LOCAL WEATHER DATA FROM A WIRELESS COMPUTERIZED WEATHER STATION AND ITS POTENTIAL FOR USE IN CROP DISEASE MANAGEMENT

M.B. HØSTGAARD

Hardi International A/S, Helgeshøj Allé 38, 2630 Taastrup, Denmark

ABSTRACT

The HARDI METPOLE® is a new fully equipped weather station with the major advantage of wireless transmission of weather data to a PC. The equipment and its data presentation software have been developed to be utilized by farmers, agricultural advisers and researchers.

It is equipped with sensors for collection of the following weather data:

Wind velocity,	2.0 metres above the ground.
Surface wetness,	2.0 metres above the ground.
Global radiation,	2.0 metres above the ground.
Air temperature,	1.5 and 0.2 metres above the ground.
Air humidity (%RH),	1.5 and 0.2 metres above the ground.
Rainfall,	1.2 metres above the ground.
Soil temperature,	0.1 and 0.3 metres depth.
Soil water content,	0.1 and 0.3 metres depth.

The data are transmitted by radio waves to a receiver at the farm and presented in the PC-software. All data can be transferred to files in ASCII-format and used in any other software programme for future use in computerized monitoring and forecasting systems. This has been done in the computer-based Danish decision support system: PC-Plant Protection for yellow rust, powdery mildew and *Septoria tritici* in winter wheat for tests in 1994. With the NEGFRY model for potato blight the results from 1993 and 1994 show that it is possible to reduce the number of sprayings against potato blight by 50% when using local weather data in the forecasting model.

INTRODUCTION

These years much work is being done to develop monitoring and forecasting models in many different crops. In most cases various types of weather data form part of the models. To achieve optimum utilization of the models it is important that the used weather data are measured locally. Hardi has developed a portable weather station - the HARDI METPOLE® - intended to be placed in or at the actual crop. This weather station is fully equipped with the immense advantage of having wireless transmission of data to a PC. As there is no need for cables or manual logging of data, the Metpole is especially suited for registration of weather data at localities far from electrical installations and where changing sitings are suitable, just as the constant and automatic registration of weather data would be a big advantage to all researchers who are to develop forecasting models and evaluate test results.

GENERAL USE OF WEATHER DATA

In many countries models comprising weather data for the forecasting of growth, fructification, fruit quality, size and yield are already used. Likewise, there are models today which through recorded weather data can forecast the best time for tillage, sowing, weed control and attack of diseases and pests, irrigation, pruning, and harvest. There are, of course, good models too for the risk evaluation of nitrate leaching. Within the framework of the EU, forecasting models for the yield of all main crops within the Union have been developed. These models are all based on recorded climatic data.

USE WITH CROP PROTECTION MODELS

One purpose of developing weather based monitoring and forecasting models within crop protection is to be able to determine the need for protection and a possible exact time of spraying. This means that unnecessary sprayings could be avoided, for instance preventive disease control. In the Danish computer-based decision support system PC-Plant Protection, weather data are being incorporated, and preliminary forecasting models for fungal diseases and pests have been field tested in 1994 (Secher, 1993). An example of the graphic presentation in PC-Plant Protection of the daily indices for yellow rust, powdery mildew and *Septoria tritici* is shown in Fig. 1. Two indices for septoria are shown in this example. One generel using daily weather data, and a specific for *Septoria tritici* using hourly data.

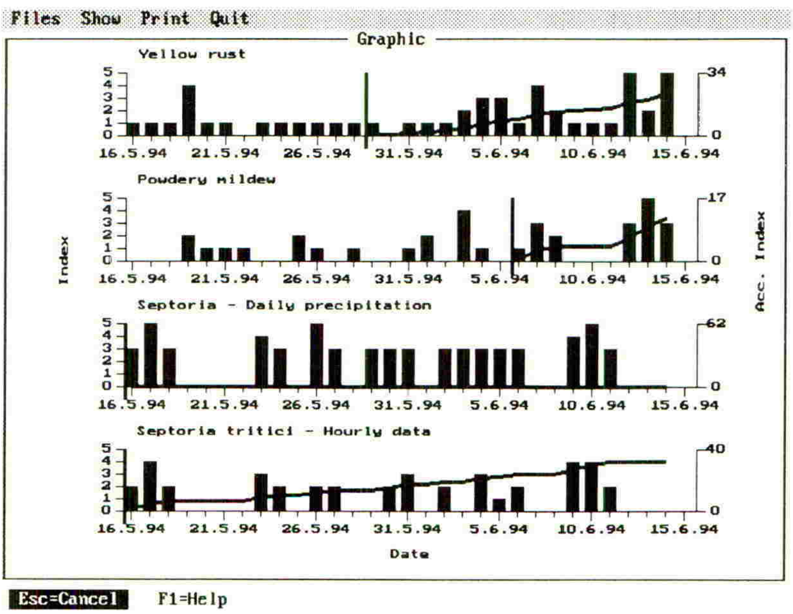

FIG. 1 Disease indices in winter wheat as presented by the PC-Plant Protection weather module. The columns show daily risk indices. The graphs show accumulated risk indices. The vertical lines indicate the start of the latest latent period.

Bugiani *et al.* (1992) and Gutsche (1992) proved in tests through several years that the utilization of monitoring and forecasting models based on registered weather data averaged resulted in a 50% reduction of the number of sprayings against late blight (*Phytophthora infestans*) in potatoes. Tests carried out in Denmark with local weather data measured with the Metpole in 1993 and 1994 confirm this experience (Hansen & Simonsen, 1994). Fig. 2 shows the accumulated risk value and blight units for the 1993 season. The first preventive spraying is recommended at an accumulated risk value of 160. Each time the horizontal line is reached (e.g. 40 for a susceptible cultivar) preventive spraying is recommended. The spray recommendations are shown for three cultivars with different susceptibilities.

WEATHER DATA FOR OPTIMUM SPRAYING

For most pesticides there will be conditions under which the product has the best effect. If we are talking about spraying against weeds, the development stage of the weed is of immense importance, but furthermore it applies to all sprayings that the actual weather conditions have a great influence on the dosage necessary to solve the problem in question. You may define **the optimum spraying conditions** in the following way:
Minimum 3 consecutive h between 4 a.m. and 8 p.m. where the following conditions have been met: the temperature must be above 1°C at the time of spraying and must reach 10°C during the day. Temperature must not be below 1°C the following night. Less than 0.1 mm rain should fall during the spraying and less than 2 mm from 3 h before till 6 h after the spraying. The relative humidity should be between 50 and 95%. The wind velocity must not exceed 4.0 m/s. When these demands have been fulfilled, you may as a rule (dependent on the developmental stage of the crop) use a minimum dosage.

Optimum spray hours

By analyzing weather data from 10 official weather stations in Denmark from 1988-1991 we find that the above mentioned optimum spraying conditions on an average have been met 4.5 h/d in May. However, it varies a great deal from station to station: Foulum states 2 h and Tystofte on Sealand states 7 h. If the farmer has his own weather station and knows the weather forecast of the day, he may check with his PC screen immediately before the spraying that the spray conditions are the optimum for the crop in question. In the future the developed forecasting programmes and more to come will be integrated in the Danish PC-Plant Protection programme and the weather data are then transferred automatically from the Metpole programme and can be combined with a model for optimum spray conditions.

THE WEATHER STATION

The weather station is equipped with 12 sensors as shown in Fig. 3. The total height of the pole is 2.5 m, where 0.5 m is placed in a drilled hole in close contact with the soil. The total weight of the pole is about 5 kg, including the supporting metal tripod. The power is supplied by a pack of seven (1.5 volt) alkaline batteries in a battery house, which is also placed under the soil surface.

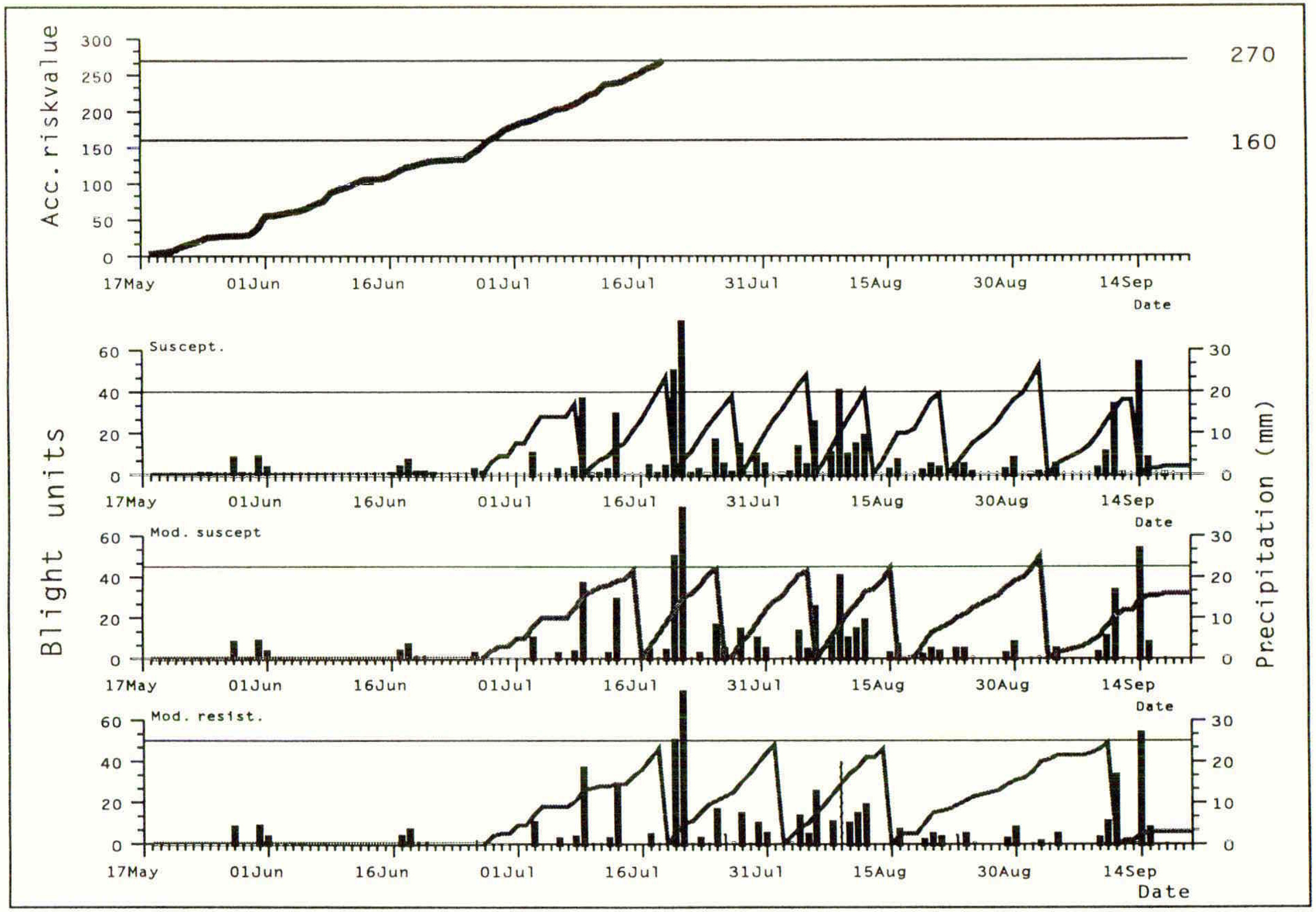

FIG. 2. The accumulated risk value and blight units in three potato cultivars with different susceptibilities as presented in the NEGFRY forecasting programme.

The weather data are measured at 10 min intervals. Every 30 min the three measurements from each sensor are averaged and transmitted to a receiver at the farm. The transmission distance is up to 5 km. One receiver is able to handle data from up to 20 Metpoles.

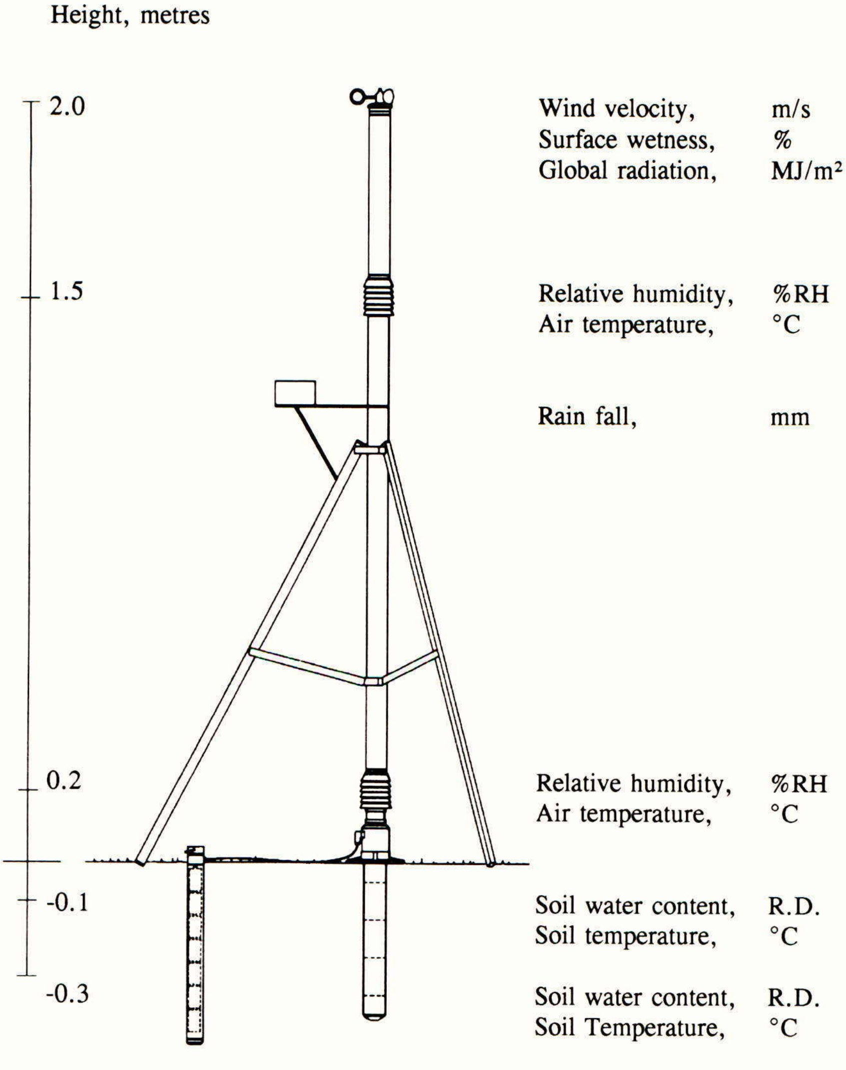

FIG. 3. The weather station with battery house.

The receiver

The receiver will turn on the PC when the data store is full and transfer all data to the Metpole software on the PC harddisk, or it can be preset to transfer data twice every day. The receiver is able to store a number of data such as that from four poles during 5 d. This prevents data from being lost, if the PC has been turned off.

The software programme

In the computer programme developed for the weather station, all data are presented as half hourly figures on a 24 h basis; and as 24 h averages on weekly, monthly and a seasonal basis. In addition, all data can be presented as tables, graphs and print outs. Finally, all data can be transferred to files in ASCII-format and used in any other software programme for future use in computerized monitoring and forecasting systems.

CONCLUSION

The described weather station is a new fully equipped climatic station with the major advantage of wireless transmission of weather data to a PC. Since there is no need for cables or for the manual logging of data, it is paticularly suited where changing locations for recording of data and distances up to 5 km are required. The data can be transferred to ASCII-files for subsequent use in the forecasting models which will thereby help pesticide users derive the most apropriate dose to be applied in the field at the right time.

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FLUAZINAM - CONTROL OF POTATO LATE BLIGHT - UK EXPERIENCE 1992-3

R.P. TUCKER, D.J. LEAPER, S.T. LAIDLER

ZENECA Crop Protection, ZENECA Ltd, Fernhurst, Haslemere, Surrey, GU27 3JE

ABSTRACT

Fluazinam, a fungicide of the new chemical group, the diarylamines, offers control of late blight in potatoes at low rates (150-200 g AI/ha) compared with existing materials. This paper reviews its biochemical activity, the persistence of late blight control on the potato plant and its effects in the life cycle of the pathogen, *Phytophthora infestans*. Its control of foliar blight and consequent effect on yield and tuber blight in field trials conducted in 1992-3 are described in comparison with the other materials used.

INTRODUCTION

Fluazinam, from the diarylamine chemical group, has unique and very potent activity against the potato blight pathogen *Phytophthora infestans*, allowing extremely effective control at low application rates. M.A.F.F. Approval for this use in the UK was received in May 1994 for "Shirlan", a 500 g/l SC formulation of fluazinam. The results from UK field trials from the previous two years are discussed here following a review of the mode of action.

MODE OF ACTION

Biochemical activity

Fluazinam interrupts the fungal cell's energy production process, by an uncoupling effect on oxidative phosphorylation and is exceptional in combining this type of fungicidal activity with low mammalian toxicity (Guo *et al.*, 1991). As the biochemical activity is non specific, a significant advantage of fluazinam is that selection of resistant fungal strains appears extremely unlikely.

Retention and activity on the potato leaf surface

When applied to plant leaf surfaces fluazinam gives very effective protectant control of a wide range of diseases (Anema *et al.*, 1992).

Further work (ZENECA Agrochemicals Report TMJ3262B) demonstrated that the LC95 for fluazinam was 10-30 mg/l when potato plants were inoculated with a spore suspension of *Phytophthora infestans* 14 d after fungicidal treatment. Also, in rainfastness comparisons, optimum rainfastness of fluazinam was achieved within 2 to 6 hours, while an interval of at least 24 hours, from fungicide treatment to application of "rain" (10mm), was necessary to allow stabilisation of mancozeb deposits. In the case of a fentin acetate/maneb mix, disease control activity was greatly reduced when rain occurred 24 hours after treatment.

Activity through the life cycle of *Phytophthora infestans*

Fluazinam is effective on *Phytophthora infestans* during the spore stages of its life-cycle, affecting indirect spore germination, cystospore germination and inhibiting spore production from existing disease lesions (Anema *et al.*, 1992). While activity on spore germination is essential in providing a barrier to primary infection of a field crop the latter property offers additional potential in the suppression of secondary infection.

Field trials conducted in Holland have consistently demonstrated very useful effects in reducing incidence of tuber blight (Anema *et al.*, 1992). This activity has been attributed to effects on the zoospore stages and recent tests (ZENECA Agrochemicals Report TMJ3262B) have confirmed that fluazinam is extremely effective in this area, interfering with zoosporangial dehiscence, zoospore germination and, particularly, zoospore motility (Table 1).

TABLE 1. LC95s (mg/l) for fluazinam on zoospore stages of *Phytophthora infestans*. (From ZENECA Agrochemicals Report TMJ3262B).

Zoosporangial dehiscence	Zoospore motility	Zoospore germination
0.2-1.0	0.04	0.2-1.0

FIELD PERFORMANCE

UK field trials with fluazinam (150 g/ha) carried out by ZENECA Crop Protection field teams and by specialist contractors at various locations in England and Wales during 1992/3 have provided comparisons with other materials. Foliar blight was assessed on a % basis using ADAS key 2.1.1 (ANON) and treatments are compared here on the basis of "days delay" until reaching a blight threshold, with threshold levels selected on a site by site basis depending on the extent of disease development with the best treatment. Measurements were carried out for tuber yield and disease at harvest (1992 trials) or following post-harvest storage (1993 trials). Trials were all of randomised block design, with four replicates. All sites had untreated "infector" rows planted between replicates while disease development was further aided by (1) artificial inoculation of these infectors and/or (2) irrigation in some cases.

1992 Results

In five 1992 trials fluazinam applications were made on a programme basis, aiming at a 7 to 10 d interval and compared to a mancozeb standard, applied at the same timings (ICI Agrochemicals Report TMF4260B). The blight susceptible main crop cv. King Edward was used at all sites except Somerset (1) where a susceptible "first early" (cv. Arkula) was employed.

Foliar blight delay

Fluazinam on a site by site basis always gave longer delays to foliar blight development than mancozeb programmes and gave, on average, a 26 d delay to foliar blight threshold levels compared to 18 days from mancozeb régimes (Table 2), even though spray intervals were often less than the minimum 10 d approved in the UK for the standard.

TABLE 2. Day's delay in foliar blight development - 1992 trials.

Trial location	Somer-set (1)	Somer-set (2)	Suffolk	Derby (1)	Derby (2)	**Mean**
Fluazinam (150 g/ha)	13	35	15	32	34	26
Mancozeb (1,275 g/ha)	11	19	10	27	24	18
Blight threshold (%)	45	6	15	65	66	
Spray intervals (days)	7-10	7-11	6-11	6-9	6-9	

Tuber yields

Both fluazinam and mancozeb programmes produced significant ($P<0.05\%$) yield increases over untreated controls in trials conducted on main crops (Table 3). Even in the case of the early harvested cv. Arkula - Somerset(1) - numerical advantages were seen.

Comparison of treatment programmes shows fluazinam giving higher numerical yields at all maincrop sites. At two irrigated sites in Derbyshire - where the yield potential of the crop would have been most easily achievable - yield improvements over mancozeb were significant at the $P<0.05\%$ level.

TABLE 3. Tuber yields at harvest (fresh weight) as a percentage of untreated control yields - 1992 trials.

Trial location	Somer-set (1)	Somer-set (2)	Suffolk	Derby (1)	Derby (2)	**Mean**
Fluazinam (150 g/ha)	125	159	2164	204	247	580
Mancozeb (1,275 g/ha)	126	155	2072	169	186	542

Tuber blight

Average tuber blight levels were 4.4%, 8.7% and 9.2% for fluazinam, mancozeb and untreated, respectively (Table 4). Levels of tuber blight seen from untreated plots varied widely between trial sites. An explanation of this is that early loss of haulm would lead to a reduction in zoospore activity and therefore a reduction in potential for tuber infection in the latter part of the growing season. Thus in two cases - Suffolk and Derby(1) - tuber blight levels in the untreated plots were consequently lower than in treated areas.

TABLE 4. Tuber blight levels (%) - 1992 trials.

Trial location	Somer-set (1)	Somer-set (2)	Suffolk	Derby (1)	Derby (2)	**Mean**
Fluazinam (150 g/ha)	1.8	1.6	2.8	5.0	10.9	4.4
Mancozeb (1,275 g/ha)	8.7	3.4	5.6	10.1	15.6	8.7
Untreated	14.3	6.1	1.2	0.9	23.7	9.2

1993 Results

In 1993 trials fluazinam programmes were compared with two types of standard régime as follows:

A Mancozeb-based programmes:
1.275 kg/ha mancozeb at 10 day intervals throughout the season - OR
1.36 kg/ha mancozeb applied 6 times (ADAS Liskeard) or 7 times (ADAS Trawsgoed) followed by 2 sprays of fentin hydroxide (280 g AI/ha).

B Three stage programmes:
(1) A proprietary mixture of oxadixyl (200 g/ha) + cymoxanil (80 g/ha) + mancozeb (1.4 kg/ha) applied as the first 4 or 5 sprays, followed by
(2) two sprays of mancozeb (1.3 kg/ha), followed by
(3) two sprays of either fentin hydroxide (280 g/ha) or a proprietary mixture of fentin acetate (270 g/ha) +maneb (80 g/ha).

Trials were conducted using cv. King Edward with one exception (Warwickshire), where Bintje, another main crop cultivar, susceptible to blight, was utilised.

Foliar Blight Delay
Four trials produced comparisons of fluazinam, applied at 7 or 10 d intervals, with standard programmes at 10 d intervals. These sites were as follows:
I - Warwicks II - S Wales III - Derbyshire (1) IV - Derbyshire (2)

At a further two sites all treatments were applied at 10-14 d intervals (ADAS Contract Report No C00174):
V - ADAS, A Rickwood VI - ADAS, Trawsgoed

On a site by site basis fluazinam programmes always gave longer delays to foliar blight development than mancozeb régimes (Table 5). Fluazinam applied at 10 or 10-14 d intervals gave on average 27 days delay to reaching blight threshold levels, compared to 21 days delay from mancozeb programmes (with applications at similar timings).

Overall, fluazinam applied at 10 or 10-14 d intervals also gave longer delays to foliar blight development than the three stage standard programme B which gave 24 days delay (Table 5). On a site by site basis, in five cases out of the six, fluazinam, at this interval, was superior to B. In the one exception (site IV) a seven day interval was needed for a fluazinam programme to fully match B. However, foliar blight development was slow in this trial and the threshold used to measure foliar blight delay necessarily low (5%).

TABLE 5. Days delay in foliar blight development - 1993 trials

Trial Location	I	II	III	IV	V	VI	**Mean**
Fluazinam (x7 days)	17	35	25	36	--	--	28
Fluazinam (x10 or 10-14 days)	14	31	25	27	26	40	27
A	7	21	23	24	24	28	21
B	8	19	24	38	25	33	24
Blight threshold (%)	50	60	45	5	30	5	

Tuber Yields

Fluazinam and standard programmes produced significant ($P < 0.05\%$)yield increases over untreated controls in five of the six trials (Table 6). In the exception (location I) the foliar blight epidemic occurred late in the season, towards the end of the "bulking up" period, so that treatment effect on yield was not so pronounced. Comparison of treatment programmes (10 or 10-14 day intervals between sprays) shows fluazinam giving a mean yield of 208% of the untreated level, compared to 175% and 193% for standards A and B respectively.

TABLE 6. Tuber yield levels (saleable fresh weight after storage) as a percentage of untreated control levels - 1993 trials.

Trial Location	I	II	III	IV	V	VI	**Mean**
Fluazinam (x10 or 10-14 d)	115	415	168	174	169	208	208
A	112	279	148	149	151	210	175
B	111	374	133	172	156	210	193
Untreated yield (t/ha)	31.9	3.4	33.7	27.5	33.3	22.1	

Tuber Blight

Tuber blight occurred at substantial levels at three trials in 1993 (Table 7).

At ADAS Liskeard 100% control was achieved from a programme of eight fluazinam applications, significantly ($P < 0.05\%$)better than standard type programmes A and B. Through the season there had been relatively low levels of foliage blight in any of the treatments. However, there was apparently enough zoospore activity in the soil, probably as a result of intense and heavy rainfall during mid September, to produce relatively high risk of infected tubers.

At ADAS Trawsgoed lower levels of tuber blight were detected but again fluazinam performed well relative to standards, giving significant reductions ($P<0.05\%$)in numbers of infected tubers compared to standard B.

At Marloes, S.Wales there were very high levels of blighted tubers, reflecting very early disease combined with a very open crop canopy allowing easy zoospore access to the soil throughout the season. The fluazinam programme again was better than the standards.

TABLE 7. Percent tuber blight levels (post storage) - 1993 trials

Trial location	ADAS Liskeard	ADAS Trawsgoed	S.Wales	**Mean**
Fluazinam	0.00	0.50	17.6	6.0
A	7.00	2.00	26.8	11.9
B	3.00	2.25	24.9	10.0
Untreated	5.00	1.75	13.3	6.7

As in 1992 trials levels of tuber blight from untreated plots varied widely according to timing of loss of haulm.

CONCLUSIONS

Fluazinam has performed extremely effectively in controlling late blight of potatoes in field trials in the UK in 1992/3. Control of foliar blight (and consequent effect on yield) has proven consistently good compared to programmes based on multiple active ingredient materials and régimes based solely on mancozeb. Additionally, in comparison to existing materials, fluazinam has proven effective in controlling tuber blight, as expected from glasshouse tests and as seen in previous Dutch field experiments. It is predicted from this that fluazinam will quickly become a very significant contributor to the fight against late blight in UK potato production.

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DEVELOPMENT OF AN INTEGRATED CONTROL STRATEGY FOR POWDERY SCAB OF POTATOES

P.J. BURGESS, S. J. WALE

Crop Biology Department, Scottish Agricultural College - Aberdeen, 581 King Street, Aberdeen AB9 1UD

ABSTRACT

In four trials a number of factors (cultivar, seed health, zinc oxide seed treatment, zinc soil treatment, irrigation and physiological age) known to influence the severity of powdery scab were applied to field plots in all possible combinations using a multifactorial design. The most important factor governing the subsequent severity of powdery scab was cultivar resistance. Zinc treatment of seed or soil had small effects on disease severity that were not significant in individual experiments. However, results from these experiments suggest that the efficacy of zinc treatment was improved when the disease pressure had been reduced by the use of healthier seed or more resistant cultivars. Treatment of seed tubers with zinc oxide appeared to be more effective than treatment of soil with a mixture of zinc oxide and sulphates.

INTRODUCTION

Powdery scab of potatoes is caused by the plasmodiophorales fungus *Spongospora subterranea* subsp. *subterranea*. The pathogen causes a range of symptoms on the roots, stolons and, most importantly, tubers of the potato plant. Tuber infection results in the formation of unsightly scabs containing masses of cystosori that erupt through the periderm. Under some conditions, a cankerous form of the disease can develop. Although powdery scab has not been reported as being detrimental to tuber yield, the appearance of tubers is such that the marketability of the crop is much reduced. The disease is of particular concern to seed producers as it is seed as well as soil borne.

Control of powdery scab currently relies principally upon a range of cultural measures. However, these have frequently given inadequate control of disease. Parker (1984) reported that a mixture of maneb and zinc oxide applied to seed tubers reduced powdery scab severity and this fungicide combination is currently the only product with approval for the control of powdery scab in the UK (Anon., 1994). More recently, it has been shown that disease severity could be reduced using a range of zinc compounds applied either as seed or soil treatments (Burnett *et al.*, 1990; Burnett, 1991; Burgess *et al.*, 1992). Burgess *et al.*, (1992) reviewed the results from a large number of trials and concluded that the effect of zinc on powdery scab severity was variable, but of benefit in some instances. The effectiveness of zinc compounds appeared to be similar to that of the approved formulation of maneb and zinc oxide. Burnett & Wale (1993) reported that zinc treatments were most effective, in pot experiments, when low levels of initial inoculum had been used. They suggested that the efficacy of zinc treatments in the field may be improved if other measures to reduce the pressure from disease were also taken.

The trials reported in this paper investigate the control of powdery scab using a number of different control measures, both applied alone and in combination with one another. The overall objective of the trials was to develop an integrated strategy for the control of powdery scab.

MATERIALS AND METHODS

In both 1992 and 1993, two field trials were conducted. In each season one trial was at a site (Sunnybrae Farm, Craibstone Estate, Aberdeen) where potatoes had not been grown for many years and there was no record of powdery scab infection. At this site diseased seed tubers were planted and these constituted the main source of disease. The second trial was conducted at a site where severe powdery scab had previously occurred. At this site (Rothienorman, Aberdeenshire) healthy seed tubers were planted and the main source of disease was thus the soil. All plots consisted of 100 tubers grown in four drills of 25, with the centre two drills of each plot being used for all assessments. Fertiliser and agrochemical applications were as recommended for local conditions.

Each trial was of a multifactorial design with five factors applied in all possible combinations. The factors included in this trial series are given below. A summary of the treatments included in each trial is given in Table 1.

1. Irrigation. Irrigation was applied with the objective of preventing a soil moisture deficit of greater that 18 mm during the period of tuber initiation and for a period of 5 weeks thereafter.
2. Cultivar. Two or three cultivars with different levels of resistance to powdery scab were included in each trial. The cultivars were: Estima (NIAB disease resistance rating, 3), Nadine (8). Pentland Dell (7) and Record (7) (Anon., 1993)
3. Seed health. A naturally, infected, certified seed potato stock was used for trials where disease was seed borne. This seed was described as 'diseased'. Tubers without symptoms of powdery scab were selected from the same seed stock and planted as 'healthy' seed tubers.
4. Chitting. Tubers were chitted for *ca* 240 day ^{o}C ($>4^{o}C$) under fluorescent lights.
5. Zinc seed treatment. Zinc oxide powder was applied immediately prior to planting at a rate equivalent to 1 kg product t^{-1} (0.8 kg Zn t^{-1}) seed tubers.
6. Zinc soil treatment. Two types of treatment were used in this trial series

   a) Zinc mixture. A mixture of zinc oxides and sulphates, 20% zinc content (as Micromate, Stoller Chemicals Ltd.), was incorporated into soil immediately prior to planting at a rate equivalent to 75 kg product ha^{-1} (15 kg Zn ha^{-1}).

   b) Zinc sulphate ($Zn\ SO_4.7H_2O$) spray. Zinc sulphate, 20% zinc content, was sprayed onto soil before planting at a rate equivalent to 75 kg product ha^{-1} (15 kg Zn ha^{-1}) in 240 l water ha^{-1}.

The haulm of each trial was destroyed with diquat or sulphuric acid and the progeny tubers harvested between 3 and 6 weeks later from the centre two drills of each plot. The total yield from each plot was measured. The severity (mean percentage surface area infected) of powdery scab on 100 randomly selected washed tubers from each plot was determined by visual estimation.

RESULTS AND DISCUSSION

The main effect of each of the factors on disease severity is given Table 2. For each trial the interaction between the different factors was calculated and selected results are given in Tables 3 and 4.

Cultivar was the only factor to consistently have a highly significant (*P*<0.01) effect on the severity of powdery scab. Estima, included in all 4 trials, was more severely diseased than other cultivars. In trial 4, the difference between the two cultivars (Estima and Pentland Dell) was smaller that in others. This reflected the intense disease pressure at this site in which the relatively high resistance of Pentland Dell was apparently overwhelmed by the pathogen.

TABLE 1. Summary of treatments applied in each of four multifactorial field trials.

Main factor	Level	Trial 1* (Disease seed borne) 1992	Trial 2 (Disease soil borne) 1992	Trial 3* (Disease seed borne) 1993	Trial 4 (Disease soil borne) 1993
Irrigation+	1	Yes		Yes	
	2	None		None	
Cultivar	1	Estima	Estima	Estima	Estima
	2	Record	Record	P Dell	P Dell
	3		Nadine		
Zinc seed treatment	1	Yes	Yes	Yes	Yes
	2	None	None	None	None
Zinc soil treatment	1	Zn Mixture	Zn Mixture	Zn Mixture	Zn Mixture
	2	None	None	None	Zn SO_4
	3				None
Chitting	1		Chitted		Chitted
	2		Not-chitted		Not-chitted
Seed Health	1	Diseased		Diseased	
	2	Healthy		Healthy	
Replicates of each treatment combination		2	2	2	2

* Zinc seed and soil treatments combined to form a single factor with three levels; (i) none (ii) seed and (iii) soil application. The combination of soil and seed zinc was not included in these trials.

\+ Irrigation was applied as a mainplot treatment with two replicates of each level. Other factors were applied to subplots within mainplots.

TABLE 2. Main effects of treatments on the severity (mean percentage surface area infected) of powdery scab on progeny tubers in each of four trials.

Factor	Level	Trial 1	Trial 2	Trial 3	Trial 4
		1992		1993	
Irrigation	Yes	3.12		2.91	
	None	2.44		3.73	
		ns		ns	
Cultivar	Estima	4.58	7.02	5.25	25.4
	Nadine		0.91		
	Record	0.97	1.24		
	P Dell			1.39	18.4
		***	***	***	**
Zinc seed treatment	Yes	2.36	3.04	2.68	22.1
	None	3.29	3.07	3.46	21.7
		ns	ns	ns	ns
Zinc soil treatment	Zn mixture	2.68	3.65	3.82	20.3
	Zn SO_4				22.4
	None	3.29	2.47	3.46	23.0
		ns	ns	ns	ns
Chitting	Yes		1.95		22.4
	None		4.17		21.4
			ns		ns
Seed health	Diseased	3.32		4.69	
	Healthy	2.23		1.95	
		ns		***	

ns Not significant, $P>0.05$, ** Significant $P<0.01$, *** Significant $P<0.001$

In trial 2, chitting of seed was the most effective means (although not significant), apart from cultivar resistance, of reducing powdery scab severity. However, in the subsequent season (trial 4) there was no apparent effect of chitting. The difference between these results would appear to be related to the rainfall pattern and time of tuber initiation, which Burnett (1991) reported as being the period when most infection occurred. Tuber initiation of chitted stocks (in particular the second earlies Estima and Nadine) was earlier than that of the not chitted tubers and had passed before conditions suitable for powdery scab infection had occurred, thus less disease was observed on these chitted stocks. In 1993 the pattern of rainfall was such that conditions suitable for infection to occur persisted through most of the growing season and no difference between chitted and not chitted stocks was observed.

In 1992 (trial 1), there was a highly significant increase ($P<0.001$) in the proportion of cankered tubers (from 3.0 to 3.4%) due to irrigation. In this trial the application of irrigation also improved the efficacy of zinc seed treatment. In 1993 (trial 3), an extremely wet season, irrigation appeared to decrease disease severity (not significant). This result corresponds with observations by Burnett (1991) that *S. subterranea* infection, was higher under a regime of alternating wet and dry conditions. In trial 3, the combination of high rainfall and additional

TABLE 3. The effect of zinc seed and soil treatments applied to different cultivars on the severity (mean percentage surface area infected) of powdery scab on progeny tubers in each trial.

Trial Number	Cultivar	Powdery scab severity (% surface area infected) Zinc soil treatment None	Treated	% reduction	Zinc seed treatment None	Treated	% reduction
1	Estima	5.2	4.6	12	5.2	3.9	25
1	Record	1.3	0.8	38	1.3	0.8	38
2	Estima	5.3	8.8	-66	6.7	7.4	-10
2	Record	0.9	1.6	-77	1.2	1.2	0
2	Nadine	1.3	0.6	54	1.3	0.5	62
3	Estima	5.2	6.5	-25	5.2	4.1	21
3	P Dell	1.7	1.1	35	1.7	1.1	35
4	Estima	27.2	22.3	18	23.7	27.0	-14
4	P Dell	18.8	18.2	3	19.6	17.2	12

irrigation resulted in the soil being at or very near to field capacity for much of the season. This apparently suppressed *S. subterranea* infection.

Zinc seed treatment resulted in a small overall decrease (not significant) in the severity of powdery scab in both trials where the disease was seed borne. The effect of zinc seed treatment on each cultivar was to reduce disease severity in a majority of instances (Table 3). In each trial, the percentage reduction in disease was greater when zinc seed treatment was applied to the more resistant cultivar. Soil treatment was less effective than seed treatment, resulting in an overall decrease in disease severity in trials 1 and 4.

In trials 1 and 3 powdery scab developed with both 'diseased' and 'healthy' seed tubers. However, a decrease in disease severity was observed in both trials (highly significant, $P<0.001$, for trial 3) when healthy seed was compared to diseased seed. It was likely that inoculum in the form of cystosori, carried symptomlessly on the surface of otherwise healthy tubers remained.

The efficacy of zinc treatment (applied either to seed and soil) was improved when application was made to 'healthy' rather than 'diseased' seed tubers (Table 4). This was particularly notable in trial 1 where use of healthier seed alone was of relatively little value in reducing the severity of powdery scab. This result confirms that of Burnett & Wale (1993) who demonstrated that zinc treatments were most effective when the amount of inoculum was low.

CONCLUSIONS

The use of more resistant cultivars is the single most important step that can be made by growers to reduce disease severity. Other methods that reduce the disease pressure, such as planting healthy seed tubers or choosing fields with a lower risk of soil contamination with

TABLE 4. The effect of zinc seed and soil treatments applied when using seed tubers of different health status on the severity (mean percentage surface area infected) of powdery scab on progeny tubers.

Trial No.	Healthy seed			Diseased seed			SED (24df)
	No zinc	Seed zinc	Soil zinc	No zinc	Seed zinc	Soil zinc	
1	3.26	1.76	1.68	3.32	2.95	3.69	1.513
3	2.32	2.03	1.50	4.61	3.33	6.13	1.133

cystosori of *S. subterranea* should also reduce the reduce the severity of powdery scab. Treatment of seed tubers with zinc oxide did not result in a significant reduction in disease but was more consistently effective than treatment of soil. There were indications that the efficacy of all zinc treatments was improved when used in combination with other methods of reducing disease such as the use of more resistant cultivars or planting healthier seed.

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CONTROL OF FUNGAL STORAGE DISEASES OF POTATO BY USE OF PLANT-ESSENTIAL OIL COMPONENTS

L.G.M. GORRIS, K. OOSTERHAVEN, K.J. HARTMANS, Y. DE WITTE, E.J. SMID

Agrotechnological Research Institute (ATO-DLO), Bornsesteeg 59,
P.O. Box 17, NL-6700 AA Wageningen, The Netherlands

ABSTRACT

The potency of some essential oils and purified components thereof to counteract fungal storage diseases of potato (*i.e. Fusarium sulphureum, F. solani* var. *coeruleum, Helminthosporium solani, Phoma exigua* var. *foveata*) was investigated. An *in vitro* assay was employed to select potentially useful compounds, which were then tested *in situ* on laboratory scale. Several essential oil components were found to suppress growth of fungi either during short or long term, although a substantial variation between individual potato storage diseases was apparent. For instance, carvone was found to be fungicidal towards *H. solani*, fungistatic for *P. exigua* var. *foveata* and *F. sulphureum* and not effective against *F. solani* var. *coeruleum*.

INTRODUCTION

The awareness of the negative impact on man and the environment of chemical fungicides used in crop production nowadays has initiated research for more friendly alternatives. The essential oils of many plants are composed of compounds with fungicidal or bactericidal properties. The importance of these volatiles (*e.g.* aldehydes, ketones and terpenes) in plant resistance towards pathogens has long been recognized by plant pathologists, but they may be utilized as well outside their natural source in disease control. Due to marked antibacterial properties several have found use as preservatives in traditional and more novel food preparations. A number of compounds have been assigned the Generally Recognized As Safe (GRAS)-status. Recent interest in the monoterpene and aldehyde classes of essential oil components also derives from their ability to inhibit sprouting of potato tubers during storage (Diepenhorst & Hartmans, 1993; Oosterhaven *et al.*, 1993; Vaughn & Spencer, 1991; Vokou *et al.*, 1993). Here we report, in follow-up of earlier reports (Gorris, 1993; Gorris *et al.*, 1993), on the identification of essential oil components that have a sound potential to control growth of important fungal storage diseases of potato.

MATERIALS AND METHODS

Fungi

Fungi included in this study were *Fusarium sulphureum* ('dry rot'), *Fusarium solani* var. *coeruleum* ('dry rot'), *Helminthosporium solani* ('silver scurf') and *Phoma exigua* var. *foveata* ('gangrene'). All strains were obtained from the Culture Collection of the Research Institute for Plant Protection (IPO-DLO, Wageningen).

Essential oil components

Essential oils and the principle components thereof were purchased from Roth, Fluka and Merck and were used without further purification.

In vitro assay

The *in vitro* assay employed comprised of a Petri-dish with potato dextrose agar as the growth medium and sealed with a plastic ring. A small glass container that held 10 µl of the volatile compound to be tested was included in the Petri-dish. Plates were inoculated in the centre with 10 mm^2 plugs taken from the growing edges of mycelial mats. The increase in the colony diameter was determined at 21°C during 8 weeks as a measure of the effect of a compound.

In vivo assay

To test the effect of essential oil components on the growth of fungi on potato tissue a laboratory scale system was employed consisting of a 20-l plastic container in which 30 potato tubers ('Bintje', size 45/50 mm) were placed on a stainless-steel grid. Two glass Petri-dishes with 250 µl of oils each were placed under the grid in the test containers. In each tuber, five holes of 30 µl volume were pierced using a sterile probe. The holes were filled with an average of 0, 2.5, 10, 40 and 160 spores of a fungus, respectively. The lid of each container was taped to the bottom. Containers with *P. exigua* var. *foveata* were stored at 7°C, whereas the others were kept at 10°C for 2 months.

TABLE 1. *In vitro* effect of some essential oils on the growth of fungal storage pathogens of potato

Essential oil (principle component)	*Fusarium sulphureum*	*Fusarium solani* var. *coeruleum*	*Phoma exigua* var. *foveata*	*Helmintho-sporium solani*
Caraway, enriched (95% S-carvone)	++	+	+	+
Spearmint (71% R-carvone, 17% limonene)	+	0	+	++
Dill (36% R-carvone; 46% limonene)	0	0	0	+
Mandarin (80% limonene)	0	0	0	0
Cassia (91% cinnamaldehyde)	0	+++	+++	+++
Cumin (56% Cuminaldehyde)	+	+	+	+

0= no effect; += growth suppressed up to 3 weeks; ++: 3-5 weeks growth suppression; +++= > 5 weeks growth suppression

RESULTS

Using the *in vitro* assay, essential oil extracts were found to have only limited inhibitory effects (Table 1). Of the oils of caraway, spearmint and dill which have the monoterpene carvone as a prominent component, caraway oil suppressed the growth of the four fungi the best, though only up to 3 weeks in most cases. Mandarin oil, mainly consisting of limonene, had only a limited inhibitory effect. Best results were obtained with cassia oil of which cinnamaldehyde is the main component. Cumin oil, containing the related aldehyde cuminaldehyde, was much less inhibitory than cassia oil.

Preparations of purified essential oil components were able to suppress *in vitro* growth of the fungi in many instances for long periods of time (Table 2). The aldehydes benzaldehyde, cinnamaldehyde and cuminaldehyde as well as the monoterpene carvone were the most potent overall. The monoterpenes menthol, pulegone and eugenol suppressed growth of *P. exigua* var. *foveata* and *H. solani* for 3-5 weeks or more, but were rather ineffective towards the two fusaria. Limonene and dihydrocarvone were the least effective purified compounds.

TABLE 2. *In vitro* inhibition of growth of fungal storage pathogens of potato by purified compounds of essential oils

Purified compound	*Fusarium sulphureum*	*Fusarium solani* var. *coeruleum*	*Phoma exigua* var. *foveata*	*Helmintho-sporium solani*
S-Carvone	+++	0/+++	+++	+++
Dihydrocarvone	+	0	+	+
Menthol	+	0	+++	+++
Pulegone	+	+	++	++
Eugenol	0	0	+++	+++
Limonene	+	0	+	+
Cuminaldehyde	+++	++	+++	+++
Benzaldehyde	+++	+++	+++	+++
Cinnamaldehyde	+++	+++	+++	+++

0= no effect; += growth suppressed up to 3 weeks; ++: 3-5 weeks growth suppression; +++= >5 weeks growth suppression; 0/+++= variable effect

To test whether the effect of carvone on the growth of the fungi was fungistatic or fungicidal, mycelial inocula of the fungi which had been exposed to it and had been inhibited in their growth were transferred to fresh growth medium without the inhibitory compound. Table 3 shows the results obtained with *H. solani* and *F. sulphureum*. In both cases, growth was completely suppressed in the presence of carvone. After transfer, the inoculum of *F. sulphureum* started to grow at about the same rate as the control (not exposed), whereas the inoculum of *H. solani* did not resume growth for the duration of the experiment. Thus, the effect of carvone can either be fungistatic, as with *F. sulphureum*, or fungicidal, as in the case of *H. solani*. The reasons underlying this difference are not yet known, but may be related to the observed insensitivity of *F. solani* var. *coeruleum* towards carvone.

TABLE 3. Growth (size of mycelial mat in cm^2) of two fungal storage pathogens of potato in the presence or absence of S-carvone.

Incubation period (days)	*Fusarium sulphureum* Control	*Fusarium sulphureum* Carvone	*Helminthosporium solani* Control	*Helminthosporium solani* Carvone	*Fusarium solani* var. *coeruleum* Control	*Fusarium solani* var. *coeruleum* Carvone
0	0	0	0	0	0	0
4	7	0	11	0	18	4
8	20	0	57[*1]	0	57	8
12	29	0	57	0	57	26
		transfer		transfer		
3		2		0		
6		12		0		
10		37		0		
14		57		0		

[*1] maximum size of the mycelial mat.

One of our hypotheses for the insensitivity of *F. solani* var. *coeruleum* towards carvone has been that this fungus, unlike the sensitive types, is able to perform a pronounced bioconversion of carvone into non- or less-inhibitory compounds. The possibility of a detoxification mechanism was checked by incubation of the insensitive fungus in liquid cultures containing carvone and determining the breakdown products arising in time. A culture of a sensitive fungus (*i.e. F. sulphureum*) was used as a control.

It was found that both fungi were capable of conversion of carvone (Table 4). In both cases, iso-dihydrocarvone and neo-iso-dihydrocarveol were amongst the principle conversion products. In the case of *H. solani*, iso-dihydrocarveol was a prominent breakdown product too. It is not yet known what the growth suppressive effect of the various conversion products relative to carvone is. From the experiment shown in Table 2 it follows that dihydrocarvone is much less active than carvone, but this is only a minor breakdown product in both cases. The activity of the other products remains to be investigated.

In this study, carvone has been identified as a rather broad range antifungal compound. Since other studies at our institute have shown that carvone can very well be used also to inhibit tuber sprouting (Diepenhorst & Hartmans, 1993; Oosterhaven *et al.*, 1993), this compound seems to have an excellent potential for practical application.

TABLE 4. Conversion products (relative amounts) of S-carvone in liquid cultures of *Fusarium solani coeruleum* and *F. sulphureum* after 400 h of incubation at 18°C.

Component	*Fusarium solani* var. *coeruleum*	*Fusarium sulphureum*
S-carvone	0.0	0.0
dihydrocarvone	5.3	9.4
iso-dihydrocarvone	55.0	66.1
iso-dihydrocarveol	21.2	1.5
neo-iso-dihydrocarveol	18.5	23.0

An *in situ* laboratory scale test system was designed to test the activity of volatile compounds, such as carvone, under semi-storage conditions. In fact, due to the rather high humidity prevailing in the containers, the conditions were more favourable to fungal growth than practice. In Table 5 representative results obtained with the highest doses of inoculum are given for three fungi. It was not possible to conduct an experiment with *H. solani* because, despite several attempts, the fungus did not grow actively on potato tubers after sub-peridermal inoculation. In the case of *Phoma exigua* var. *foveata* and *Fusarium sulphureum*, the experiment was performed twice with an interval of two months. With both pathogens, a very good suppressive effect of carvone was noticed. With *Fusarium solani*, the experiment could not be repeated with the same batch of potatoes, but results presented here were found to be exactly reproducible with subsequent batches, showing no sensitivity of the fungus for carvone.

Our findings are generally in agreement with those recently published by others on the efficacy of several of the aldehydes tested here in suppressing growth of thiabendazol-resistant *F. sulphureum* (also known as *F. sambucinum*) when applied via the atmosphere around a product or in liquid media (Vaughn & Spencer, 1994).

CONCLUSION

The results obtained in this investigation show the potency of several purified essential oil components, rather than of the essential oil preparations investigated, to control the *in vitro* growth of fungal storage diseases of potato tubers. The *in vitro* assay identified compounds with short term (*e.g.* limonene, pulegone) or long term (*e.g.* carvone, eugenol, menthol, cuminaldehyde, benzaldehyde, cinnamaldehyde) fungistatic effects. Carvone and the aldehydes tested were most generally potent, being active towards 3 or 4 out of the 4 different fungi. Short-term exposure of *H. solani* towards carvone was found to be fungicidal, whereas the compound had a fungistatic effect on *F. sulphureum*, *H. solani* and *Phoma exigua* var. *foveata*, and no effect on *F. solani* var. *coeruleum*. Both sensitive and insensitive types of fungi were able to convert carvone into, possibly, less inhibitory compounds. The *in situ* results are in accord with the *in vitro* findings and show the good potential of carvone to suppress growth of carvone-sensitive fungi such as *F. sulphureum* and *P. exigua* var. *foveata* on potato tubers under conditions favouring fungal growth. Semi-full scale experiments are ongoing to verify the practical application of carvone.

TABLE 5. *In situ* growth of the various fungal potato pathogens in the presence or absence of carvone[1]

Fungus[2]		Percentage of inoculum sites (with 160 spores/site) that developed disease symptoms	
		Control	Carvone
Phoma exigua var *foveata*	(1)	35	5
	(2)	98	0
Fusarium sulphureum	(1)	60	6
	(2)	73	0
Fusarium solani var *coeruleum*	(1)	98	100

1 both stereo-isomers were tested with comparable results.
2 The experiment was repeated with two months time interval. (1) and (2) indicate the first and the second experiment, respectively.

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AIR-ASSISTED SPRAYING IN WINTER WHEAT - RESULTS OF DEPOSITION MEASUREMENTS AND THE BIOLOGICAL EFFECT OF FUNGICIDES AGAINST LEAF AND EAR DISEASES

J.C. VAN DE ZANDE*, R. MEIER** AND M.T. VAN IJZENDOORN**

* IMAG-DLO, Institute of Agricultural and Environmental Engineering, Mansholtlaan 10-12, P.O.Box 43, 6700 AA Wageningen, The Netherlands

** PAGV, Research Station for Arable Farming and Field Production of Vegetables, Edelhertweg 1, P.O.Box 430, 8200 AK Lelystad, The Netherlands

ABSTRACT

During three growing seasons the use of air assistance was compared with conventional spraying at two volume levels. The biological effects were determined in a randomized field test with spray concentrations of the active ingredient varying from 0 to 100 % of the dose advised, and volume rates of 100 l ha^{-1} and 200 l ha^{-1}. Deposition was measured at the time of spraying of the winter wheat crop. The total deposition and deposition pattern on the crop was established by washing paper strips and winter wheat leaves from different heights in the crop, using the dye Brilliant Sulfo Flavine (BSF). Biological effects of the sprayings were investigated by quantifying the percentage of the leaf area covered with brown rust (*Puccinia recondita*) and leaf spot (*Septoria tritici*) on the three toplevel leaves. The use of air assistance resulted in a different distribution of the spray in the crop, and a higher emission to the soil surface beneath the crop. Significant differences were found in the biological efficacy between volume rates and dosage. A sprayed volume of 200 l ha^{-1} sometimes resulted in better disease control than 100 l ha^{-1}. Air-assistance was not significantly better. Full dosage and 75% dosage of active ingredient resulted in better disease control than 50 % dosage.

INTRODUCTION

Because of environmental contamination a general reduction in the use of pesticides is required. The aim in The Netherlands is to reduce the use of pesticides by 50% by the year 2000. Drift of spray to surface water next to cultivated land should be reduced by more than 90% (Tweede Kamer der Staten-Generaal, 1991). In accordance with the Multi Year Crop Protection Plan research has been set up to develop improved application techniques for pesticides. Improvements in spraying application techniques can contribute to these goals by better deposition on the leaves and reduction of drift to soil, surface water and air (Tijink, 1993).

If the essential aspects of dose-effect relations of the chemicals are not well understood, this is often compensated by an overdosage of the active ingredient. Reducing the use of chemicals now having top priority, more attention needs to be paid to achieving a better leaf coverage with less chemical. Furthermore, emission of crop protection chemicals is a major problem in chemical crop protection. New spray application techniques might improve the deposition and reduction of drift. In a series of experiments spray-deposition and biological effect were determined in a winter wheat crop using a sprayer equipped with an air-assisted system. In the set up volume rates, the rate of active ingredient and the use of air assistance was compared.

MATERIALS AND METHODS

During three growing seasons (1991-1993) field trials were established in a crop of winter wheat (cv. Obelisk) at Westmaas Research Station. Plots, measuring 12m wide and 25 m long, were marked out in a randomized block design incorporating three replicates. A "Hardi Twin" sleeve boom sprayer was used. For air-assistance the sprayer was operated at its maximum air flow with nozzles kept vertical,as in conventional practice. Because of its ability to be operated without air assistance, the "Hardi Twin" was also used to apply the standard conventional non air-assisted spray treatments, the air curtains on the machine being folded. The following treatments were used with and without air assistance:

Sleeve boom (Hardi Twin) 4110-18 nozzles, 1,7 bar, 200 l ha^{-1}
Sleeve boom (Hardi Twin) 4110-12 nozzles, 1,4 bar, 100 l ha^{-1}
For all treatments tractor speed was 6 kph and boom heights was 0.60 m above crop canopy.

Spray deposition

The trial areas for the deposition measurements were in a strip alongside the field trial. At the time of fungicide application deposition measurements were carried out by adding the fluorescent dye Brillant Sulfo Flavine (BSF) to the spray agent (0.5 g l^{-1} water). The detergent Agral N was added in a concentration of 1 g l^{-1} water to simulate a pesticide formulation. After the spraying the dye was extracted from the leaves or collectors. Collectors used are chromatography paper strips 20 cm long and 2 cm wide folded around leaves, and 100 x 8 cm filter tissues on the soil surface and over the crop canopy. Collectors were placed systematically on three places across the sprayer boom. A single spray pass was made across each target. The rate was measured by fluorimetry and expressed per surface area of the collector. The measured deposits were expressed as percentage of the application rate of the sprayer (spray dose). After log-transformation results of the deposition measurements were statistically evaluated using Genstat statistical software (Payne, 1993). In addition to absolute deposition (quantity of chemical), the results included the coverage and the droplet spectrum on the target area. For this part of the research, video recordings were made of the spray deposition on water sensitive paper that was suspended in the crop. The video recordings were analyzed by means of vision technology. Results are not reported.

Biological effect

Biological effects of the sprayings were investigated in randomized field trials during three following growing seasons (1991-1993). In each growing season the level of infected leaf-area of the plants with *Puccinia recondita* and *Septoria tritici* was measured. Levels of disease in the crop were recorded at time of application and at weekly intervals until desiccation of the top leaf. This was done by taking fifteen randomly selected main shoots per plot, assessing leaf diseases on the upper three leaf levels as percentage leaf area affected using key-figures.

A single fungicide treatment, (a mixture of 1 l Corbel + 0,5 l Sportak ha^{-1}, (1991 and 1992) or 1.25 l ha^{-1} Sportak Delta in 1993), was applied at flowering GS 65-69 (Zadoks). Dosages varied from 100%, 75% to 50%. An untreated control was also included. The total field received normal farm inputs for fertilizer, weed control and growth regulation.

RESULTS

Spray deposition

From the deposition measurements in 1992 it becomes clear that 100 l ha^{-1} gave proportionally higher rates of deposition on the whole wheat plant than 200 l ha^{-1} (Table 1). With 100 l ha^{-1} there was no difference between with and without air-assistance. At 200 l ha^{-1} there was a difference between with and without air assistance in deposition on the whole plant. In general the rating could be 200 l ha^{-1} least, 100 l ha^{-1} with/without air equally more and most with 200 l ha^{-1} with air-assistance. At 200 l ha^{-1} there was a difference in deposition on the second leaf between with and without air-assistance. With 100 l ha^{-1} this was only significant at the third leaf. Deposition on the top leaf between treatments was not statistically significant ($P<0.05$). On the second and third leaf 100 l ha^{-1} with and without air assistance deposited proportionally more spray volume than 200 l ha^{-1}. Deposition on the top, second and third leaf was different for all spraying systems.

TABLE 1. Median (top- and underside) deposition on upper, second and third leaf as % of sprayed volume, results 1992.

Volume (l ha-1)	Air-assistance	Leaf level Upper	Second	Third
100	none	10.3	5.8	5.4
100	full	11.6	5.5	3.2
200	none	9.5	3.7	1.9
200	full	10.7	5.1	2.8

LSD ($P<0.05$) = 1.5

In 1993 the emission to the soil surface with 100 l ha^{-1} was more with air-assistance than without air-assistance (not shown). At 200 l ha^{-1} the differences in soil deposition were not statistically significant ($P<0.05$). More spray liquid deposited on the top side of the leaves than on the under side. There was a difference in deposition on the three leaf levels. On the top side of the leaf the average deposition differed for all three leaf levels. On the bottom side the average deposition on the upper and second leaf differ from the third leaf. In total more deposition was found on the wheat leaves with air-assistance than without air-assistance (Table 2). With air-assistance more deposition was measured on the top side of the leaves than without air-assistance, especially on the top leaf and to a lesser extent on the second leaf. On the under side of the leaf air-assistance deposited no more than without air-assistance. A volume of 200 l ha^{-1} gave proportionally more deposition on the top side of the leaves than 100 l ha^{-1} with no difference between volumes on the under side of the leaves. Compared to conventional application, the deposition pattern for both 100 l ha^{-1} and 200 l ha^{-1} was for air-assistance different on the top and second leaf level ($P<0.05$) and for the 200 l ha^{-1} on the third leaf level ($P<0.10$). Air-assistance gave slightly deeper penetration in the plant canopy.

TABLE 2. Median (top- and underside) deposition on upper, second and third leaf as % of sprayed volume, results 1993.

Volume (l ha-1)	Air-assistance	Leaf level		
		Upper	Second	Third
100	none	6.8	4.3	2.7
100	full	8.5	6.0	3.3
200	none	6.7	4.1	2.0
200	full	8.4	6.3	3.1

LSD ($P<0.05$) = 1.4

Biological effect

During the individual growing seasons leaf diseases occurred in untreated as well as in treated plots; in general disease levels were low in 1991 and 1992 and moderate in 1993. In all three years all spraying systems and dosages reduced the mean level of *P. recondita* and *S. tritici* significantly ($P<0.05$) (not shown). In 1991 *P. recondita* and *S. tritici* reacted identically to effects of spraying systems, volumes and dosages (not shown). There was an effect of volume rate on all three leaf levels during recording period, and a dosage effect on second leaf at the last recording day, three weeks after spraying.

In 1992 for *P. recondita*, at the first recording day there was an effect of air-assistance on the top and third leaf (not shown). This vanished on later recording dates and after 3 weeks only a dosage and a volume effect remained on the top and second leaf (Table 3). For *S. tritici* a dosage (not shown) and volume effect was significant on the top and second leaf three weeks after spraying.

TABLE 3. Mean % leaf area affected by *S. tritici* (S) and *P. recondita* (P) on the last recording day before desiccation of the different leaf levels, 2-4 weeks after spray application, results of 1992.

Volume (l ha-1)	Air-assistance	Leaf level					
		Upper		Second		Third	
		S	P	S	P	S	P
100	none	6.1	12.7	46.0	2.2	16.7	0.3
100	full	8.6	13.5	44.3	2.1	14.8	0.4
200	none	2.0	7.5	36.7	1.0	19.5	0.2
200	full	4.1	10.3	37.7	1.1	15.4	0.5
LSD ($P < 0.05$)		6.4	5.8	10.4	0.8	4.9	0.3

In 1993 4 weeks after spraying there was an effect of dosage (not shown) and volume rate on *S. tritici* on the upper wheat leaf. Initially there was an effect of air-assistance on the second leaf (not shown) which vanished during the recording period and only a volume rate effect remained at the last recording day, 5 weeks after spray application (Table 4). On the third leaf a volume effect was significant ($P<0.05$). For *P. recondita* a dosage effect was significant on the upper and second leaf (not shown). Volume rate had an effect on the second and also on the third leaf.

TABLE 4. Mean % leaf area affected by *S. tritici* (S) and *P. recondita* (P) on the last recording day before desiccation of the different leaf levels, 2-5 weeks after spray application, results of 1993.

Volume (l ha-1)	Air-assistance	Leaf level					
		Upper		Second		Third	
		S	P	S	P	S	P
100	none	17.2	5.7	26.2	3.5	16.6	17.5
100	full	19.0	6.8	26.5	2.3	17.9	22.3
200	none	14.6	7.1	21.9	2.1	11.5	14.5
200	full	13.5	7.2	21.1	1.6	13.1	8.9
LSD ($P < 0.05$)		6.2	4.4	5.4	1.1	4.9	8.0

In general, conventional application at 200 l ha^{-1} had the best control of *P. recondita* in 1992 irrespective of dosage level. For *S. tritici* best protection was obtained by 200 l ha^{-1} by both conventional and with air-assisted spraying. In 1991, 200 l ha^{-1} sprayed conventionally and with air assistance both gave generally better control of both *S. tritici* and *P. recondita*. In 1991, 100 % dosage resulted in better disease control than 75% and 50%. A reduced dosage of 75% gave in 1992 results as good as the full dose on *P. recondita*. On *S. tritici*, the full dose was always better than reduced dose on all three leaf levels. In 1993, both full and 75% dose gave equally better results than 50% dose on both *S. tritici* and *P. recondita*.

DISCUSSION

In 1992, but not 1993, a volume of 100 l ha^{-1} had a higher deposition on the second and third leaf than 200 l ha^{-1}, with no difference between with and without air assistance. The total deposition on the wheat plants was significantly different for air-assisted and conventional spraying. The use of air assistance resulted in better penetration of the spray in the crop, resulting in a more evenly spread distribution over the crop. However air-assistance can also result in a higher emission of spray liquid onto the soil beneath the crop. A relationship between deposition pattern of the used spraying systems and biological efficacy was difficult to find. Some similarities occurred, but a higher deposition rate does not implicitly mean better disease control. There is a possibility of using reduced dosage for disease control depending on the spraying system. As found by Jørgensen & Nielsen (1992) reduced dosages had considerably less effect on disease control. Similar effects of deposition rate with different application techniques on biological efficacy against rust in wheat was found by Haden (1985). Results from field trials done by Lockley (1993) seem to be in agreement with our findings. Based on a single fungicide spray conventionally applied 200 l ha^{-1} compared well with new developments.

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EFFECTIVENESS OF A NOVEL PROPICONAZOLE / FENBUCONAZOLE MIXTURE FOR THE CONTROL OF *SEPTORIA* SPP. AND *PUCCINIA* SPP. IN WHEAT

A.G. DU RIEU, R.J. BURKE

Ciba Agriculture, Whittlesford, Cambridge, CB2 4QT

A. MURRAY

Rohm & Haas (UK) Ltd, Lennig House, Croydon, CR9 3NB

ABSTRACT

SL547 is a mixture of two triazoles, propiconazole and fenbuconazole, which have been evaluated in combination since 1991. The mixture was specifically designed to provide high levels of control of *Septoria* spp. (*Septoria nodorum, Septoria tritici*), brown rust (*Puccinia recondita*) and yellow rust (*Puccinia striiformis*) in wheat whilst being compatible with fungicides with good mildew activity. Results of trials suggest that the two triazole components have complementary activity and that the mixture exploits the strengths of the individual molecules. Yield increases reflected the good disease control obtained.

INTRODUCTION

SL547 is a novel mixture of two active ingredients, fenbuconazole and propiconazole formulated as an emulsifiable concentrate. Urech *et al.* (1979) described the basic properties of propiconazole (trade name Tilt) and gave preliminary results to show its wide range of activity against foliar and ear diseases of cereals. Propiconazole has subsequently become a well established fungicide with a broad range of activity for use against diseases of cereals and a wide range of other crops. Fenbuconazole was announced by Driant *et al* (1988) as a broad spectrum fungicide giving excellent control of *Septoria nodorum, S. tritici, Puccinia recondita* and *P. striiformis* with excellent preventative efficacy and a high level of residual activity.

This paper explores the rationale for developing a product containing two triazole components and presents results from field trials to determine whether propiconazole and fenbuconazole have complementary activity and if the mixture exploits the strengths of the individual molecules.

Why mix two triazole fungicides ?

Fungicidally active substituted azole derivatives have been evaluated for more than twenty years. A considerable number of substitutions have been made leading to the development a diverse group of fungicides with a large variation of biological and physical properties. Triazole molecules have different curative and protectant properties, display different uptake and distribution characteristics and have distinct activities against specific pathogens.

The concept of a triazole + triazole mixture was to enhance activity by exploiting the strengths of each component, resulting in a product which provides superior disease control and dose flexibility to a single conventional triazole molecule whilst allowing the possibility of reduction in overall triazole amounts applied to crops.

Product design

The mixture was specifically designed to provide high levels of control of Septoria and rust diseases in wheat whilst being compatible with fungicides with good mildew activity. Propiconazole and fenbuconazole were selected as potential mixture partners because of their good biological activity against *Septoria* spp. and rusts and their apparently complementary physiological characteristics (Table 1). Propiconazole has been a standard for Septoria control since its introduction, its strong eradicant activity has been confirmed by Hims *et al* (1992) in detailed MAFF trials where it gave excellent eradicant activity against *S. tritici* up to 175 day degrees after infection, and even after 275 day degrees was useful.

TABLE 1. The relative properties of propiconazole and fenbuconazole.

Characteristic	Relative property
Uptake	Propiconazole faster.
Movement in plant	Propiconazole faster.
Septoria activity	Propiconazole greater curative, fenbuconazole superior residual activity
Brown rust activity	Fenbuconazole superior (greater persistence)
Yellow rust activity	Propiconazole superior knockdown, fenbuconazole superior persistence

MATERIALS AND METHODS

All trials reported had plot sizes of 25-36 m^2 using a randomised complete block design and four replicates. Spray volume was 200 l/ha. Trials were located on commercial farms in areas known to be of a high risk to the target diseases.

Trials were carried out using SL547 as an emulsifiable concentrate formulation containing 37.5 g fenbuconazole /l and propiconazole 47 g /l or as a tank-mixture of propiconazole + fenbuconazole emulsifiable concentrate formulations. Rate of use was 94 propiconazole (PPZ) and 75 g fenbuconazole (FCZ) /ha. Trials had one or two applications between GS 33-59 (Zadoks *et al*, 1974) according to disease pressure. For convenience the mixture will be referred to as PPZ+FCZ (SL547) in tables.

Recent advances in diagnostic technology have enabled confirmatory analysis of Septoria species to be made on the leaf and ear. All trials had the *Septoria* species confirmed by using Ciba Agriculture diagnostic analysis for both *S. tritici* and *S. nodorum*. It is difficult to evaluate Septoria species separately when they are present as a mixed infection on the leaf. Where both species were present on the same plant Septoria was assessed as a *S. tritici* and *S. nodorum* complex.

RESULTS AND DISCUSSION

Control of *Septoria* spp.

Data presented in Table 2 demonstrates the complementary activity of propiconazole and fenbuconazole against *S. tritici*. Initial disease control was slightly better with propiconazole and residual activity at 30 days after treatment (DAT) was superior with fenbuconazole. The combination (SL547) gave most disease control.

TABLE 2. Control of *S. tritici* on winter wheat 1993.

Treatment	Dose g AI/ha	% infection *S. tritici* Leaf 2 21 DAT	Leaf 2 30DAT	Flag 30DAT	Yield t/ha	% of untreated
Untreated	-	14.6	*	*	6.1	100
Propiconazole	125	1.0	14.3	1.5	8.8	144
Fenbuconazole	75	1.6	7.4	1.1	9.2	151
PPZ+FCZ (SL547)	94+75	0.5	0.8	0.5	9.9	162
LSD (*P*=0.05)		0.6	2.4	0.3	0.44	

* untreated plants could not be assessed for *S. tritici* because leaves were no longer green.

Trials carried out during 1992 demonstrated that SL547 had superior activity against *S. tritici* compared to the range of triazole standards. Whilst all products gave good disease control at 40-42 DAT, SL547 and tebuconazole at 250g AI/ha gave the highest level of control at 54-59 DAT (Table 3).

TABLE 3. Control of *S. tritici* with SL547 in comparison to triazole standards.

Treatment	Dose g AI/ha	% infection *S. tritici* Leaf 2, 40-42 DAT	Leaf 1+2, 54-59 DAT
Untreated	-	33.1	45.5
PPZ+FCZ (SL547)	94+75	1.3	4.3
Propiconazole	125	2.5	10.3
Fenbuconazole	75	1.6	7.4
Flusilazole	160	2.8	12.6
Cyproconazole	80	3.1	10.4
Tebuconazole	250	1.3	4.9

Mean of 2 trials during 1992

In the UK *Septoria tritici* and *Septoria nodorum* are pathogenic on wheat. *S. nodorum* was the more common species up until the early 1980s. Currently *S. tritici* is considered to be the more common of the two diseases (NIAB, 1993). However both species were frequently detected during 1993 and 1994 field trials. The Ciba "Septoria Watch" survey which analysed leaf material from wheat plants sampled throughout the UK using ELISA-based diagnostic equipment confirmed that *S. nodorum* was widespread throughout the UK in both years (Smith *et al.*, 1994). In field trials in the UK during 1993 and 1994 foliar infections of *S. nodorum* occurred commonly as a mixed infection with *S. tritici*. Data presented in Table 4 show that SL547 gave excellent control of mixed infections. Duration of control was equal or superior to the standard tebuconazole with good control recorded 6 weeks or more after application.

TABLE 4. Duration of control against foliar *S. nodorum* + *S. tritici* infections following single applications at GS37-45, 1993-94.

Treatment	Dose g AI/ha	% leaf infection *S. nodorum* + *S. tritici* 15-17DAT	30-36DAT	46-54DAT
Untreated	-	37	50.5*	36.0
PPZ+FCZ(SL547)	94+75	4.2	4.8	6.1
Tebuconazole	250	5.8	4.4	8.5
No. of trials		2	6	3

* mean of 5 trials only as the untreated had completely senesced in one trial.

If *S. nodorum* continues to become more widespread again in the UK a product with long residual activity against both species would be of benefit as growers attempt to reduce the number of foliar spray applications.

Control of *Puccinia* spp.

Development of yellow rust (*P. striiformis*) is favoured by cool humid conditions and can develop rapidly on wheat early in the season. As symptoms can occur early in the season fungicides are often applied to established infections. In these situations it is necessary to apply a fungicide with rapid action and some eradicant activity. Such curative treatments were applied to a field trial during 1992 with an established infection of 1-3%. Propiconazole gave better initial disease control to fenbuconazole and the standard flusilazole with SL547 giving equivalent control to propiconazole (Table 5). At 30DAT, propiconazole alone and SL547 were still giving excellent control compared to fenbuconazole alone or flusilazole.

TABLE 5. Control of established yellow rust (*P. striiformis*) on winter wheat applied at GS33 (* 1-3% infection at application, 1992).

Treatment	Dose g AI/ha	% infection yellow rust * 13DAT	21DAT	30DAT
Untreated	-	3.3	38.0	61.3
PPZ+FCZ(SL547)	94+75	0	0	1.1
Propiconazole	125	0	0	0.1
Fenbuconazole	75	0.4	4.9	5.5
Flusilazole	160	0.2	0.6	2.2

When protectant applications were made (Table 6) control of yellow rust by SL547 was the same as the standard tebuconazole.

Relatively high temperatures favour development of brown rust of wheat (*P. recondita)*, consequently in the UK it is important as a late season disease of wheat. In UK trials during 1993 and 1994 symptoms were not observed until GS55-75 and consequently all applications were made to low disease levels or applied as protectants. The results show that control of brown rust by SL547 was similar to the tebuconazole standard (Table 6).

TABLE 6. Activity of SL547 applied as a protectant against *Puccinia* spp. 1992-94.

Treatment	Dose g AI/ha	% leaf infection *P. recondita* 25DAT	*P. recondita* 31-36DAT	*P. recondita* 31-36DAT	*P. striiformis* 28-35DAT
Untreated	-	26.3	*	*	60.3
PPZ+FCZ (SL547)	94+75	1.4	0	1.5	1.7
Tebuconazole	250	-	0	0.4	1.1
Propiconazole	125	10.5	-	-	-
Flusilazole	125	11.5	-	-	-
No. of trials		1	2	3	4

* Infection could not be determined as the untreated had completely senesced in both trials due to severe rust infection.

Activity in mixture with fungicides with good mildew activity

In common with most other triazoles, fenbuconazole and propiconazole do not provide adequate control of established mildew in sensitive wheat cultivars. Mixtures of SL547 with specific fungicides with good activity against mildew can overcome this weakness. Data presented in Table 7 show that SL547 in tank mixture with fenpropidin at 375 g AI/ha gave good control of mildew under high disease pressure.

TABLE 7. Control of established mildew with SL547 in mixture with fenpropidin (1994).

Treatment	Dose g AI/ha	% infection (*E. graminis*) Leaf (31-35DAT)	Ear (21DAT)
Untreated	-	43.8	28.7
PPZ+FCZ(SL547)+fenpropidin	94+75+375	5.6	3.7
PPZ+fenpropidin	125+375	6.6	4.5
No. of trials		3	1
Disease at application		3-5%	

CONCLUSIONS

The above data demonstrates that SL547 has good activity against *S. tritici, S. nodorum*, yellow rust and brown rust on wheat. The combination of propiconazole and fenbuconazole was as effective as the most effective single fungicide applied at a higher rate, suggesting that the combination exploits the relative eradicative and protective strengths of each molecule to give a product with very high and persistent activity. Persistence of disease control for six weeks or more could allow for a more flexible approach when devising disease control strategies.

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CONTROL OF SEED, SOIL-BORNE AND FOLIAR FUNGAL DISEASES BY TRITICONAZOLE SEED AND FOLIAR APPLICATIONS

J. MUGNIER*, M. CHAZALET*, JM. GAULLIARD**, RY. ANELICH***, and JM. GOUOT*

* Rhône-Poulenc Agro, Research and Development, 14 rue Pierre Baizet, 69009 Lyon, France

** Rhône-Poulenc Agro-France, Technical Department, 55 avenue René Cassin,69009 Lyon, France

*** Rhône-Poulenc Agrichem, PO Box 12247, Onderstepoort 0110, Republic of South Africa

ABSTRACT

Triticonazole is a novel triazole fungicide which has been developed as a seed treatment (ST) for the control of cereal seed-borne and foliar diseases. It showed good efficacy against barley leaf scald (*Rhynchosporium secalis*) under South African conditions and against corn head smut (*Sphacelotheca reiliana*) in France by ST. Due to its excellent selectivity and upward translocation in plant tissues, high rates of the product can be used on seeds (up to 1000 gAI/t on maize seed). Results from field trials also indicate that triticonazole applied as a foliar treatment provides a good level of control of turf grass diseases such as brown patch (*Rhizoctonia solani*), dollar spot (*Sclerotinia homoeocarpa*) and leaf rust (*Puccinia* sp.).

INTRODUCTION

Triticonazole was introduced by Rhône-Poulenc Agro in 1991 (Mugnier et al. 1991) as a new triazole fungicide for the control of cereal seed-borne and foliar diseases. At low rates, from 25-50 gAI/t seeds, it is effective against bunt (*Tilletia caries*), smut (*Ustilago nuda* var. *hordei, U. nuda* var. *tritici*), Septoria glume blotch (*Septoria nodorum*), seed-borne *Fusarium graminearum* and gives suppression of other seed-borne pathogens such as *Fusarium nivale* and *Pyrenophora graminea* depending on the level of infection (Mugnier et al, 1993).

When applied at high rates to seeds, 1200 gAI/t, triticonazole provides a long duration of protection against early attacks of stem and foliar diseases on wheat and barley such as yellow rust (*Puccinia striiformis)*, brown rust (*P. recondita* and *P. hordei*), powdery mildew (*Erysiphe graminis*), Septoria leaf spot (*Septoria tritici, S. nodorum*) and common eyespot (*Pseudocercosporella herpotrichoides*), as already reported (Gaulliard et al. 1994, Montfort et al. 1991). The level of control achieved against barley leaf scald (*Rhynchosporium secalis*) appears dependent on the local conditions and disease pressure.

Due to its broad spectrum of activity, triticonazole can be used against a range of other fungal diseases and results of field trials conducted to demonstrate the efficacy of the product as a seed or a foliar applied treatment are presented.

EXPERIMENTAL CONDITIONS

Field trials were carried out using either triticonazole treated seeds (barley leaf scald, corn head smut *Sphacelotheca reiliana*) or foliar applications against turf foliar diseases. The trials were designed as randomised complete blocks with four or five replicates.

Barley trials were conducted in South Africa in 1992 and 1993, treated seeds being drilled in May at a seeding rate of 120-140 kg seed/ha. The growth cycle was completed in 115-130 days and harvesting carried out 180-200 days after planting (DAP). Triticonazole was applied to the seeds as an FS 200 gAI/l formulation, at rates of 150 to 600 gAI/t seeds. The reference seed treatment material, triadimenol (Baytan : 150 gAI/l) was applied at rates of 225 gAI/t seeds. One or two foliar applications of fungicides were sprayed according to local practice. In both trials conducted in Caledon (trials 1 and 2), one application of propiconazole (Tilt EC 250) was sprayed at flag leaf emergence , 87 DAP or 82 DAP respectively. In the test conducted in Bredasdorp, flutriafol + thiophanate-methyl (Impact T) was applied at the 6 leaf stage (60 DAP), and flutriafol (Impact) and bromuconazole (Granit) applied at flag leaf emergence (109 DAP). Foliar sprays were applied using water volumes of 312 l/ha. Disease assessments were made as percent leaf area infected by leaf scald (*R. secalis*).

Corn head smut trials were conducted in 1993 in France, using hybrid seeds with a medium sensitivity (Caraco, Mona) or a high susceptibility (Celia) to corn head smut (*S. reiliana*). Planting density varied from 70,000 to 94,000 seeds/ha according to the locations. Captan + anthraquinone (Captolate) at 1000 + 1500 gAI/t seed was applied to seeds with triticonazole at 1000 gAI/t (SC 300 gAI/l). The reference standards were captan + anthraquinone (1000 + 1500 gAI/t as Captolate) and flutriafol + captan + anthraquinone at 75 + 900 + 1500 gAI/t (Stylor C). In one of the treatments a soil granule (Atout : GR at 0.42% flutriafol + 5% carbofuran) was applied in-furrow at planting, bringing 50 g flutriafol + 600 g carbofuran/ha in addition to the Stylor C seed treatment, in order to achieve a sufficient level of protection in the case of highly susceptible hybrids. The organic matter content of the soils was always below 7% in each of the four trials reported. Disease assessments were made as percent of plants attacked by corn head smut before or at harvest.

Turf trials were conducted during 1993 by RPA in France (rust) and the USA (brown patch) and under contract at Pennsylvania State University, PA, USA (dollar spot). The rust trial was carried out on bluegrass (*Poa pratensis*), naturally infected by rust (*Puccinia graminis)* before the application of the foliar treatment (spray volume : 1000 l/ha). Turf was mowed regularly throughout the season. The brown patch test was conducted on tall fescue (*Festuca arundinacea*) artificially inoculated with *Rhizoctonia solani* on oat grains before the first foliar fungicide spray. Five foliar applications were made at 14 day intervals using a volume rate of 500 l/ha. High levels of nitrogen fertilisation and irrigation were used to increase the disease pressure. Triticonazole was evaluated against dollar spot in comparison with commercial and experimental fungicides on creeping bent grass (*Agrostis palustris*), artificially inoculated 5 days prior to the initial application with a mixture of 5 different *Sclerotinia homoeocarpa* isolates. Three foliar applications were made at 28 day intervals at a volume rate of 814 l/ha .

All foliar applications of triticonazole were made with an experimental flowable formulation : SC 200 gAI/l, diluted in water. In the table of results, xDATy indicates that assessments were carried out x days after the y treatment.

RESULTS AND DISCUSSION

In the trials in South Africa, the efficacy of the triticonazole seed treatment (ST) was good against barley leaf scald (*R. secalis*) from 150 gAI/t seeds (Table 1). At 300 gAI/t triticonazole ST performed as well as the standard ST triadimenol combined with one or two foliar applications of a triazole fungicide (bromuconazole, flutriafol or propiconazole) up to the emergence of the flag leaf or later. In this country, a maximum of two foliar treatments are applied at Z30-32 (Zadoks growth stage : 6 leaves) and Z39-49 (flag leaf appearance and extension) respectively. The majority of growers however apply only one spray at Z36-40. Thus, triticonazole could be a useful tool to control *R. secalis* on barley under these conditions, as well as early attacks of powdery mildew, up to the 8 leaf stage.

TABLE 1. Control of barley leaf scald (*Rhynchosporium secalis*) by triticonazole seed treatment in three field trials conducted in South Africa -1992-1993.

TREATMENT	APPLICATION	RATE GAI/T OR GAI/HA	% LEAF AREA INFECTED				
			Caledon (1) (103 DAP)		Caledon (2) (112 DAP)	Bredasdorp (145 DAP)	
			L2	L3	L3	FLAG	L2
Control			25.9 a	41.2 a	15.3 a	11.7 a	19.9 a
triticonazole	ST	150	6.2 b	14.7 b	4.9 ab		
triticonazole	ST	300	7.8 b	7.7 b	3.3 b	0.9 c	8.4 b
triticonazole	ST	600	2.3 b	7.5 b	5.1 ab		
triticonazole bromuconazole	ST FT	300 120				1.5 bc	6.9 b
triadimenol flutriafol + thiophanate-méthyl flutriafol	ST FT FT	225 113 + 300 125				3.6 b	10.0 b
triadimenol propiconazole	ST FT	225 100	8.2 b	34.0a	9.1 ab		
LSD (P=0.05)			8.7	8.8	10.4	4.6	5.2

DAP : Days After Planting
ST : Seed Treatment
FT : Foliar Treatment (Caledon 1 : applied 87 DAP ; Caledon 2 : 82 DAP ; Bredasdorp : flutriafol treatments 60 and 109 DAP ; bromuconazole 109 DAP)

Corn head smut (*S. reiliana*) is a growing problem in France since a large proportion of the corn growing area is now infected by this soil-borne disease. The susceptibility to this disease is highly dependent on the variety (inbreds and hybrids) which means that seed disinfection is sufficient in the case of moderately susceptible seeds planted in non-infected soils but the use of a soil granule containing an additional amount of fungicide is required in the case of highly or very highly susceptible varieties.

Since triticonazole is very selective on maize seeds (data not shown) as well as on cereals, higher quantities of the product can be applied as a seed treatment than is recommended for the usual sterol inhibitor fungicides.

Good protection against corn head smut was observed in the four trials conducted in France (Table 2), with 1000 gAI triticonazole /t seeds. Such a seed treatment might allow the maize growers to omit the soil granule application in the case of susceptible hybrids. The specific conditions of application, especially for very susceptible hybrids grown in soils with a high organic matter content, are under evaluation.

TABLE 2. Efficacy of fungicide seed treatments against corn head smut (*Sphacelotheca reiliana*) in four field trials conducted in France in 1993.

			% PLANTS ATTACKED AT HARVEST			
LOCATION			BORDEAUX	TOULOUSE	BORDEAUX	ORLEANS
VARIETY			Caraco (MS)	Mona (MS)	Celia (HS)	Celia (HS)
TREATMENT	Rate gAI/t seeds	Rate gAI/ha soil granule				
Control			9.9 a	10.8 a	42 a	30.3 a
captan + anthraquinone	1 000 + 1 500		8.9 a	11.3 a	43 a	24 b
triticonazole + captan + anthraquinone	1 000 + 1 000 + 1 500		0.0 c	1.8 bc	3.2 b	3.5 c
flutriafol + captan + anthraquinone	75 + 900 + 1 500		4.2 b	4.9 ab	34 a	23.5 b
flutriafol + captan + anthraquinone flutriafol + carbofuran	75 + 900 + 1 500	50 + 600	0.9 c	0.0 c	4 b	1.5 c
LSD (*P*=0.05)			2.5	4.7	8.8	5.5

MS Medium sensitivity to corn head smut
HS Highly susceptible to corn head smut

Triticonazole, as with most of the other sterol demethylation inhibitors, shows a broad fungicidal spectrum of efficacy by foliar treatment. Because of its excellent selectivity, triticonazole can be applied at higher rates to many crops (up to 2 000 gAI/ha on turf grasses). Repeated applications of the flowable formulation (SC 200 gAI/l) gave good control of foliar diseases on turf grasses at 300-1000 gAI/ha, especially against brown patch (*R. solani)* (Table 3), dollar spot (*S. homoeocarpa*) (Table 4) and brown rust (*Puccinia sp.*) (Table 5). Other results, not shown, indicate that triticonazole controls or suppresses other foliar diseases on turf grasses. The timing of the applications will depend on the prevalent disease on the site, but is generally of the order of 2 to 4 weeks between treatments.

TABLE 3. Control of brown patch (*Rhizoctonia solani*) on turf in a field trial in the USA - 1993.

		DISEASE SEVERITY % PLOT DISEASED			TURF COLOUR SCORE
TREATMENT	Dose rate gAI/ha	13 DAT3	14 DAT 4	24 DAT 5	24 DAT 5
Control		15.5 a	27.5 a	30.0 a	6.3 b
triticonazole	320	1.0 b	6.8 b	5.5 b	8.3 a
triticonazole	640	0.0 b	3.0 b	5.5 b	8.3 a
iprodione	3 050	0.5 b	2.8 b	3.3 b	8.3 a
LSD (P = 0.05)		9.5	8.7	8.2	1.5

Turf colour score : from 0 brown to 9 dark green

TABLE 4. Control of dollar spot (*Sclerotinia homoeocarpa*) on turf in a field trial in the USA - 1993.

		DISEASE SEVERITY NUMBER OF DOLLAR SPOT INFECTION CENTRES /SQ. FT		
TREATMENT	Dose rate gAI/ha	26 DAT 1	27 DAT 2	23 DAT 3
Control		12.6 a	20.1 a	33.4 a
triticonazole	320	4.1 b	0.1 b	0.2 b
triticonazole	640	0.8 b	0.0 b	0.0 b
cyproconazole	207	1.4 b	0.0 b	0.0 b
tebuconazole	572	3.6 b	1.4 b	0.3b
P = 0.05 Duncan's MRT				

TABLE 5. Efficacy of triticonazole against rust (*Puccinia graminis*) on turf (*Poa pratensis*) in a field trial in France - 1993.

		DISEASE SEVERITY % INFESTATION		
TREATMENT	Dose rate gAI/ha	14 DAT	29 DAT	66 DAT
Control		17.2 a	24.3 a	4.8 a
triticonazole	500	0.2 b	0.2 b	0.01 b
triticonazole	1 000	0.3 b	0.1 b	0.03 b
iprodione	5 000	2.0 b	5.1 b	4.7 a
anilazine + chlorothalonil + benomyl + urea	3 500 + 5 600 + 250 + 85 000	4.8 b	6.0 b	0.5 b
LSD (P = 0.05)		5.7	6.1	2.5

CONCLUSION

Triticonazole is a new sterol demethylation inhibitor fungicide characterised by its excellent selectivity towards plant tissues and its acropetal transport in the plants after seed treatment. As demonstrated in a number of trials, triticonazole will be useful tool to control seed and soil-borne diseases of cereals and maize, at rates to be adjusted according to the local conditions of cropping and disease pressure. Triticonazole could be also used as foliar applications against other fungal pathogens such as those that cause turf grass diseases.

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CGA 219417 - DISEASE CONTROL IN CEREALS IN WESTERN EUROPE

A. J. LEADBEATER
Ciba Agriculture, Whittlesford, Cambridge CB2 4QT

J. SPEICH, G. KNAUF-BEITER
Ciba-Geigy Ltd, CH-4002 Basle, Switzerland

A. KÜHL
Ciba-Geigy GmbH, Division Agro, Frankfurt/Main, Germany

O. RAMBACH
Ciba-Geigy SA, Rueil-Malmaison, France

ABSTRACT

CGA 219417 (proposed common name: cyprodinil) is a new fungicide belonging to the pyrimidinamine chemical class, with a broad spectrum of disease control in cereals. At rates between 400g and 750g AI /ha CGA 219417 is highly active against cereal eyespot (*Pseudocercosporella herpotrichoides*), powdery mildew (*Erysiphe graminis*), barley net blotch (*Pyrenophora teres*) and *Rhynchosporium secalis*; it also has a good activity against ear infections of *Septoria nodorum* on wheat. Data are presented from trials across Western Europe demonstrating the high level of control of a broad spectrum of cereal diseases achieved by CGA 219417 between 1989 and 1993. Field results are supported by basic studies demonstrating the sites of activity of CGA 219417 in the life cycles of various target pathogens.

INTRODUCTION

Cereal production throughout Europe continues to be threatened annually by a number of damaging pathogens able to take advantage of current intensive farming practices, i.e. large areas of monocrops and a reliance on a limited number of genetically resistant or partially resistant cultivars. As a consequence, treatment by fungicides has become essential to ensure a sufficient quantity and quality of grain production to satisfy economic and social requirements. Many effective fungicides have been available to farmers in recent years which have been largely successful in meeting the disease control needs of crops. There has been however a great reliance on a limited number of chemical groups for this purpose, overuse of which has in some cases resulted in reduced efficacy of fungicides against major plant pathogens due to sensitivity shifts in pathogen populations. Examples of this can be found with the benzimidazoles and triazoles.

Cereal powdery mildew, caused by *Erysiphe graminis*, and true eyespot, caused by *Pseudocercosporella herpotrichoides*, are two of the most economically important diseases of cereals in Western Europe. Current standards against these diseases are effective, although widespread resistance of eyespot to benzimidazoles has rendered this class of fungicides ineffective and cases of reduced performance of prochloraz against the same pathogen has been reported in France (Leroux & Migeon, 1993). These cases emphasise the need for continual improvements in fungicide strategies, including a requirement for new chemistry with novel biochemical modes of action active against major pathogens.

CGA 219417 (IUPAC name: N-(4-cyclopropyl-6-methyl-pyrimidin-2-yl-)aniline; proposed common name: cyprodinil), is a new fungicide belonging to the pyrimidinamine chemical class. It is active against fungi in the Ascomycetes and Deuteromycetes and is currently being developed for use as a foliar fungicide on cereals, vegetables, grapes and deciduous fruit. As a seed treatment for barley, it controls leaf stripe (*Pyrenophora graminea*) and seed-borne net blotch (*Pyrenophora teres*) (Leadbitter *et al.*, 1994). It is currently marketed as a cereal fungicide in France and Switzerland under the name UNIX ®. In cereals, CGA 219417 is active against powdery mildew (*Erysiphe graminis*), eyespot (*Pseudocercosporella herpotrichoides*), barley net blotch (*Pyrenophora teres*), *Rhynchosporium secalis* and *Septoria nodorum*. The fungicide is systemic and has preventive and curative properties. CGA 219417 has been shown to have a novel mode of action, i.e. interference with amino acid biosynthesis (Masner *et al.*, 1994) and demonstrates no cross resistance with triazoles, imidazoles, morpholines or benzimidazoles (Heye *et al.*, 1994a). Studies show that CGA 219417 is equally effective against the fast growing ("wheat") and slow-growing ("rye") types of *P. herpotrichoides* (Heye *et al.*, 1994a).

This paper presents results from 114 field trials carried out in Great Britain, France and Germany during 1989-1993 to assess the efficacy of CGA 219417 against the major diseases in its activity spectrum. In addition, results of studies of the sites of action of CGA 219417 in *P. herpotrichoides* and *Erysiphe graminis* f. sp. *tritici* are presented.

METHODS AND MATERIALS

Field trials were carried out mainly using a 75% water dispersible granule formulation of CGA 219417 at rates between 400 and 750g AI /ha. Treatments were applied using hand-held precision plot sprayers and water volumes of 200-500 l /ha. Trials were located in the major cereal growing areas of Great Britain, France and Germany and were situated in commercial crops with natural disease infections. Trials were of randomised complete block design with plot sizes of 12.5-40.0 m^2 and four replicates.

Applications in eyespot trials were made at GS (Zadoks) 29-32 unless otherwise stated. Eyespot evaluations were made 60-90 days after application by sampling stems and either cutting transversely through the stem at the most severe point of infection and measuring the percent cross-sectional area affected by lesions, or alternatively by utilising the 0-3 index of severity (Scott & Hollins, 1974). Eyespot strains were isolated from the trials sites and were characterised according to phenotype on agar as "wheat" or "rye" types. Those from French trials were predominantly "rye type"; those from Great Britain were a mixture of "wheat" and "rye" types. Applications were made to foliar disease trials at the first signs of active disease, repeat applications being made if necessary according to good agricultural practice; in all cases the standard products were applied the same number of times as CGA 219417 treatments. Disease evaluations were made as either visual estimation of overall % leaf areas infected in the field or by randomly sampling individual leaves and assessing % leaf areas infected. As these evaluations are subjective, it is not considered valid to subject them to statistical analysis.

Site of action studies were carried out using wheat cv. Armada or Kanzler, grown under standard glasshouse conditions. Fungicide treatment for the *P. herpotrichoides* study was carried out 2 days before inoculation (protectant) and 3 or 14 days after inoculation (curative); for *Erysiphe graminis* this was 1 day before and 2 days after inoculation. Plants were inoculated appropriately (either conidial "dusts" or spore suspensions) and evaluations of the growth progress were made by light microscopy after clearing and staining the leaf material.

For convenience, standard products are referred to in tables as PPZ (propiconazole), FPD (fenpropidin), FPM (fenpropimorph), FSZ (flusilazole) and mbc (carbendazim).

RESULTS

Site of action studies.

The results of the site of action studies show CGA 219417 to have curative and protectant properties against both *P. herpotrichoides* and *E. graminis* f. sp. *tritici* (Table 1). The formation of haustoria, and as a consequence mycelial growth, were clearly the major target sites for CGA 219417 against *E. graminis*, leading to a strong suppression of sporulation. Against *P. herpotrichoides* the major target site of CGA 219417 seems to have been the penetration step. In consequence mycelial growth was inhibited - this situation is comparable to that of powdery mildew; first inhibition of an infection step which took place in the epidermis, leading to the further inhibition of fungal infection. For both pathogens no effect of CGA 219417 was found on germination or any other infection stage occurring only on the plant surface. This work is supportive evidence of the systemicity of CGA 219417; a fungicide with curative activity at the steps in a pathogen's life cycle where CGA 219417 is active must be taken up by the plant to reach the site of action.

TABLE 1. EC50 values for the inhibition of various fungal growth stages of *P. herpotrichoides* and *E. graminis* f. sp. *tritici* by CGA 219417 in glasshouse studies.

	EC50 values (mg AI /litre)			
	P. herpotrichoides		*E. graminis* f. sp. *tritici*	
Fungal growth stage	Protectant	Curative	Protectant	Curative
Germination	> 1200	> 1200a	-	-
Appressorium formation	-	-	> 600	not eval.*
Penetration hyphae formation	50	65a	na	na
Primary haustoria formation	na	na	100	not eval*
Secondary haustoria formation	na	na	25	26
Mycelial growth	67	320b	32	38
Symptom development	138	364b	170	> 600
Sporulation inhibition	-	-	70	26

* = not evaluated because germination & primary haustoria formation was generally completed within 48 hours of inoculation, curative application made 2 d after inoculation.
a = 3 d curative application b= 14 d curative application na = not appropriate.

Control of eyespot

Field trials were carried out in France and Great Britain during 1989-1993 against *P. herpotrichoides*. The results of these trials (Tables 2 and 3) show that CGA 219417 at 750g AI /ha gave control of eyespot equal or superior to the prochloraz standard. At 500g AI /ha in Great Britain and Germany, and 600g AI /ha in France, although the activity of CGA 219417 was reduced compared with the 750g rate, performance was still very good and was commercially acceptable. Data also given in Table 2 show that a high level of eyespot control was given by two repeat applications of CGA 219417 at 500g AI /ha. Trials against eyespot of winter barley in Great Britain (Table 4) show that in this crop CGA 219417 also achieved control of eyespot at least equal, and usually superior, to the standard prochloraz.

TABLE 2. Control of *P. herpotrichoides* on winter wheat in Great Britain.

Treatment	Dose (g AI/ha)	% cross-section infection 1989	1990	1990**	Eyespot index of infection 1992	1992**	1993	1993**
Untreated	-	73.5	63.8	70.5	46.4	32.5	59.9	40.9
Prochloraz	400	42.2	53.4	63.0	26.8	5.6	42.9	21.7
CGA 219417	500	48.4	40.8	-	30.9	4.1	46.8	-
CGA 219417	750	45.1	34.3	41.0	28.1	3.6	37.7	7.9
Number of trials		5	4	2	4	2	4	2
% "rye types"		na	76	58	59	42	81	65

** = in these trials all products were applied twice, at GS 29-32 and GS32-33.

TABLE 3. Control of *P. herpotrichoides* on winter wheat in France.

Treatment	Dose (g AI/ha)	% cross-section infection 1992		1993		
Untreated	-	55.5	47.0	53.3	46.5	45.8
Prochloraz	450	-	38.1	-	39.6	-
Prochloraz	600	36.1	-	41.7	-	32.1
CGA 219417	600-625	35.2	-	31.4	-	17.9
CGA 219417	750	31.2	24.9	25.7	14.7	-
Number of trials:		4	4	3	4	2
% "rye types"		84	92	81	89	77

TABLE 4. Control of *P. herpotrichoides* on winter barley in Great Britain.

Treatment	Dose (g AI/ha)	Eyespot index of infection 3600291*	360491*	350592*	350692*	350892*
Untreated	-	63.0	56.3	70.9	40.3	33.7
Prochloraz	400	59.7	55.7	37.3	10.5	10.9
CGA 219417	500	55.0	50.7	19.3	7.3	3.3
CGA 219417	750	43.7	31.3	14.9	4.3	4.0

* = trial reference number

Control of *Erysiphe graminis*

Field trials were carried out in Germany, France and Great Britain to determine the efficacy of CGA 219417 against wheat powdery mildew in comparison with the standard products fenpropidin and fenpropimorph (Table 5). Under severe disease pressure across 27 trials CGA 219417 at 750g AI /ha gave disease control similar to the standards. Reducing the rate of CGA 219417 to 500g AI/ha led to a corresponding reduction in efficacy. On winter barley in the same countries, CGA 219417 at 400-500g AI/ha also gave good disease control, similar to the standard products (Table 6). In both wheat and barley, reduced rates of CGA 219417 in mixture with propiconazole (500g + 125g or 375-400g + 125g AI/ha respectively) gave control of mildew equal to the morpholine or piperidine standards. Such mixtures are useful in further broadening the spectrum of disease control as well as offering an anti-resistance strategy. Rates of CGA 219417 lower than those used in wheat are effective against barley powdery mildew.

TABLE 5. Control of *Erysiphe graminis* on winter wheat in Western Europe.

Treatment	Dose (g AI /ha)	% leaf area infected in: Germany	France	Great Britain
Untreated	-	26	48	32
Standard*	*	8	4	5
CGA 219417	500	8	10	11
CGA 219417	750	5	-	7
CGA 219417+PPZ	500+125	7	6	7
Number of trials		9	5	12
Years		89-92	89-92	90-93

* standard: Germany = FPM 375-750g AI /ha, France = FPM 375-750g AI /ha, FPD 562g AI /ha (2 trials), Great Britain = FPM 750g (9 trials), FPD 750g AI /ha.

TABLE 6. Control of *Erysiphe graminis* on winter barley in Western Europe.

Treatment	Dose (g AI /ha)	% leaf area infected in: Germany	France	Great Britain
Untreated	-	28	64	59
Standard*	*	1	7	5
CGA 219417	400-500	6	11	4
CGA 219417+PPZ	375-400+125	3	11	4
Number of trials		3	1	11
Years		91/93	90	90-92

* Standard: Germany = PPZ+ FPM 125+300 g AI /ha, France= FPM at 375g AI /ha, Great Britain= FPM at 750g AI /ha.

Control of barley net blotch (*Pyrenophora teres*).

Trials in winter barley carried out in France, Germany and Great Britain were subject to high levels of attack by net blotch. Good control of this disease was given by standard treatments of either propiconazole + fenpropimorph, propiconazole + carbendazim or flusilazole + carbendazim. CGA 219417 applied at 400-500g AI /ha also gave very good control of this disease. A mixture of CGA 219417 + propiconazole at 375-400g + 125g AI /ha gave excellent control of net blotch and was superior to the standards (Table 7). CGA 219417 offers a useful potential anti-resistance strategy for triazoles against this barley disease as well as powdery mildew and *R. secalis* (next section).

TABLE 7. Control of *Pyrenophora teres* on winter barley in Western Europe

Treatment	Dose (g AI /ha)	% leaf area infected in: Germany	France	Great Britain
Untreated	-	31	48	36
Standard*	*	7	9	3
CGA 219417	400-500	5	11	2
CGA 219417+PPZ	375-400+125	3	5	1
Number of trials		3	5	6
Years		92-93	91-93	90-93

* standard: Germany = PPZ+FPM 125+300g AI /ha (2 trials), FSZ+mbc 125+250g AI/ha, France = PPZ+FPM 125+375g AI/ha (3 trials) and PPZ+mbc 125+150g AI /ha (2 trials). Great Britain = PPZ+FPM 125+375g AI /ha

Control of *Rhynchosporium secalis.*

Control of *R. secalis* on winter barley by CGA 219417 at 400-500g is shown in Table 8. The activity of CGA 219417 against this disease can be seen to be high although under extreme disease pressure conditions control was enhanced by the addition of a partner product such as propiconazole, thus increasing the reliability of disease control.

TABLE 8. Control of *Rhynchosporium secalis* on winter barley in Western Europe.

Treatment	Dose (g AI /ha)	% leaf area infected in: Germany	France	Great Britain
Untreated	-	25	31	33
Standard*	*	10	8	5
CGA 219417	400-500	4	11	6
CGA 219417+PPZ	375-400+125	3	6	3
Number of trials		2	5	7
Years		90/93	91-93	91-93

* standard: Germany = FSZ+mbc 125+250g AI/ha, France = PPZ+FPM 125+375g AI/ha (3 trials) or PPZ+mbc 125+150g AI /ha (2 trials). Great Britain = PPZ+FPM 125+375g AI /ha.

CONCLUSIONS

CGA 219417 has been tested across Western Europe under conditions of severe disease pressure against some major cereal diseases. This paper shows that it is highly active against eyespot, powdery mildew, net blotch and *R. secalis*, offering disease control at least equal to modern standards. Yield data obtained from these trials (not presented in this paper) are consistent with a high level of crop safety and disease control and have in many instances been significantly greater than would be expected from disease control alone. CGA 219417 represents an ideal mixture partner for other fungicides such as propiconazole, since their spectra of activity are complementary on both wheat and barley. The good activity of CGA 219417 against powdery mildew, eyespot, net blotch, *R. secalis* and ear infections of *Septoria nodorum* (data not included here) together with its novel mode of action, make it an ideal anti-resistance partner for use with current standards.

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