extracted with ethylacetate, and imazalil and fenpiclonil with acetone. These fungicides were determined directly by reverse phase hplc using fluorescence detection for TBZ and ultra-violet diode array detection for the remainder.

RESULTS

Deposits of imazalil were similar when applied alone or in the mixture (Table 1). The proportion of fungicide deposited on the tubers relative to the intended dose was 44% for imazalil, 38% for TBZ, 34% for prochloraz, 43% for tolclofos-methyl and 58% for fenpiclonil. Much less 2-AB was present on tubers from stock 1 (3%) than from the other two stocks (11%).

TABLE 1. Fungicide deposits (mg/kg) on unwashed tubers of three stocks treated with fungicide after harvest.

Fungicide	Stock number 1	2	3
2-aminobutane	5.7	24.8	19.8
imazalil	4.0	5.1	2.9
thiabendazole + imazalil	15.0 + 5.3	13.6 + 4.4	17.0 + 4.5
prochloraz manganese complex + tolclofos -methyl	18.7 + 58.9	19.4 + 59.7	13.6 + 41.9
fenpiclonil	32.8	28.7	25.7

Gangrene developed on stock 2 only (Table 2). All fungicides reduced the incidence of rots; 2-AB was most effective giving a 90% reduction and fenpiclonil least effective giving a 33% reduction. Dry rot developed on the untreated tubers of all stocks and was most prevalent on stock 3 (Table 2). Virtually all rots were caused by *F.solani* var. *coeruleum*. On all stocks the incidence of dry rot was greater following treatment with 2-AB than with no treatment. The mixture of TBZ and imazalil gave 100% reduction in dry rot whereas imazalil alone was ineffective in controlling dry rot on stocks 1 and 3 but was 100% effective on stock 2. The mixture of prochloraz and tolclofos-methyl, and fenpiclonil also gave good control with reductions ranging from 78 to 100%.

TABLE 2. Percentage (degrees) tubers affected by gangrene (*Phoma foveata*) and dry rot (*Fusarium solani* var. *coeruleum*) on three stocks in relation to fungicide treatment after harvest.

Fungicide	Gangrene	Dry rot		
	2	1	2	3
Nil	15.5	4.7	6.6	16.9
2-aminobutane	1.6	11.5	8.8	27.6
imazalil	6.4	6.9	0	13.9
thiabendazole + imazalil	4.0	0	0	0
prochloraz manganese complex + tolclofos -methyl	6.6	1.6	0	3.8
fenpiclonil	10.4	0	1.6	2.2
SED (32 DF)	2.81	1.72	2.18	3.19

Skin spot was most severe on stock 2 (Table 3). The mixture of TBZ and imazalil gave the best control of skin spot on all stocks (66-86% reduction). Control with 2-AB was similar on stocks 1 and 3 but less (48%) on stock 2. The other three fungicides gave smaller reductions in skin spot. Silver scurf on stock 1 was almost three times as severe as on the other stocks. The mixture of TBZ and imazalil gave best control although the reduction, 55-75%, was smaller than that achieved for skin spot. Fenpiclonil was slightly less effective than the mixture of TBZ and imazalil; however both imazalil and prochloraz/tolclofos-methyl mixture reduced the severity of silver scurf only on stock 1.

TABLE 3. Surface area (index) affected by skin spot and silver scurf on three stocks in relation to fungicide treatment after harvest.

Fungicide	Skin spot			Silver scurf		
	1	2	3	1	2	3
Nil	4.4	13.0	6.7	41.5	14.8	9.3
2-aminobutane	1.3	4.4	1.4	31.1	11.6	7.2
imazalil	2.2	6.8	2.3	27.2	15.0	9.4
thiabendazole + imazalil	1.5	1.8	1.5	10.2	6.2	4.2
Prochloraz manganese complex + tolclofos-methyl	3.1	8.1	3.5	24.9	14.7	8.8
fenpiclonil	3.6	7.8	3.8	15.6	7.3	8.2
SED (32 DF)	0.80	0.80	0.66	2.67	1.22	1.45

DISCUSSION

Our results show that overall the best control of the four diseases was achieved by applying the mixture of TBZ and imazalil. This formulation was as effective as 2-AB in controlling gangrene. Furthermore this mixture provided complete control of dry rot whereas the application of 2-AB appeared to enhance its development. Carnegie et al., (1990) also reported a stimulation in dry rot associated with 2-AB treatment which was partly related to the treatment causing necrosis of damaged tissue allowing entry of the pathogen. However, this type of chemical damage of the tuber skin was not seen in this experiment.

Imazalil and the mixture of prochloraz and tolclofos-methyl tended to give the same degree of control except for dry rot; this mixture gave good control on all stocks but imazalil was ineffective on 2 stocks. Both fungicides reduced silver scurf but were not as effective as fenpiclonil or the mixture of TBZ and imazalil. Leadbeater & Kirk (1992) reported that fenpiclonil was effective in controlling tuber rotting by F.solani var. coeruleum after planting. Our results show that the fungicide is effective in controlling dry rot in store but is less effective in controlling gangrene. Also fenpiclonil was slightly less effective in controlling skin spot than imazalil whereas Leadbeater & Kirk (1992) found that the fungicides were similar in their effectiveness.

In trials where tubers were dipped in suspensions of the mixture of TBZ and imazalil, the ratio of TBZ to imazalil deposited on the tuber was in the range of 1:1 to 1:2 (Carnegie et al., 1994). In these trials where the formulation was applied as a spray the ratio was 3:1 matching the ratio of the formulated product. It would thus appear that the method of application can effect the amount of fungicide deposited on the tuber. This emphasises the importance of measuring chemical residues on the tubers in any experiments evaluating the efficacy of fungicides.

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