**Proceedings of the Workshop on the European
network for development of an integrated control
strategy of potato late blight**

Carlow, Ireland 24 September - 27 September 1997

Huub Schepers & Erno Bouma (eds.)
Applied Research for Arable Farming and
Field Production of Vegetables
P.O.-Box 430
NL-8200 AK Lelystad
Tel: +31 320 291111
Fax:+31 320 230479

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European Network for development of an integrated control strategy of potato late blight (EU.NET.ICP)

Second Workshop, Carlow, 1997

This report contains the papers and posters presented at the Second Workshop on the European network for development of an integrated control strategy of potato late blight held in Carlow, Ireland 24 September - 27 September 1997. The Workshop was the second of four Workshops to be held as part of the activities in the Concerted Action EU.NET.ICP.

EU.NET.ICP

EU.NET.ICP is a network of 16 research groups from 10 European countries, all working on integrated control of late blight caused by the fungus *Phytophthora infestans* in potatoes.

The network is funded by the European Commission as a Concerted action within the Programme for research, technological development and demonstration in the field of agriculture and fisheries 1994-1998.

With the establishment of a network for communication between scientists and research groups who work on control of late blight trhe following objectives are envisaged:

- to coordinate ongoing research in order to avoid duplication of efforts.
- survey the state of the art on control of Phytophthora infestans and indicate information gaps to regards to integrating a Decision Support System.
- development of European Integrated Control Strategy and a Decision Support System in which all available knowledge is integrated.
- by harmonising ongoing field trials an Integrated Control Strategy and a Decision Support System will be validated on a European level.
- results will be diffused to extension officers and farmers.

The papers presented in the Proceedings give a survey of the state of the art in controlling *Phytophthora infestans* in potatoes in Europe. During the Workshop sub-groups were formed on epidemiology, fungicides and Decision Support Systems. In these sub-groups first steps were made towards on indication gaps and coordinating ongoing research.

For further information please contact the network secretariat where additional copies of this report and the Newsletter can be ordered.

Secretariat

Research Station for Arable Farming

and Field Production of Vegetables

P.O.-Box 430

NL-8200 AK Lelystad

Att: H.T.A.M. Schepers

Telephone +31 320 291111

Telefax +31 320 230479

E-mail: H.T.A.M.SCHEPERS@PAV.AGRO.NL

http://www.agro.nl.appliedresearch/pav/pavintp.htm

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an Integrated Control Strategy of potato late blight
Carlow, Ireland, 24 - 27 September 1997[1]

The development and control of

Phytophthora Infestans in Europe in 1997

H.T.A.M. SCHEPERS

Applied Research for Arable Farming and Field Production of Vegetables

P. O. Box 430, 8200 AK Lelystad, The Netherlands

Introduction

From 24-27 September 1997 a Workshop was held in the framework of a Concerted Action on control of *Phytophthora infestans*. Representatives from 12 European countries presented the development and control of late blight in their country in 1997. In this paper these presentations are summarised. The weather conditions of 1997, the disease progress and the input of fungicides are presented.

Weather conditions

Weather conditions in the Po Valley (**Italy**) were not very favourable for blight outbreaks. Negative prognosis I.P.I model's threshold was averagely overcome in mid June due to heavy and persistent rain fall specially in the north of the Po river. Waterlogged soils did not allow farmers to enter the potato plots to protect the crops and first blight symptoms were detected on potato from June 20. South of the river the lack of rainfall in May and few showers in June failed to be conducive to the disease on potato. However, later in the first week of July late blight was detected on tomato plots sporadically within the most important tomato growing areas of central and northern **Italy**. In the north of **Spain** rainfall was high in May-July resulting in high risk for late blight. After 10th June heavy rainfall in **France** increased risk enormously; the risk was only higher in 1981. August was dry and warm which lowered the risk, but heavy showers at the end of August again increased the risk. In **Austria** most crops were dense and heavy in June and amount of rainfall was high during the second half of the month. Low temperatures prevented the first occurrence of late blight. Rise in temperature in

combination with temporary waterlogging favoured a delayed but severe outbreak of the disease in most production areas in the second half of July (17/7 - 20/7). From beginning to middle of August a second period with high infection pressure caused severe damage especially in middle late crop. The end of the vegetation period was characterised by dry and warm weather conditions preventing or reducing significantly tuber infection. Favoured by the climatic conditions in 1997 outbreak of the disease was much more severe than in 1996 in particular as the temporary waterlogging of the fields did not allow fungicide treatment during these periods.

In **Switzerland** the high risk weather conditions are characterised by "Main Infection and Sporulation Periods"(MISP). In 1997, 21 of these periods were recorded and only 6 in 1996. Also in **Belgium, The Netherlands** and **Norway** the weather conditions were very favourable for the development of late blight. In the east of **Scotland** high risk periods occurred earlier than normal. Many Smith periods were recorded in June, July. Blight favourable weather as determined by "Smith-periods" was recorded in all areas of **England** and **Wales** during the growing season, but in some areas, notably the South West and the North, the risk was extremely high. In **Northern Ireland**, a near Smith period 17-20 May was followed by an unusually early outbreak of blight in one crop on 30 May. Smith periods were recorded in June, July, August and September, but cold weather in June slowed the spread of blight in the early part of the season and blight, although widespread, was not severe in most crops. In **Ireland** the rainfall was high during 1997 (500 mm from June-September) which resulted in an accumulated risk value that was nearly double that of 1996. In the southern part of Jutland **(Denmark)** late blight was observed in several fields in the last week of June. The late blight warning based on the Negative Prognosis was for the first time in many years, about one week too late in this area. Early and heavy attacks including a lot of stem lesions were seen especially in the cv Godiva. In the first part of July weather became unfavourable for late blight and in mid July late blight seemed to be under control in conventional fields. July and August were very hot and dry. In organic crops late blight epidemics started about mid July. That is 2-3 weeks earlier than normal. In **Sweden** the weather was favourable in the end of May and in June, but a dry July reduced the risk for late blight considerably. As a whole 1997 was not a extremely severe "blight" year in Sweden. In the south of **Finland** high rainfall produced an increased risk for late blight when compared to other regions and most years. An estimation of the weather conditions favourable for the development of late blight during the growing season of 1997 is presented in Table 1.

In most countries the first recorded outbreak of late blight was earlier than in other years. Only in Norway and Italy, was the first recorded outbreak later than in previous years (Table 1).

Fungicide input

The early attack of late blight in many countries and the continuously favourable weather conditions during the growing season caused an increased input of fungicides in almost all countries. Sometimes the availability of fungicides was low, and growers had to use what was available rather than the first choice products. Active ingredients with curative and eradicant properties were used more frequently than in previous years, also fentin-based fungicides were used more to minimise the risk of tuber infection. In the periods with high rainfall, fungicides with a good rainfastness (eg. fluazinam) were preferred to other products. The average number of treatments per growing season was higher in most countries (Table 2). The input of fungicides in 1997 is estimated to be 15-40% higher than in 1996.

Tuber blight

In Belgium, France, Italy, The Netherlands, Sweden, Switzerland and Austria no serious problems with tuber blight were recorded. In Ireland serious problems were encountered in stored potatoes. Sporulation of the fungus on the surface of infected tubers has led to significant spread of infection during handling processes. Problems with tuber blight have also been detected in some areas of Spain, Jersey, England/Wales, Northern Ireland, Finland, Norway and Scotland. Tuber blight will occur on a larger scale when heavy rain showers can wash down spores from an infected crop to a wet soil. There are also indication that lower soil temperatures ($<16°C$) promote the development of tuber blight.

Table 1. Weather conditions favourable for the development of late blight and dates of first recorded outbreaks in 1997 in relation to other years.

	May	June	July	August	September	First outbreak 1997	1996	1995
AU	*	**	***	***	*	17 July	(7-10 days later than normal)	
B	***	***	**	**	**	15 May[1]	September	30 May[1]
CH		***	***			16 May	23 May	29*April
D	?	?	?	?	?	?	?	?
DK	**	***	*	*	*	end June	begin June	20 June
E	**	***	***	**	*	1-7 June		
F	*	***	***	**	**	23 May[2]	13 June[2]	1*April[2]
I	*	**	**	*	*	20 June	19 May	30 May
IRL	*	***	***	***	***	25 June	31 July	
N	***	***	**	**	**	7*August	29 July	
NL	***	***	**	**	**	2 June		
S		***	**	**	**	24 May[1]		
FIN		**	**	**	***	1 July	(2 to 4 weeks earlier than normal)	
Northern Ireland	**	***	***	***	***	30 May	27 June	20 June
England/Wales	***	***	***	***	**	29 May		
Jersey	***	***				7 March[1]	(earliest outbreak since 1992)	
Scotland		***	***	**		3 July	(2 to 4 weeks earlier than normal)	

*	=	low risk
**	=	moderate risk
***	=	high risk

[1] polythene covered crop
[2] waste piles

Table 2. The estimated use of fungicides. Average number sprays/season.

	1997	1996
AU	5-6 x	4-5 x
B	14-15 x	8-12 x
CH	7-9 x	6-7 x
D	?	6 x
DK	7-10 x	6 x
E	5-6 x	3 x
F	poster	11-20 x
I	6-8 x	6-8 x
IRL	?	?
N	4 x	2.9 x
NL	7-15 x	5-12 x
S	4-5 x	4-5 x
FIN	4-5 x	3-4 x
UK	4-18 x	2-10 x

Second Workshop of an European Network for Development of[2]
an Integrated Control Strategy of potato late blight
Carlow, Ireland, 24 - 27 September 1997

Report of the discussions of the subgroup

epidemiology

D. ANDRIVON

Participants: Nicole Adler (D), Björn Andersson (S), Didier Andrivon (F) (chair), Ruairidh Bain (UK), Annelies Beniers (NL), Lars Bödker (DK), Laura Cobelli (I), Louise Cooke (UK), Frank Fleischmann (D), Dennis Griffin (IRL), Jan Hadders (NL), Arne Hermansen (N), Hector Lozoya-Saldãna (MEX), Kurt Möller (D), Seamus O'Sullivan (IRL), Magnus Sandström (S), Alexandra Schlenzig (D), Diedert Spijkerboer (NL), Anita Strömberg (S)

The discussions in the subgroup focused on three main topics, on which several presentations had been made during the workshop:

    i) the population structure of *Phytophthora infestans*;

    ii) epidemiological parameters, including aggressiveness differences, and their relevance to DSS in current *P. infestans* genotypes;

    iii) the occurrence and epidemiological importance of oöspores.

The meeting started by a brief presentation of the research programmes of the participants and/or their groups, as related to these three topics. These will be presented under the corresponding sections.

1. Population structures of *P. infestans*.

Among the participants present, several are engaged in studies of the population structure of local *P. infestans* populations, both in Europe (France, Ireland, the Netherlands, Scandinavia...) and abroad (Mexico). However, it appears that much of the information is scattered and that a compilation of the existing data sources should be useful. To this end, a questionnaire will be prepared by Didier Andrivon, and sent to all participants in the Concerted action be-

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fore the end of 1997. The goal of this questionnaire is to list the kind of information available on local population structures of *P. infestans* in Europe (markers used, sample sizes, period surveyed, etc...), and the sources where this information can be obtained. The questionnaire should be returned to Didier Andrivon before the end of February, 1998, and a compilation of the data will be produced for the Uppsala meeting.

The relevance of investigation of population structure for DSS management was not unanimously recognised, although it seemed clear that knowledge on the composition and evolution of populations was of importance for controlling the late blight pathogen. One of the problems raised was that DSS do not aim at modelling the epidemics incited by every genotype in the pathogen population, but at describing the epidemic incited by the population as a whole. In other terms, while the variability among genotypes constituting the pathogen population is not accounted for by DSS, the modelling systems should be based on the parameters relevant for the most threatening genotypes present in the population. The nature of these critical genotypes (most frequent genotype in the population, or most aggressive one?) is at the moment difficult to determine, since too little is known about variation among genotypes in their requirements concerning epidemiologically significant parameters (see infra).

2. Epidemiological parameters and their relevance to DSS

Again, several groups are actively involved in measuring epidemiological parameters for current isolates of *P. infestans*. A number of groups (Norway, the Netherlands, UK, France) also are engaged in gathering information about variation for aggressiveness, either to leaves, stems or tubers, of local *P. infestans* isolates. Again, because this information is rather scattered and often unpublished, it seemed of use to produce the same sort of questionnaire as decided for population characteristics. Didier Andrivon agreed to add the corresponding questions to the first questionnaire, so that both aspects are covered simultaneously.

Jan Hadders explained that he considers that the main gap in information available now concerns the requirements for and kinetics of penetration of potato tissue, rather than aggressiveness per se. Some work on these aspects is under way in Munich (Nicole Adler). Diedert Spijkerboer explained that he will focus on spore production, infection efficiency (in particular relative to inoculum concentration), and spore dispersal. The latter point may benefit from spore trapping experiments performed in Bavaria and Italy, although the latter are basically

intended as an aid to forecasting. Arne Hermansen indicated that he started an experiment (still in progress) aiming at the comparison of aggressiveness of a number of A1 and A2 isolates at different temperatures.

Ruairidh Bain intends to further investigate the relationships between foliage blight and tuber blight, with special attention paid to the importance of stem lesions. He stressed the fact that little information was available relative to the conditions leading to tuber infections in their relationships to foliage blight, and proposed that a survey of the existing literature on this topic be carried out. He volunteered to review the British literature, and welcomes support from other participants willing to review the data published in other languages.

The question of latent infections and seed-borne inoculum was also raised. The group in Munich plans to further investigate this topic using PCR as a detection method of latent infections, as well as through a survey of several organic crops in Bavaria. So far, there is little evidence to show that seed tubers are a major source of primary infections, but even rare foci originating from diseased tubers may put neighbouring crops at a serious risk.

3. Oospore biology and epidemiological importance

This was a major topic in the presentations at the workshop, particularly since evidence was obtained for the implication of oospores in primary infections at several sites, particularly in the Nordic countries. A number of research activities are starting or are planned for the next few months or years on the different problems raised by oospores, mainly in Scandinavia and in the Netherlands:

- demonstration of the implication of oospores in primary infections, particularly through their effect on population structures (mating type distribution, occurrence of recombinant genotypes, diversity increase...);
- conditions required for germination and production in the field, so as to devise guidelines (to be included in DSS) for scouting fields at risk;
- oospore production on different cultivars;
- oospore survival in the field.

The Nordic group will investigate most of these issues in a field under natural infections reinforced each year, while the Dutch group at PAV has plans to set up similar experiments in a

situation with one single infection. Furthermore, work on oospore biology is also carried out in Mexico by W. Flier and L. Turkensteen, who will also take part in the Dutch experiments.

Finally, the group agreed that epidemiological and population studies are an obvious prerequisite for efficient control of plant pathogens, and that much of this work is still to be done, as shown by the list of prospects and misses enumerated above. Although part of this work is being carried out in the participating institutions on existing funds, and while some benefit will hopefully be gained from the compilations of data allowed by the questionnaires to be produced shortly and from the co-operation between groups currently engaged, the group also strongly insisted that joint research projects should be devised and proposed for funding to national or European authorities.

Second Workshop of an European Network for Development of[3]
an Integrated Control Strategy of potato late blight
Carlow, Ireland, 24 - 27 September 1997

Report of discussions of the subgroup

potato late blight fungicides

H.T.A.M. SCHEPERS

Participants

The group was composed of the following participants:

Leslie Dowley (IRL), Serge Duvauchelle (F), Asko Hannukkala (SF), Frans Heuts (NL), George Little (UK), David Lockley (UK), Raquel Marquinez (E), Javi Michelante (B), Seamus O'Leary (IRL), Huub Schepers (chairman, NL), Elisabeth Schiessendoppler (AU).

Subject areas

1) Fungicide questionnaire

2) Application technology

3) Stem blight

1) Fungicide questionnaire

The main objective of the subgroup was to discuss a draft questionnaire previously prepared by Serge Duvauchelle designed to gather information relating to fungicide efficacy and factors affecting efficacy. Additional questions concerning other specific properties of fungicides were also included. Schepers agreed to ammend the draft questionnaire in consultation with participants of the Workshop by early November 1997, and that a coordinator representing each of the countries present at the Workshop would be sent the finalised questionnaire. The coordinator would then be responsible for liaising with colleagues at other research institutes/extension organisations to complete the questionnaire for the ten most important fungicides used for the control of late blight in that country. The coordinator would also contact the agrochemical companies/approval holders marketing the fungicides in that country also to complete the questionnaire. In addition, the agrochemical companies permission would be

sought to include their products in any Decision Support System.

To prevent any misinterpretation the responses of the agrochemical companies and independants in the various research/advisory institutes would need to be compared and it was therefore agreed that the information would be independantly evaluated. The completed questionnaires should be returned to the overall coordinator (Schepers-NL) by the end of January 1998 at the latest. A compilation of all the questionnaires would be made by Schepers and the results presented at the Workshop in 1998 and published in the Proceedings. The resulting information would then be available for inclusion in the various DSS being developed in different countries and also identify areas where further effort is required.

Action: Schepers; coordinators

2) Application technology

Several factors were also thought to affect the deposition of spray droplets on potato leaves eg speed of spray boom, height of spray boom above the crop, spray pressure and nozzle type, use of air assistance etc. The subgroup considered that application techniques may therefore influence the efficacy of a particular fungicide and that when comparing efficacy data from field evaluations it was necessary to compare those using similar methodologies (or Standard Operating Procedures). In order to prevent spray drift into nearby water courses, sprays producing larger droplets which are less prone to drift were being actively investigated in The Netherlands, however, little information is available on the biological activity of larger droplets.

3) Stem blight

Also, as there are indications that the amount of stem blight infection may be important in maintaining the progress of the epidemic and particularly in the tuber infection process, the subgroup recommended that stem blight measurements should also be made in addition to assessments of leaf infection.

Action: subgroup

PRACTICAL CHARACTERISTICS

OF FUNGICIDES USED

TO CONTROL POTATO LATE BLIGHT

COMPLETED BY (name & address, institute/company):

FUNGICIDE - COMMERCIAL NAME:

FUNGICIDE - ACTIVE INGREDIENT(S):

I - GENERAL CHARACTERISTICS OF THE FUNGICIDE

– Commercial name(s):

– Licence/approval holder(s) :

– fungicide composition: . active ingredient   quantity :   cc or g / l or kg

                                 . active ingredient   quantity :   cc or g / l or kg

                                 . active ingredient   quantity :   cc or g / l or kg

                                 . active ingredient   quantity :   cc or g / l or kg

– Formulation(s) :

– Label recommended dose rate against potato late blight :

– Date and authorisation number :

– First year of marketing for potato late blight control :

– Variation in label recommended dose(s) and applicable condition(s) (general):

– Label recommendations (if any) for reduced rate use(s) and applicable condition(s):

– Other uses besides *Phytophthora infestans* control :

II - "BIOLOGICAL" CHARACTERISTICS OF THE FUNGICIDE IN RELATION TO DISEASE CONTROL (HOST-PATHOGEN INTERACTION)

CHARACTERISTICS AND ASSESSMENTS	ACCOR-DING TO YOU	ACCOR-DING TO FIRM	COMMENTS AND BIBLIOGRAPHICAL RÉFÉRENCES
OVERALL EFFECTIVENESS AGAINST PHYTOPHTHORA INFESTANS			
Reasonable			
Good (= registered dose of mancozeb = ... g/ha))			
Very good (> registered dose of mancozeb)			
Is an undeniable plus for :			
EFFECTIVENESS AGAINST LEAF BLIGHT			
Effectiveness (0/+/++/+++) Cf I			
Persistence = number of days with effective control of late blight in the absence of critical rainfall			
Average treatment interval before repeating a spray (number of days)			
Average treatment interval after the use of another fungicide type, specify the fungicide and the conditions			
Other information			

EFFECTIVENESS AGAINST BLIGHT IN NEWLY DEVELOPING GROWING POINT (PROTECTION OF NEW FOLIAGE GROWTH)			
CHARACTERISTICS AND ASSESSMENTS	ACCOR-DING TO YOU	ACCOR-DING TO FIRM	COMMENTS AND BIBLIOGRAPHICAL RÉFÉRENCES
No particular information			
Effectiveness (0/+/++/+++) Cf I			
Protects only those parts of the foliage which are treated			
Protects the newly developing growing point due to diffusion on the leaf surface (no systemic action)			
Protects the newly developing growing point due to diffusion into leaflets and a systemic movement towards the new growth			
Required interval before repeating the spray so as to ade-quately protect the newly formed foliage			
Other information			
EFFECTIVENESS AGAINST STEM BLIGHT			
No particular information			
Effectiveness (0/+/++/+++) Cf I			
Protectant activity only, on stem parts which receive treatment			
Other activity (give details)			
Other information			
EFFECTIVENESS AGAINST TUBER BLIGHT			
No particular information			
Effectiveness (0/+/++/+++) Cf I			
The essential mechanisms are :			

Legend_I (Cf I): 0 = not good enough, + = reasonable, ++ = good, +++ very good

III - ACTION MODE OF FUNGICIDE ON THE LIFE CYCLE OF *PHYTOPHTHORA INFESTANS*

CHARACTERISTICS AND ASSESSMENTS	ACCORDING TO YOU	ACCORDING TO THE FIRM	COMMENTS AND BIBLIOGRAPHICAL REFERENCES
PROTECTANT ACTIVITY			
Effectiveness of the action mode (0/+/++/+++) Cf II			
Comments			
CURATIVE ACTIVITY			
Effectiveness of the action mode (0/+/++/+++) Cf II			
Number of days curative activity after spore germination (average)			
Conditions that positively or negatively influence the curative activity (for example: temperature, potato variety). Give difference with average number of days.			
Comments			
ANTISPORULANT ACTIVITY			
Decreases the number of spores generated on lesions (0/+/++/+++) Cf II			
Action on spore quality (sporangia/zoospores) : - Spore viability (0/+/++/+++) Cf II - Survival on the soil surface (0/+/++/+++) Cf II - Survival in the soil (0/+/++/+++) Cf II - Mobility in the soil (0/+/++/+++) Cf II - Other actions (give details)			
Comments			

Légend II (Cf II): 0 = no action, + = secondary, ++ = complements well the other actions, +++ = essential

IV - EFFECT OF EXTERNAL CONDITIONS ON THE PERFORMANCE OF THE FUNGICIDE

CHARACTERISTICS AND ASSESSMENTS	ACCORDING TO YOU		ACCORDING TO THE FIRM		COMMENTS AND BIBLIOGRAPHICAL RÉFÉRENCES
RAINFASTNESS RESISTANCE					
	Quanti-ty	Dura-tion	Quanti-ty	Dura-tion	
Maximum period of rainfastness under different conditions of: -rain duration -rain quantity -rainfall quality ie. different droplet sizes Please give details					
Repeat spray application required after:					
Factors which affect rainfastness: - Penetration speed (number of hours) - Formulation - Other information					
ACTIVE INGREDIENT REDISTRIBUTION					
Effect of rainfall: -quantity -quality -duration					
Comments					
RECOMMENDATIONS FOR USE IN CONJUNCTION WITH IRRIGATION					
Recommended (0/+/++) Cf III					
Minimum interval between the fungicide application, before or after irrigation (number of hours)					
Average interval in practice between each application (number of days)					
Describe irrigation strategy					
RAINFASTNESS TRIALS - EXPERIMENTAL CONDITIONS					
Describe experimental conditions of trials which produced this information (eg. chemical analyses or bioassay, glasshouse grown plants or field conditions)					
ACTION OF OTHER CLIMATIC PHENOMENA					
Solar light (comments) :					
Other information					

Légend III (Cf III): 0 = no action, + = interesting, ++ = very interesting.

V - USE STRATEGY

Summarise in approximately 10 lines your main recommendations about this fungicide, taking into account aspects such as crop growth stages, epidemic stages, product price, product (phyto)toxicity.

ADDITIONAL INFORMATION

Provide information on factors such as baseline sensitivity, resistance, resistance management strategies, effect of adjuvants, the behaviour of tankmixes, which you think are relevant for use strategy of the fungicide.

Second Workshop of an European Network for Development of[4]
an Integrated Control Strategy of potato late blight
Carlow, Ireland, 24 - 27 September 1997

Report of the discussions of the subgroup

Decision Support Systems (DSS)

J.G. HANSEN

Participants

Roland Sigvald (SV), Nigel Hardwick (UK), Rosemary Collier (Jersey), Riccardo Bugiani (IT), Wim Nugteren (NL), Robert Leonard (IR), Pieter Vanhaverbeke (BE), André Verlaine (BE), Hans Hausladen (GE), Peter Raatjes (NL), Hans-Rudolf Forrer (CH), Markus Ruckstuhl (CH), Volkmar Gutsche (GE), Johan Habermeyer (GE), Erno Bouma (NL), Jens G. Hansen (DK)

Agenda

1. Report on DSS system descriptions
2. Discussion on validation results
3. Validation of DSS´s in filed experiments
4. Discussion of DSS submodels and components
5. Availability and use of meteorological data
6. Black boxes in DSS
7. Exchange of researchers
8. Election of new chairman
9. Other matters

1. Report on DSS system descriptions

During the first workshop of the EU concerted action "European network for development of an integrated control strategy of potato late blight" it was decided to validate some existing

decision support systems for late blight control with use of meteorological data from all participating countries in the project. The systems for validation were: Simphyt (GE), ProPhy (NL), Plant-Plus (NL), Guntz Diveau (FR), Milsol (FR) and NegFry (DK). Based on a proposal from Wim Nugteren a questionnaire on DSS system description was sent to all model builders. A report will be made with descriptions of the DSS systems including key articles of each system. The systems description report will be send to all participants of the concerted action.

2. Validation of DSS

Meteorological data from 11 countries was quality controlled, harmonized and made available for model builders on an FTP-server in Denmark. Model builders were asked to run their systems for each set of data including weather data and biological data. The data for late blight development related to the meteorological data were not given to the model builders in the first place. Model outputs were compared with late blight development on the second workshop in Carlow, Ireland, 24-28 September 1997. Each model group should make a report with DSS output on I) Dates of recommended fungicide applications (and fungicide type) during the season and II) A graphics output if possible.
At the workshop in Carlow reports were given for NegFry, ProPhy and Plant-Plus.

During the discussion it was stressed by the model builders that this kind of validation was **not** a true validation because a lot of assumptions had to be done for more of the systems (see below). It was decided to focus on a selected part of the data and outputs from Prophy, Plant-Plus and NegFry were compared for the following datasets:

NO1095, FOU94, DK96_27, KOMPAS95, CH96A and HARDI96

The results of the validation on historical data was discussed and compared with biological data for late blight. During the discussion it became clear that it will be necessary to I) run some of the models again with additional data and II) go into detail with the submodels of the systems. It was decided:
1. To run the systems again with use of additional data (see below) and with new data from 1997.

2. Next time to focus on submodels and components in the systems to discuss why and how the systems differ in mode of action.

3. To find out if it is possible to validate some of the systems in field trials at 1-3 localities in EU.

Additional data for DSS

Additional data for Simphyt:

1. Long term average of precipitation in June (of the region where the weather station is placed)

2. 2. Long term average of temperature in June 3.Height of the region in m (NN)

Additional data for Prophy:

1. Date when plants are 15 cm heigh*

2. Date of row closing

3. Crop data (Susceptibility*, Growth rate (weekly),Development (phenology)) and 4. Presence of blight in the field and/in the area*

*=very important

Additional data for Plant Plus:

1. Leaf/crop growth

2. 2. Ground coverage [%]/ crop heaviness

Additional data for NegFry:

1. Presence of blight in the field and/or in the area

Additional data should be sent by e-mail or on diskette to Jens G. Hansen. Data will be available on FTP-server for model builders.

3. Field trial validation of DSS

Nigel Hardwick (UK), Roland Sigvald (SE), Hans-Rudolf Forrer (CH) and Volkmar Gutsche (GE) agreed to find out, if it is possible to include a field validation of some of the DSS´s in

their ongoing research programs. They also agreed to make a short report on harmonization and standardisation for this experiment DSS (responsible: Nigel). If it is possible to arrange such a validation program, the model builders agreed to meet 1-2 days in each country to implement their programs for proper use in the field trial validation. Expenses for travel and accommodation should be paid by the concerted action. Erno Bouma was asked to contact the EU commission if extra money for the validation part is possible. It was not decided if the field trial validation should take place in 1998 or 1999, but I suggest that we plan for 1998. The question was raised if it was possible to make an "end user validation" of the systems (userfriendliness etc.).

4. Submodels and components in DSS

To compare systems it is will be necessary to compare submodels and methods in the systems. Erno Bouma and Jens Grønbech Hansen will make a report on description of DSS. In this report only a short description of submodels and components in the DSS´s will be given. During the next workshop we will compare and discuss in detail some of the most important submodels. It is suggested that some of the presentations in Sweden, 1998, should focus on advantages and constraints in late blight submodels and methods.

5. Availability and use of meteorological data

A report on availability and use of meteorological data was made by J. Wieringa (COST-711) and a copy of this publication was send to all participants of the concerted action. During discussion several members of the group stressed that availability and use of meteorological data is still a major problem in development, validation and implementation of DSS systems - especially when DSS systems are to be used in operation by farmers and advisors. One problem is high cost of primary meteorological data from the national meteorological institutes referring to the international ECOMET agreement on costs of weather data for different user groups. Even if end users are willing to pay the price for the met data, data are often not available on an operational basis and often not in a form that can be used by DSS´s directly.

It was decided to make a questionnaire and an updated report on availability and use of meteorological data for late blight warning (Responsible: Erno Bouma & Roland Sigvald). The

objective is to identify major problems on availability and use of meteorological data for late blight warning and use of weather based DSS´s in the participating countries. Secondly but maybe most important, the report may be a help in a process to increase the pressure on national met offices to build weather information systems for agriculture with access to operational, high quality and low cost meteorological data. It has no meaning to build high quality DSS systems for the farmers if data to run the systems are not available or the price for data is too high !!

As an alternative to data from ordinary met stations, local (on farm) weather stations (Hardi Metpole, METOS, ADCON and others) are now available. Some of these have been integrated with late blight DSS`s (fx. Plant Plus and Prophy in Holland and NegFry in Denmark). Problems of concern with this concept are:
– Weather data quality and calibration
– Use of micro climate data or data from standard height
– Local to regional scale applications
– No harmonisation of data storage and accessibility in different local weather systems.

A Climate Data Interface (CDI) is now under construction in Denmark, that can import, transform, quality control and merge data from a wide range of data sources. The CDI is defined to be used as a standard met data interface for PC-programs and internet applications. In this way a DSS can use data from different on-farm weather stations and via the internet automatically from a national met office webserver. One advantage of using such a standard component for data import in a DSS will be that DSS´s more easily can be transported from one country to another. On the next workshop in Sweden, the CDI will be demonstrated as a part of NegFry version 5.0.

6. Black boxes in late blight DSS´s

We had only short time for discussion on this item, but the following areas was identified

1. The importance of oospores as inoculum source
2. Quantification of inoculum potential
3. Basic weather criteria in late blight epidemiology

4. Quantification of aggressiveness of different P. Infestans populations

5. Quantification of the risk of tuber infections

There will be more attention on this subject during discussions on submodels and methods during the next workshop in Sweden 1998.

7. Exchange of researchers

Erno Bouma encouraged participants to take advantage of the "exchange researchers" task in the frame of the project. Only a very small amount of money was spent on this task until now.

8. Election of new chairman

Jens G. Hansen was elected as chairman of the subgroup DSS for the period 1997/98.

9. Any other matters: Internet survey system for late blight development

Interactive internet applications and geographical information systems are now in operational use (fx. at DACOM), Pl@nteinfo or as part of research projects (fx. a Nordic project). It was decided that. Jens G. Hansen, Peter Raatjes and R.Bugiani agreed to investigate the IT problems of making an EU map with updated data for late blight development in regions of Europe. In the frame of EU.NET.ICP we should discuss the aim, possibilities, advantages and constraints in developing an EU internet survey system for late blight development. Such a system may be used as a part of a model validation program and in the long run as a part of an EU warning system for late blight development.

Deadlines	Issue	From	To
98.02.01	Key articles and reports on DSS descriptions and validation results	E. Bouma	All participants
98.02.01	Additional data for datasets: NO1095, FOU94, DK96_27, KOMPAS95, CH96A and HARDI96	A. Hermansen, J.G. Hansen, A. Verlaine, E. Bouma, M. Ruckstuhl, L. Dowley	J.G. Hansen (FTP server)
98.02.01	1997 Met data, standard biological data and addi tional data (if possible) for validation of DSS -	All national contact persons	J.G.Hansen (FTP server)
98.02.01	Questionnaire on availability and use of mete- oro- ogical data for late blight warning	Erno Bouma and Roland Sigvald	National contact per- sons
98.03.01	Proposal for standard and harmonized field trial validation of DSS	Sigvald, Forrer, Hardwick, Gutsche	Model builders and oth- ers
98.04.01	Questionnaire on availability and use of mete- oro- ogical data for late blight warning	National contact persons	Erno Bouma
98.06.01	DSS output results with use of historical data including 1997 data	DSS responsible	J.G.Hansen

National contact persons:

Sweden	Roland Sigvald & Björn Andersson	Norway	Arne Hermansen
Finland	Asko Hannukkala	Denmark	Jens Grønbech Hansen
UK	Nigel Hardwick	Italy	Riccardo Bugiani & Laura Cobelli
Ireland	Leslie Dowley	Belgium	André Verlaine
Switzerland	Markus Ruckstuhl	Germany	Volkmar Gutsche
France	Ludovic Dubois	Austria	E. Schiessendoppler
Spain	R. Marqvinez	Scotland	R. Bain
Holland	Erno Bouma		

Second Workshop of an European Network for Development of[5]
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Epidemiological parameters in decision support systems

for *Phytophthora Infestans*

H.T.A.M. SCHEPERS

Applied Research for Arable Farming and Field Production of Vegetables

P. O. Box 430, NL-8200 AK Lelystad, The Netherlands

Abstract

The temperature and relative humidity play an important role in the development of *Phytophthora infestans*. The influence of temperature and relative humidity on all relevant stages in the life cycle of *P. infestans* is presented in tables. Also the influence of these factors in Decision Support Systems is presented. The influence of new genotypes of *P. infestans* on the design of Decision Support Systems is discussed.

Keywords: DSS, epidemiology, fungicides, late blight, *Phytophthora infestans*, potato

Introduction

During the discussions in the epidemiology subgroup of the Workshop in Lelystad 1996 it was recommended that a compilation of data on disease-weather relationships would be very useful in the process of discussing and developing Decision Support Systems.

In this paper information is presented that is available in reviews on this subject (Harrison, 1992; Schepers et al. 1995; Bouma & Schepers, 1997). Since the population of *P. infestans* is changing, this can have important consequences on the epidemiology of the pathogen. Therefore, results of three papers with comparisons between the fitness of 'old' and 'new' genotypes are presented. It is also important to know whether the 'new' isolates require a different control strategy than 'old' isolates. Therefore, the infection efficiency of these isolates on fungicide treated plants was investigated.

Results

Temperature

In tables the influence of temperature is presented on germination of sporangia and zoospores and on the infection process (Table 1), on growth of hyphae and incubation time (Table 2), on production of sporangia (Table 3), on survival of spores and hyphae (Table 4) and on the development of an epidemic (Table 5). In Table 6 the influence of temperature as included in DSS, is given.

Table 1. **Influence of temperature on germination of sporangia and zoospores and on the infection process.**

Stage of life cycle	reference	optimum temperature	effect
indirect germination	Crosier, 1934	3 h at 12-13°C	60-80%
(of sporangia)	Bohnen, 1963	12-16°C	
	Yamamoto & Tanino, 1961	2 h at 12°C	70-80%
	Schrödter & Ullrich, 1967	10-12°C	
direct germination	Crosier, 1934	24 h at 24°C	20%
(of sporangia)	Schrödter & Ullrich, 1967	20-22°C	
germination of zoospores	Crosier, 1934	4.5 h at 21°C	50% infection
germination of oöspores	Pittis & Shattock, 1994	20°C	stored in sterile water
		5°C	stored in sterile sand
infection process	Rotem, 1971	15°C or 5-25°C	depending on spore load and wetting duration

Table 2. **Influence of temperature on growth of hyphae and incubation time (=time between infection and first symptoms).**

Stage of life cycle	reference	optimum temperature
growth of hyphae	Crosier, 1934	21°C (range 2 - 30°C)
	Zan, 1962	20°C (range 4 - 30°C)
	Harrison, 1990	13 days at 12°C → 5.3 mg mycelium in leaf
		13 days at 17°C → 18.9 mg mycelium in leaf
incubation time	Schrödter % Ullrich, 1967	ET-7) = 1543 degree-hours with T>7°C
	Hartill & Young, 1985	i = 513 - 44.7 x T + 1.11 x T^2

Table 3. **Influence of temperature on production of sporangia.**

Reference	optimum temperature
Crosier, 1934	21°C (range 3 - 26°C)
	48 h at 9°C produced numerous sporangia!
Schrödter & Ullrich, 1967	10-12°C & 20-22°C
Kluge & Gutsche, 1990	temperature influences duration of sporulation fase
Hartill & Young, 1985	temperature influences time before lesion starts sporulating

Table 4. Influence of temperature on survival of spores and hyphae.

Reference	optimum temperature
Crosier, 1934	7 h at 20°C & 100% rh → 60% germinated loss of viability higher at 25 & 30°C
Kable & MacKenzie, 1980	30°C did not affect hyphae in stem lesions from 32.5°C → 40°C survival declined linearly

Table 5. Influence of temperature on the development of an epidemic (= sum of effects on the different stages in the life cycle).

	Temperature		
Reference	minimum	optimum	maximum
Martin, 1923			<23.3°C
Grainger, 1979			>23°C
Hyre, 1954	7.2°C		25.5°C
Post, 1959	8°C		
Smith, 1956	10°C		
Duvauchelle, 1993	7°C		
Bruhn & Fry, 1981	3°C	13 - 22°C	27°C
Kluge & Gutsche, 1990	formation of new lesion is function of T with T<19°C		
Beaumont, 1948	10°C		
Bourke, 1957	10°C		
Førsund, 1983, (1995)	10°C (8°C)		17-24°C (15/16-24°C)
Winstel, 1992	10°C		23-30°C
Van Everdingen, 1935	10°C		
Schrödter & Ullrich, 1967	10°C	10-12°C & 20-22°C	24°C

Table 6. Influence of temperature in Decision Support Systems for *Phytophthora infestans*.

	Temperature		
DSS	minimum	optimum	maximum
Guntz Divoux	8°C	16.6 - 20°C	30°C
Prophy	8°C		25°C
PLANT-Plus	?	?	?
Lufft/Agricast	?	?	?
Negativ Prognose	10°C	10 -12°C & 20 - 22°C	24°C
Fry-model	°C	13 - 22°C	27°C
MILSOL	temperature influences different stages		
SIMPHYT	temperature influences different stages		
PhytoPRE	as in Negativ Prognose		
BLITECAST	7.2°C	15.1 - 26.6°C	26.6°C
IPI-Italy model	temperature influences different stages		

Relative humidity

In tables the influence of relative humidity is presented on the infection process (Table 7), on production of sporangia (Table 8), on survival of spores (Table 9), and on the development of an epidemic (Table 10). In Table 11 the influence of relative humidity as included in DSS, is given.

Table 7. Influence of relative humidity on the infection process (= germination of spores + penetration).

Reference	(relative) humidity	effect
Crosier, 1934	>2 h leaf wetness	% infection increases with duration leaf wetness
Schrödter & Ullrich, 1967	>4 h with rh>90%	
Hartill & Young, 1990	>3-4 h with rh>90%	2 h break in leaf wetness is critical

Table 8. Influence of relative humidity on production of sporangia.

Reference	(relative) humidity	effect
Crosier, 1934	>95%	rh measured close to spores
Schrödter & Ullrich, 1967	>90%	rh measured at 2 m
Rotem et al., 1978	97 - 98%	
Harrison & Lowe, 1989	90-100%	at low air speed
	100%	at higher air speed

Table 9. Influence of relative humidity on survival of spores.

Reference	(relative) humidity
Crosier, 1934	7 h at 100% rh resulted in 60% germination
	7 h at 50% rh resulted in 10% germination
Warren & Colhoun, 1975	5 min at 95% rh **without water film** resulted in 100% mortality
	2.5 min at 90% rh **without water film** resulted in 100% mortality

Table 10. Influence of relative humidity on the development of an epidemic (= sum of effects on different stages in the life cycle).

Reference	critical (relative) humidity
Gutsche, 1990	>7 days without >10 hrs with >75% rh inhibit epidemic
Schrödter & Ullrich,1967	hrs with rh <70% negatively influence epidemic
Førsund, 1983	>75% rh at 12.00 hrs and > 0.1 mm rain
Winstel, 1992	>10 hrs with >90% rh
Beaumont, 1948	48 hrs with >75% rh
Van Everdingen, 1935	>4 hrs leaf wetness followed by cloudy day and >0.1 mm rain
Wallin, 1962	>90% rh
Bourke, 1957	>12 hrs with rh >90%
Smith, 1956	>48 hrs with in each day >11 hrs with rh >90%

Table 11.   Influence of relative humidity in Decision Support Systems for *Phytophthora infestans*.

DSS	critical relative humidity
Guntz Divoux	>90% rh
Prophy	>6 hrs with high rh followed by >2 hrs of leaf wetness or rain
PLANT-Plus	?
Lufft/Agricast	?
Negativ Prognose	hrs with >90% rh or hrs with >0.1 mm rain
Fry-model	hrs with >90% rh
MILSOL	rh influences different stages
SIMPHYT	rh influences different stages
PhytoPRE	as in Negativ Prognose
BLITECAST	hrs with >90% rh
IPI-Italy model	rh influences different stages
NEGFRY	Negativ Prognose + Fry model

Pathogenic fitness

Table 12 shows the data from three papers on the fitness of 'old' and 'new' isolates. The 'new' isolates seem to grow faster, sporulate more abundantly and infect more efficiently. We investigated the infection efficiency (IE) on fungicide treated plants of an 'old' isolate (1,4) and of two 'new' isolates (428-2, 655-2a). Potato plants in pots were sprayed with Shirlan (500 g/l fluazinam) in three different dosages namely: 0.05 l/ha, 0.1 l/ha and 0.2 l/ha. Four days after application of the fungicide, leaflets were artificially inoculated. Two inoculation densities were used, namely 50 spores/leaflets and 500 spores/leaflet. After 7 days of incubation at 15 °C , the number of infected leaflets was assessed. On plants treated with Shirlan in 0.1 and 0.2 l/ha hardly any infected leaflets appeared. In table 13 infections are shown that were observed on plants treated with 0.05 l/ha Shirlan. No differences in infected leaflets between the three isolates were observed when leaflets were inoculated with the lower inoculation density of 50 spores/leaflet. When leaflets were inoculated with 500 spores, the 'new' isolate (428-2) infected more leaflets than the other two isolates. In other experiments on untreated plants, isolate 428-2 also showed a higher fitness than the other two isolates.

Table 12.   Pathogenic fitness of "old " and "new" *Phytophthora infestans* isolates.

Reference	isolate	latent period	sporulation	lesion area	infection efficiency (IE)
Turkensteen et al. 1997	old	109.7	4.72	nd[1]	0.0123
	new	84.7	5.23	nd	0.0426
Sato et al. 1997	US-1	70.5	119	4.06	nd
	US-7	63.0	144	4.65	nd
	US-8	66.0	196	5.24	nd
Day & Shattock, 1997	old type 1b isolates were less pathogenic (=IE x sporulation) than new type 1a or 2a isolates				

[1] not determined

Table 13. Infection of potato leaflets sprayed with 0.05 l/ha Shirlan and artificially inoculated 4 days after application with three *P. infestans* isolates.

inoculation density	'old' isolate (1,4)	Infected leaflets (%) 'new' isolate (428-2)	'new' isolate (655-2a)
50 spores/leaflet	5	0	5
500 spores/leaflet	15	35	0

Discussion

The influence of temperature and relative humidity on the development of *P. infestans* has been described in many papers. Differences in methods of measurements and use of different isolates are factors that can probably account for the considerable variation in data. The DSS have all included the influence of temperature and relative humidity in their systems but all in a slightly different way, depending on the region in which they are used and on the architecture of their system. Large scale validation under practical conditions will show whether the assumptions in the models are valid to generate recommendations for an optimal control of late blight. However, an important aspect that now needs attention is the change of the *P. infestans* population. Goodwin (1997) states that: "DSS were all designed and verified against previous populations. The new genotypes may have different temperature optima, shorter generation times, or better tuber-colonizing abilities that give them a fitness advantage. Expert systems need to take into account recent changes in the biology of pathogens that may have been the result of these migrations. Knowing which components of fitness are different in new migrant genotypes may be important for improving disease management strategies".

The control of isolates with a higher fitness may also require more fungicide input (Sato et al., 1997; Turkensteen et al., 1997).

It is concluded, that in order to adapt DSS to the present population of *P. infestans*, information is needed on the influence of temperature and relative humidity on new isolates, the fitness of new isolates and the control of these isolates with fungicides.

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Pictipapa, an international strategy for potato late blight research

H. LOZOYA-SALDAÑA

International Cooperative Program on Potato Late Blight.
Apartado Postal 2-2, Conjunto SEDAGRO
Metepec, México 42142
México

Abstract

PICTIPAPA is the spanish acronim for the International Cooperative Program on Potato Late Blight. This international cooperative effort was launched in 1990 by scientists from Poland, the Netherlands, Canada, United States, México, and the International Potato Center (CIP). In 1994 the permanent headquarters were established at the Toluca Valley. Its main objective is to facilitate the link and execution of research of mutual interest on potato late blight among and by national and international scientists and institutions. The specific priority research modules include field evaluation of international potato clonal selections for resistance to late blight in the Toluca Valley; identification of new sources of durable resistance in the wild *Solanum* species; epidemiology, basic studies and control; distribution of blight resistant cultivars; and the establishment of standard international field trials. So far, PICTIPAPA has been directly involved in the first module, and has supported activities of different institutions on the first three topics.

Introduction

In México, potato is not as an important food crop as corn and beans, or as wheat, rice, and several horticultural crops, like peppers and tomatoes. However, potatoes are grown in about 65,000 hectares, from which 36,000 (55 %) are irrigated. The rest is rainfed. The crop can be found from 0 to 3,000 m over sea level at different times of the year, and fresh potatoes are available in the market all the year round.

The yields vary according to the geographical area, the cultivar, and to the growing condi-

tions, ranging from 10 to 30 ton/ha, with a national average of 18 ton/ha. Almost half of the area is grown with Alpha, an old Dutch variety susceptible to late blight under the Mexican conditions. Other important cultivar is Atlantic, mainly for processing. Atlantic is also susceptible to the fungus.

Late blight is the number one problem when potatoes are grown under rainfall in the highlands, where several of the resistant Mexican cultivars are better adapted (Rosita, San José, Marciana, Atzimba, and Norteña, among other). The disease is also important under sprinkler irrigation in the valleys. The Mexican Potato Program from the National Institute for Agriculture, Livestock and Forestry Research (INIFAP), in a joint effort with other Institutions, has released more than 25 blight resistant cultivars in the last 40 years. Nevertheless, only few of them have been permanently accepted by the growers as well as by the general public. In addition, some of these materials have lost resistance in time.

Mexico, and particularly the Toluca valley, has been recognized as the place of origin of the fungus that causes the late blight disease (*Phytophthora infestans*). The valley has three characteristics that makes it an ideal location for late blight research:
- The two mating types and most of the existing pathogenic races are found in the valley every rainy season (June-September).
- The valley has the ideal conditions for the development of the disease.
- Central Mexico, including the valley, is the native home of a number of wild potato species that have been used as a source of late blight resistance in breeding programs all over the world.

Fungicide sprays twice a week to susceptible cultivars is a common practice not only in the Toluca Valley, but also in the high sierras of Michoacan, Puebla, Chihuahua, and Chiapas. For the past 40 years, scientists of the Mexican National Potato Program (INIFAP) have collaborated with their colleagues from abroad, providing unique Mexican genetic resources both for the identification and testing of sources of resistance and for the study of the late blight pathogen itself.

PICTIPAPA
PICTIPAPA is the spanish acronim for the International Cooperative Program on Potato Late

Blight. It was established to facilitate the link and execution of research of mutual interest on potato late blight among and by national and international scientists and institutions, in order to promote sustainable potato production worldwide.

In 1990 scientists from Poland, the Netherlands, Canada, United States, México, and the International Potato Center (CIP), supported by the Mexican Potato Growers Association, launched an international cooperative effort on late blight research. This initiative was to provide an operating base in Mexico for further international cooperation on late blight projects of high priority. In 1993 a sound proposal emerged to establish the permanent headquarters at the Toluca Valley, under PULSAR/INTEGER sponsorship. Thanks to the interest and substantial support provided by this private sector group in Monterrey, México, early in 1994 PICTIPAPA held an international meeting with delegates from 16 countries to organize, define and appoint the Board of Directors Members. This new initiative is sponsored, initially for a 5-year period, as a project of a new Mexican foundation (Fondo Terra) established by PULSAR/INTEGER.

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Is information on latent infection and sporangial movement of *Phytophthora infestans* in potato crops useful in support of forecasting systems?

A. SCHLENZIG, J. HABERMEYER

Lehrstuhl für Phytopathologie,

TU München-Weihenstephan, D-85350 Freising, Germany

Summary

Phytophthora infestans in potato stems was detected before disease outbreak in the crops by using an indirect ELISA. The results of the ELISA were set in relation to the visible symptoms which appear later in the fields. Furthermore the development of the epidemic was investigated with the aid of sporetraps. The sporangial movement was correlated with the weather conditions.

Keywords: *Phytophthora infestans*, late blight, latent infection, ELISA, sporetrap, forecasting

Introduction

Blighted seed tubers which produce infected stems are a main source of the first inoculum of *Phytophthora infestans* in potato fields. But the first symptoms of late blight usually occur 6 weeks or later after the planting date. Obviously in this time the fungus grows invisible upwards into the potato stems. The detection of such latent infected stems could give valuable information on the first infection pressure. To calculate the infection risk in forecasting systems it is not sufficient to measure the weather conditions. A survey about the present inoculum is also necessary. This is possible by visual observation of the potato crop or by monitoring of the sporangial movement using a sporetrap. Poor disease control due to inadequate fungicide application should be avoided for economical and environmental reasons.

Materials and Methods

Detection of the latent infection

The detection method for the latent infection of *P. infestans* was an indirect ELISA and is described by BECKMAN ET AL. (1994). Only the last incubation period after addition of the substrate was prolonged up to 3 h. The applied polyclonal antiserum were provided by the Scottish Crop Research Institute. In the examined potato fields the plants were numbered and one stem of each plant was taken for the assay. In plot 1 1995 and 1996 the seed tubers were artificially infected with 50-200 sporangia per tuber in 1995 and 10-40 sporangia per tuber in 1996. In the other plots healthy seed tubers without any symptoms were planted. Usually just the lowest 3 cm of the stem was used for further preparation of the samples. This part grows under the soil surface, so a secondary infection caused by windborne inoculum is excluded. After taking the samples for the ELISA, each plant of the fields was checked as a rule twice per week for late blight symptoms. The visible infestation were compared with the results from the ELISA.

Monitoring of the sporangial movement

For the monitoring of the sporangial movement Burkard sporetraps were used. They were placed inside of unsprayed potato crops and sampled at 10 l/min. The observations were made over three years and at two sites per year. The sporangia were stained with lactophenol-cottonblue before counting under microscope (x 16 objective).

Results

Detection of the latent infection

Fig.1 to 3 present the comparison between the ELISA-results and the later visible symptoms in three selected plots. The rows of the field are symbolized in grey lines. The plants with positive ELISA result are marked black. On the right side of every plant, the visible symptoms are recorded.

In plot 1 in 1995 (Fig. 1) with infected seed tubers only the numbered plants formed stems. The sprouts of the other tubers rotted and died without reaching the soil surface. The ELISA detected a latent infection in the sample of 4 plants. But no symptoms appeared on this plants. The first two diseased plants were observed on June 30th. One of them developed leaf symptoms and the other one developed stem top symptoms. The ELISA result of these plants 4 days earlier was negative. The same disagreement was observed in the other plots in both ex-

amination years.

In plot 3 in 1995 (Fig. 2) the samples for the ELISA were taken more than 5 weeks before disease outbreak which was observed in July 7th. Symptoms appeared at the same time on different locations in the plot. 16 latent infected stems were detected with the assay.

Figure1. **Latent infection and later outbreak of** *P. infestans*, **plot 1, 1995.**
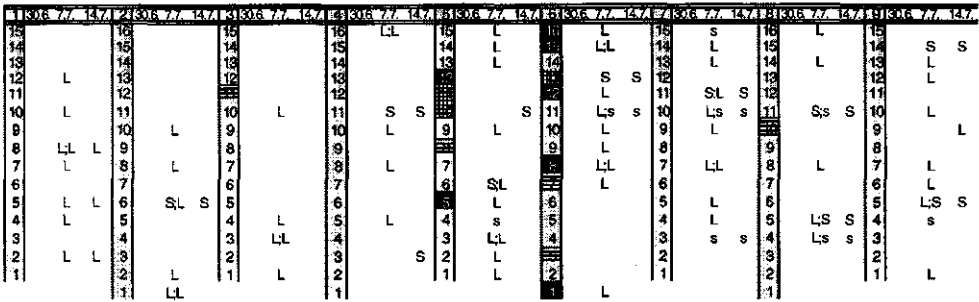
planting date: April 24th
planting date: May 29th

visible infection
L=leaf symptom
S=stem symptom
s = stem top symptom

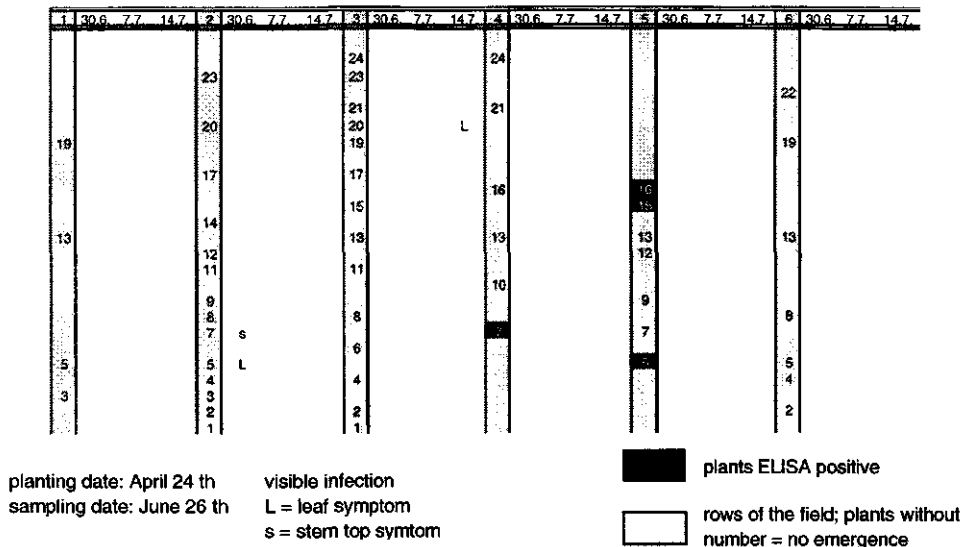ELISA positive in both examined stem parts

ELISA positive in the upper 3 cm of the stem

ELISA positive in the lowest 3 cm of the stem

Figure 2. Latent infection and later outbreak of *P. infestans*, plot 3, 1995.

planting date: April 24 th
sampling date: June 26 th

visible infection
L = leaf symptom
s = stem top symtom

plants ELISA positive

rows of the field; plants without number = no emergence

In this plot additional to the lowest 3 cm the next upper 3 cm were examined by ELISA. In some stems the fungus was just detected in one of the two parts, even just in the upper part. Remarkable was the concentration of the latent infected plants in row 5 and 6. In other fields of this year this accumulation of ELISA-positive plants was recorded too.

In 1996 the amount of latent infected shoots detected by ELISA was much lower than in 1995 and no concentration of latent infected plants was observed. In plot 1 (Fig. 3) for example only 3 out of 646 samples reached a positive ELISA result, although in this plot the seed tubers were artificially infected. Nevertheless, a very early and severe outbreak of late blight on June 1st was noticed just three days after taking the samples. Furthermore all the shoots of 48 potato plants of this plot were examined with the assay but in none of them the ELISA detected a latent infection.

Figure 3.   Latent infection and later outbreak of *P. infestans*, plot 1, 1996.
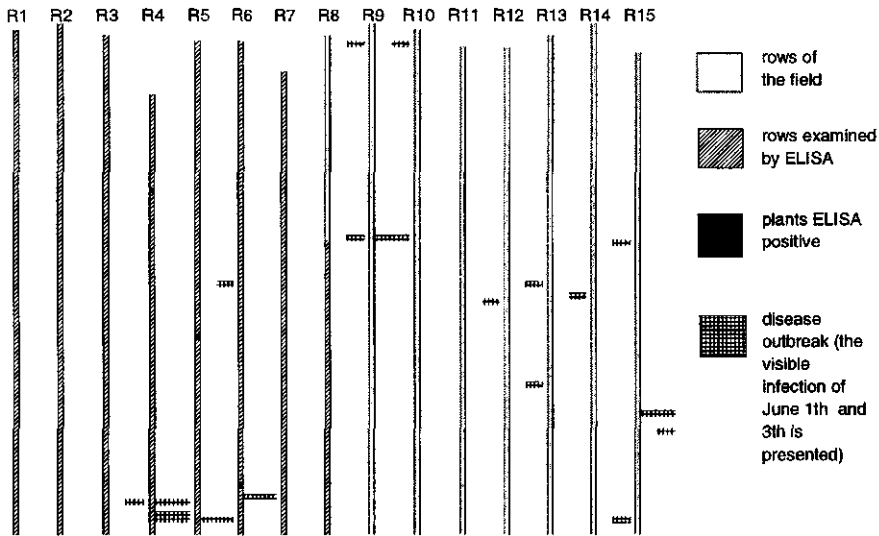
Monitoring of the sporangial movement

There was only a clear correlation between sporangia discharge and precipitation. In 1994 in field A 13 this correlation was very distinct because of the few rainfalls (Fig. 4). After placing the sporetrap a low spore concentration was measured already from the first day on. But this small amount and a disease frequency (number of diseased plants in the field) less than 0.5 % couldn't progress the epidemic in consequence of the absence of rain. The rainfall on June 29th effected optimum conditions for a zoospore infection. The result was an abrupt increase of sporangia movement 5 days later (arrows in Fig. 4). Combined with rain and lower temperatures this sporangia caused the start of the epidemic on July 8th. Nearly 60 000 Sporangia per day were caught at the top of the epidemic.

Figure 4. Weather conditions and sporangia movement in Scheyern 1994, plot A 13.
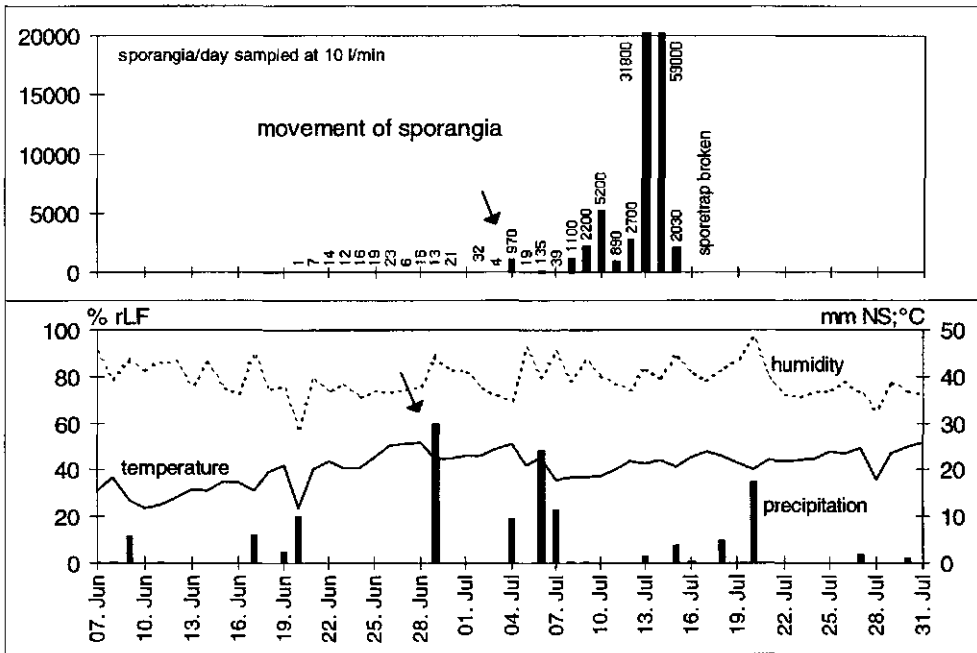
In 1995 the sporetrap were placed before first sporangia movement. The first diseased plant was detected on June 15th, but the sporetrap caught the first inoculum 5 days later, when the disease extended on 4 plants (Fig. 5). At the end of June a period of very hot and dry weather started until August, therefore *Phytophthora* decreased. The rainfalls in July just were short and heavy thunder showers. Together with high temperatures and very low amounts of inoculum of 3 to 4 sporangia per day they couldn't effect an epidemic progress. After the start of a rain period in August (arrow in Fig. 5), the numbers of sporangia increased, followed by the late blight epidemic. On August 23rd the potato foliage was mechanically destroyed, which terminated the epidemic development. Only 2000 sporangia were caught at maximum.

In the sporangia movement a daily trend was measurable, probably due to the changing conditions in humidity and temperature in the dawn. It started between 10 and 11 a.m., reached a peak between 14 and 15 p.m. and decreased until 11 p.m. to the night level (Fig. 6).

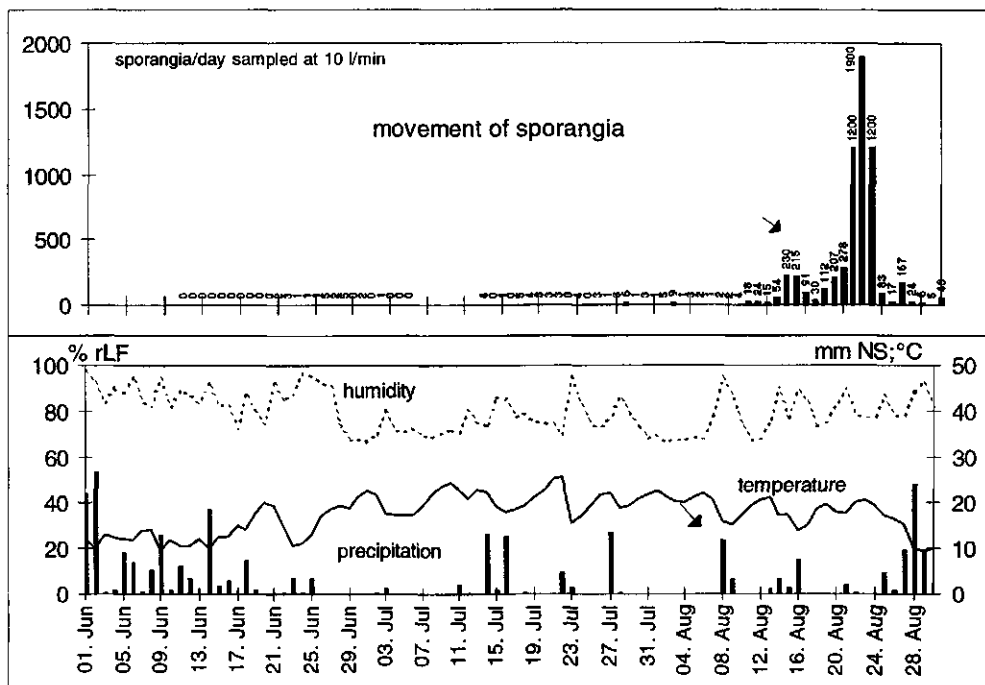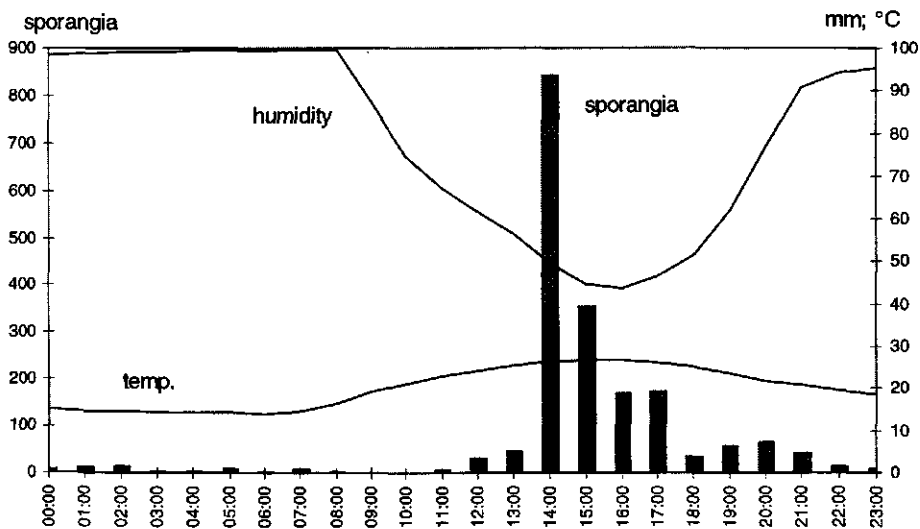**Figure 5.** Weather conditions and sporangia movement in Scheyern 1995.

Figure 6. Daily trend of sporangia movement (Scheyern 22/8/95).

Discussion and Conclusions

It was possible to detect *P.infestans* in its latent stage in young potato stems, but on a single plant there was no agreement between the latent infection and the later outbreak of the disease. Obviously an infected tuber produces both: healthy and invaded stems. Therefore the ELISA result of just one stem cannot represent the state of health of the whole plant. In many cases infected tubers didn't produce any latent invaded stem at all. The artificially infected seed tubers didn't develop more latent infected shoots than the 'healthy' ones. HIRST and STEDMAN (1960) had estimated, that it is necessary to plant 150 blighted but live tubers to produce one diseased stem. VAN DER ZAAG (1956) found just one primary focus per km², so the small amount of diseased stems seems to be sufficient to cause a late blight epidemic.

Only sometimes it was possible to find a latent infected stem within a first focus of visibly attacked plants. No correlation was discovered between the quantity of latent infection and the time or severity of disease outbreak in the examined fields. Therefore information on latent infection seems not to be useful for prediction.

To look for a possible explanation of the local accumulation of the latent infected plants in 1995 it is necessary to compare the weather conditions of the two examined years. In 1995 the soil water content two weeks after the planting date surpassed nearly 20% in average the soil water content in 1996. Under nearly saturated conditions the zoospores should be able to move from tuber to tuber transported by soil water, in the way it is discussed for other *Phytophthora sp.* too (CARLILE, 1983). Because of the lower distances the spread happened favoured within a row.

The sporetrap didn't catch inoculum before the first diseased plants are visible in the field. A prediction of the outbreak was not possible. Therefore the necessary monitoring can be done also with a visual check of the crop twice per week, for which the same time is required like for spore counting.

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Variation for pathogenicity in old and new populations of

Phytophthora Infestans: a brief review

D. ANDRIVON

INRA,

Station de Pathologie Végétale,

BP 29, F-35653 Le Rheu Cedex, France

Abstract

The major migration that affected *P. infestans* populations world-wide during the 1970s and 1980s and the subsequent population replacements led to the hypothesis that newly intro-duced genotypes of the pathogen might be more pathogenic than their former counterparts. However, no comprehensive assessment of the data available to test this hypothesis has been attempted yet. The present review focuses on variation for host specificity, cultivar specificity and aggressiveness in *P. infestans*, and shows that a general increase in pathogenicity has not been observed in all situations following the 1970s migration. This highlights the need for an in-depth analysis of each local situation to accurately describe and understand the mecha-nisms responsible for observed population displacements.

Introduction

Phytophthora infestans, which causes late blight of Solanaceae, is often described as a highly variable pathogen. When applied to pathogenicity traits, this variability is regarded as the major cause for the breakdown of resistance used to control the disease. Therefore, over the last seventy years, a large corpus of research has been dealing with the characterisation of pathogenicity in *P. infestans* isolates or populations world-wide. Its primary aim has been to make a better use of the resistance sources available to the breeder and grower, by choosing them according to the pathogenicity features prevalent in local *P. infestans* populations.

The introduction, beginning in the mid-to late 1970s, of a number of pathogen genotypes into Europe, and subsequently to most potato cropping areas in the world (Spielman *et al.*, 1991;

Fry *et al*, 1992, 1993; Goodwin *et al.*, 1994), has led to further concern about the extent and sources of variability present in *P. infestans*. Because the introduction was made from Mexico, an area with extensive variation both in potential hosts (Rivera-Peña, 1990a) and in the pathogen (Tooley *et al.*, 1985; Rivera-Peña, 1990b; Goodwin *et al.*, 1992), and because it involved isolates belonging to both mating types (A1 and A2), it has been postulated that 'new' populations, resulting from this introduction, might be more pathogenic and, hence, fitter, than previous, 'old' ones (Fry *et al.*, 1992). However, the validity of this hypothesis has not been conclusively established yet.

Different types of pathogenicity features must be considered in species which, like *P. infestans*, can interact with their hosts at various levels of specificity. Host specificity at the genus/species or at the cultivar level allow to define the host range and physiological races of the pathogen, while the quantitative assessment of the disease induced on susceptible hosts is a major, but completely different component of pathogenicity (see for a discussion Andrivon, 1993). We therefore investigated the extent of pathogenic variation present in 'old' and 'new' populations of *P. infestans* (*sensu* Spielman *et al.*, 1991) at the different specificity levels, through a review of some of the published data.

Host specificity at the genus/species level
P. infestans is known to be pathogenic to at least forty species of Solanaceae (Turkensteen, 1978), but most investigations on species specificity within the fungus have dealt with its two hosts of major agricultural importance, i.e. potato (*Solanum tuberosum*) and tomato (*Lycopersicum esculentum*). However, host specificity may have led to a speciation event between *P. infestans* and *P. mirabilis*, two species with mutually exclusive host ranges, but morphologically indistinguishable (Galindo & Hohl, 1985) and giving rise to fertile hybrids (Goodwin & Fry, 1994). *P. mirabilis* is thus considered either as a *forma specialis* of *P. infestans* (Möller *et al.*, 1993) or as valid species (Goodwin & Fry, 1994).

Many authors observed isolates more specifically adapted to either potato or tomato, both in 'old' (e.g., Berg, 1926; Small, 1938) and in 'new' populations (Legard *et al.*, 1995; Lebreton *et al.*, 1996), but specificity was never restrictive enough to warrant the 'formae speciales' denomination. Furthermore, it is possible to revert the initial adaptation of any isolate by repeated passages through the other host. Although this process is unlikely to be of significance

in agricultural practice, it shows a high level of genetic plasticity in the *P. infestans* genome regarding pathogenicity determinants.

Host specificity at the cultivar level

The existence of race-specific resistance genes in *Solanum tuberosum* and of matching physiological races in *P. infestans* has been recognised since the 1940s and extensively investigated since the early 1950s (see Wastie, 1991 for a review). All 11 R genes currently described originate from *Solanum demissum*, but similar genes exist in many other tuber-bearing *Solanum* species (Hawkes, 1958; Rivera-Peña, 1990b; Tooley, 1990).

Because the evolution of races is largely determined by the deployment strategies of R genes, complex races existed in 'old' populations from areas where popular potato cultivars carried combinations of R genes, such as Great Britain (Shattock *et al.*, 1977). In some instances, the introduction of 'new' populations led to a marked increase in the complexity of races (Deahl *et al.*, 1993; Drenth *et al.*, 1994). However, a comparative analysis of race structure characteristics in 'old' and 'new' populations of *P. infestans* collected world-wide and surveyed with the same set of differential clones showed no consistent trend towards an increase in virulence complexity or virulence diversity in the most recent populations (Andrivon, 1994). Interestingly, isolates present on tomato generally belong to simpler races than those collected on potato (Deahl *et al.*, 1993; Lebreton *et al.*, 1996).

Aggressiveness

P. infestans isolates are known to vary largely in their aggressiveness towards potato cultivars. This variation is not related to physiological races (e.g., Jeffrey *et al.*, 1962; Denward, 1967; Caten 1974), and can be detected both in controlled conditions and in the field (e.g., Tooley & Fry, 1985; Tooley *et al.*, 1986; Day *et al.*, 1997). Aggressiveness can decrease during repeated subculturing on artificial media, but be restored via inoculation of living plant material (Jeffrey *et al.*, 1962; Jinks & Grindle, 1963). In several experiments, aggressiveness remained stable over successive transfers to potato plants (Caten 1974). Furthermore, specific components of aggressiveness have been detected repeatedly (eg., de Bruyn, 1947; Jeffrey et al., 1962; Jinks & Grindle, 1963, Caten, 1974), reflecting the fact that each isolate usually grows better on the variety it was recovered from than on other varieties with the same R genes.

Evidence is accumulating to show a higher aggressiveness in isolates belonging to 'new' populations than in their 'older' counterparts (Flier & Turkensteen, 1996; Day & Shattock, 1997; Kato *et al.*, 1997). However, these data should be interpreted with caution, because of methodological limitations. Aggressiveness among isolates is a composite of many traits, and is thus difficult to measure accurately. Variation exists for most of aggressiveness components (e.g., latent period, infection efficiency, sporulation), but is not always directly correlated with disease progress in the field (Spielman *et al.*, 1992). Therefore, comparisons made on single components might not accurately describe actual differences in global aggressiveness between isolates. Furthermore, 'old' and 'new' isolates being compared may not have been subjected to the same number of transfers on artificial media. Finally, the extensive variation present among 'new' isolates of *P. infestans* sometimes overlaps the range of differences between 'old' and 'new' isolates (Schepers *et al*, this volume).

Conclusions

Variation exists in *P. infestans* for all components of pathogenicity. This variation is extensive both in 'old' and in 'new' populations. Although evidence exists that 'new' populations might be on average more virulent (ie, include more complex races) and more aggressive than their former counterparts, this trend does not apply equally to all situations, and exceptions can be easily found in the existing data. The extent to which these pathogenicity changes affected population structures therefore cannot be evaluated on a general and uniform basis, but needs to be assessed for each particular situation.

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Second Workshop of an European Network for Development of[9]
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Quantification of infection pressure on different potato varieties

from distant sources of *Phytophthora infestans*

H.P. SPIJKERBOER, J.E. BENIERS AND H.J. SCHOUTEN

CPRO-DLO
PO box 16
NL-6700 AA Wageningen
The Netherlands

Presentation of plans for a 4 year project.

July 1996 - June 2000

Outline of the project

The aim of the project is to determine the risk of infection with late blight from distant fields and its consequences for the fungicide requirements for different potato varieties. This risk analysis will be carried out with an epidemiological model that calculates the chance that a diseased field or cull pile infects nearby fields. The model will consist of sub models that describe the different steps in the infection cycle.

Many data on the components of the infection cycle are available in the literature. The information that is still lacking will be obtained from experiments in the field and in climate cabinets.

The components of the infection cycle that we are going to model are: spore production on lesions, sporulation, escape from spores from the crop to the air above the crop, dispersion to distant fields, deposition onto a susceptible crop and infection.

In the summer of 1997, we carried out experiments to validate our models for spore dispersal and deposition. In the winter of '97-'98 we will carry out climate cabinet experiments on spore production, sporulation and infection. We also start our modelling studies of regional spread of potato late blight and the effects of different spraying strategies. For the summer of 1998, two field experiments are scheduled. In one experiment, we will measure the escape of

spores from a crop. In the other we will measure the infection efficiency on four potato cultivars. Other parts of the infection cycle will be studied in future experiments. The project finishes with.

Spore dispersal experiment, summer 1997

We wanted to test the validity of the gaussian plume model for describing spore dispersal in a potato field. The gaussian plume model was developed for air quality studies and has since been applied successfully to risk analysis of control of forest weeds with fungi (de Jong et al., 1990). This model predicts particle concentrations downwind from a source.

We released spores from a bottle in a 4 ha. potato field. At different distances downwind from this apparatus (25 - 100 m.), we placed masts with spore traps (2 Burkard 7-day recording volumetric spore traps and 10 Rotorod Model 20 spore samplers) at different heights (2-8 m above the ground) to measure spore concentrations in the air.

Spore deposition experiment, summer of 1997

We used an indirect method for measuring spore deposition. The method is based on the measurement of the net transport of spores into the crop. We put disks with greased tape in the field just above the crop and counted spore deposition on the upper and lower side of the disks. The spores on the upper side are the spores that go down into the crop. The spores on the under side are the ones that come back out. The net transport into the crop is the difference between these two. We measured spore concentrations at 2m. height during the same experiments.

Our model for deposition relates deposition onto the crop D (spores m^{-2} s^{-1}) to the concentration of spores in the air above the crop C (spores m^{-3}):

$$D = v_d \cdot C$$

The proportionality constant v_d (m s^{-1}) is called the deposition velocity. The measurements of spore concentration and deposition allow us to estimate the deposition velocity.

Plans for climate cabinet experiment in the winter of '97-'98

Aim:

1. Measure the infection efficiency for four different potato varieties.

2. Test if the number of spores produced per lesion area is the same on different potato cultivars and under different climate conditions.

Method:

We will grow potato plants of different varieties in pots in the greenhouse. The plants are then put in a climate cabinet. The leaves of these plants will be inoculated with a spore suspension under optimal conditions for infection.

In one experiment, the infection efficiency is determined for suspensions with different spore concentrations.

In a second experiment we infect the plants with a spore suspension with a high spore concentration to guarantee infection. When lesions become visible, the climate in the cabinet is controlled to measure lesion growth rate, spore production and sporulation under different environmental conditions (temperature and humidity).

Plans for infection efficiency experiment in the summer of 1998

Aim:

Determine the infection efficiency on four different potato varieties.

Method:

Potato plants of four varieties will be grown in a patches with repetitions. leaves of these plants are collected and the infection efficiency will be determined under optimal conditions for infection (prolonged leaf wetness duration, temperature of 15°C, relative humidity of over 90%) in a climate cabinet.

Acknowledgements

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Is *Phytophthora infestans* the only cause for low yield in organic potato crops? The impact of potato nitrogen nutrition

K. MÖLLER, V. ZINKERNAGEL, H.J. REENTS and J. HABERMEYER

Technische Universität München, D - 85350 Freising, Germany

Introduction

Potatoes are one of the most interesting crops in organic farming. The reason is the possible high profit, growers get high prices per kg. Therefore yield losses have a great economical impact. The yields in organic potato production are distinctly lower than in conventional potato production, yield fluctuations are very high (more than 300%). Usually it is assumed that P. infestans is the most important cause for low yields recorded in organic potato production (KARALUS, 1992; HERRMANN and PLAKOLM, 1991; STÖPPLER et al. 1990). No considerations about impact of other growing factors like nutrient supply (mainly nitrogen supply) on yield in organic potato production are found in literature (MÖLLER, 1994). For this reason extensive studies from 1995 to 1997 were carried out on organic cropped potato fields in Southern-Bavaria and on the research station Klostergut Scheyern about impact of *Phytophthora infestans* and nitrogen-supply on tuber growth and yields in organic potato production.

Material and Methods

Survey on organic cropped fields

On organic cropped potato fields 100 km around Freising (near Munich) an intensive survey was carried out between 1995 and 1997: soil samples were taken from the end of April/begin of May to middle of June with a ten day interval; on mid of June, beginning of July, third week of July and at harvest time plant samples and sequential harvests were taken to determine potato tuber growth and nitrogen contents in foliage. The soil and plant samples were taken within a limited area of about 1000 m². During potato growth plant samples were taken

from an area of 3,75m². The sampling area to determine the yield was 15m². For a description of the phytopathological situation late blight necrosis and unspecific necrosis (% necrosis, % of infected plants) were weekly assessed.

Field Trial

To confirm the data obtained on the organic fields a field trial was carried out in 1996 and 1997 an the research station Klostergut Scheyern. Organic manure was ploughed in on the entire test field. The trial with cv. Agria was established in four treatments: Variant 1 was an imitation of organic cropping without further mineral fertilization as well as no *Phytophthora* control; variant 2 got a "complete" *Phytophthora* control with fungicides; variant 3 got an additional nitrogen fertilization (100 kg N as mineral fertilizer), without any *Phytophthora* control; variant 4 was an imitation of conventional potato cropping (100 kg N as mineral fertilizer and complete *Phytophthora* control). Each treatment had four replicates. From 1996 only harvest data are available, 1997 weekly records of tuber growth (sequential harvests from an area of 3m²) from middle of June until harvest time were collected.

Results

Survey on organic cropped fields

Figure 1.   Tuber growth on organic cropped potato fields in South- Bavaria in 1995- different cultivars.
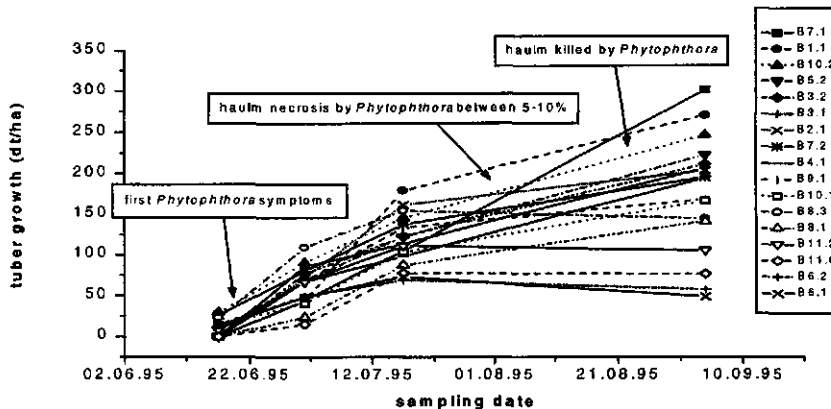

Figure 1 shows tuber growth curves on 16 different fields and date of appearance of *P. infestans* and foliage killing by the fungus in 1995. In nearly half of the examined fields tuber growth ceased in the middle of July, although *Phytophthora* killed the haulm in 1995 between four and five weeks later, between 15th and 25th of August.

Figure 2. Soil nitrate content (kg/ha in 0-60 cm), tuber growth and Phytophthora disease on four organic cropped potato fields in South-Bavaria, 1995-cv. Agria.
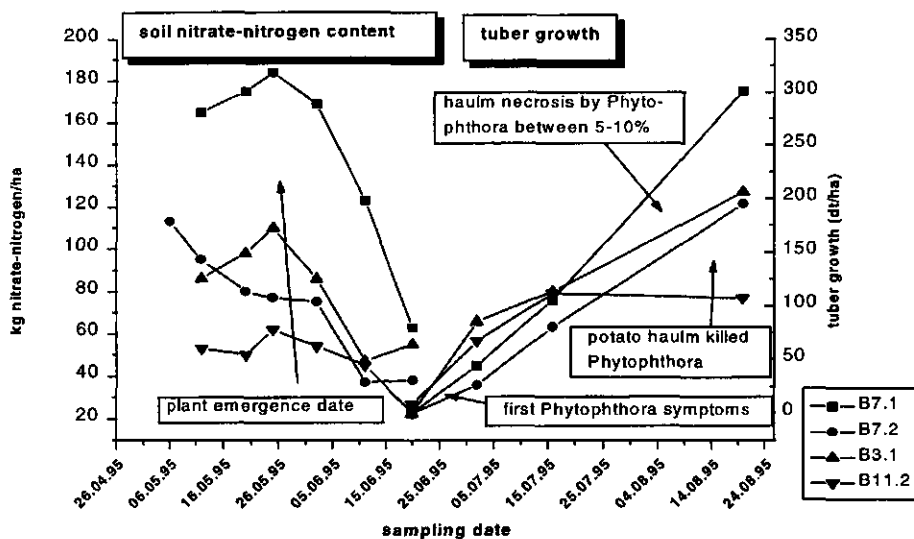
Figure 2 shows nitrate-nitrogen-contents in soil in 0-60 cm depth from planting date until middle of July with the corresponding yields. The field B7.1 with high nitrate contents at the beginning of the growing season had high yields, while the yield on fields with intermediate nitrate contents (fields B7.2 and B3.1) was distinctly lower in yield, the field with the lowest nitrate content (field B11.2) had only one third of the yield of the field with the highest nitrate supply. Tuber growth of these four fields are shown on figure 2: tubers in field B11.2 with low nitrate supply didn´t grow from the middle of July, while tubers on fields with intermediate nitrogen supply grew a little and tuber growth on field with high N-supply was very strong in the last weeks until destroying of haulm by *Phytophthora*. Additionally the field with lower nitrogen supply showed an increased ratio of chlorosis and unspecific necrosis than the fields with higher nitrogen status (not described).

Figure 3. **Tuber growth and Phytophthora disease on organic cropped potato fields in South-Bavaria-1996.**
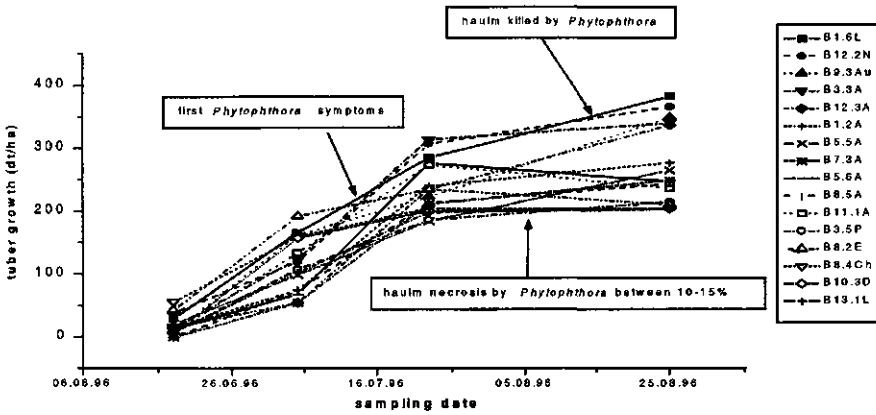
Figure 3 shows the situation in 1996: in this year similar results as one year before was obtained: the yields were generally higher than in 1995, but tuber growth on nearly one half of the examined fields ceased - like 1995 - in the middle of July, three weeks before *P. infestans* became obvious and four weeks before haulm destruction by *Phytophthora*.

Figure 4. **Soil nitrate content (kg/ha in 0-60cm), Phythophthora disease and tuber growth on two adjacent organic cropped potato fields in South-Bavaria, 1996 cv. Désirée.**
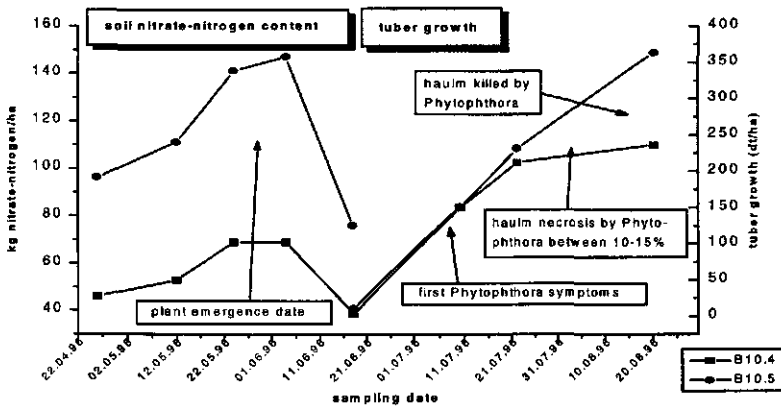
In figure 4 one example of two adjacent fields with differences only in nitrogen supply is represented: tuber growth in field B10.4 with low nitrogen supply nearly ceased after the third

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week of July, while in field B10.5 tuber growth continued until haulm killing by *Phytophthora*. Necrosis assessment in this two fields shows, that at the beginning of strong *Phytophthora* development (8th Aug.) the field with higher nitrogen status showed a lower ratio of unspecific necrosis (40%) than the field with low nitrogen supply (60%).

In 1997 the situation was different in comparison to prior years, because after appearance of *P. infestans* in the second week of July the weather conditions were very favourable for fungus development, potato haulm was killed in the last week of July or in the first week of August. Nevertheless there were big differences in tuber growth and yields between fields with different nitrogen supply. Tubers on one half of the examined fields (mostly the fields with low nitrogen supply, i.e. field N8.8, N12.4, L10.6, L1.15) didn´t grow after middle of July, while the fields with higher N-supply (i.e. N1.9, N1.11, L1.11, L1.10) continued to grow until haulm destruction by *Phytophthora* (figure 5).

Figure 5. Soil nitrate content (kg nitrate-nitrogen in 0-60 cm depth), Phytophthora disease and tuber growth on organic cropped potato fields in South-Bavaria, 1997 - cv. Linda (=L) and cv. Nicola (=N).
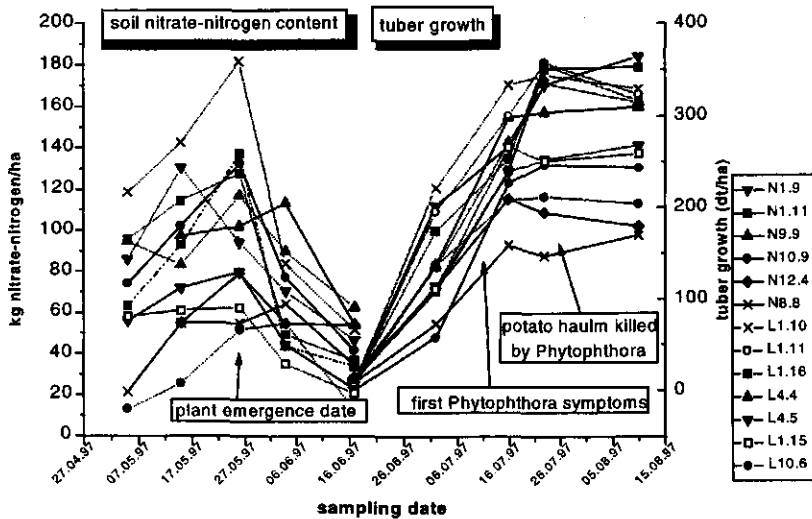
In figure 6 nitrogen supply and tuber growth on one field with different previous crops and organic fertilization are described. This results confirm earlier findings of previous years. In the three years of investigation only a small amount of tubers with tuber blight was found.

Figure 6. Soil nitrate content in 0-60 cmdepth, Phytophthora disease and tuber growth on one organc potao field in Oldezhausen, South-Bavaria, cv. Désirée - 1997.
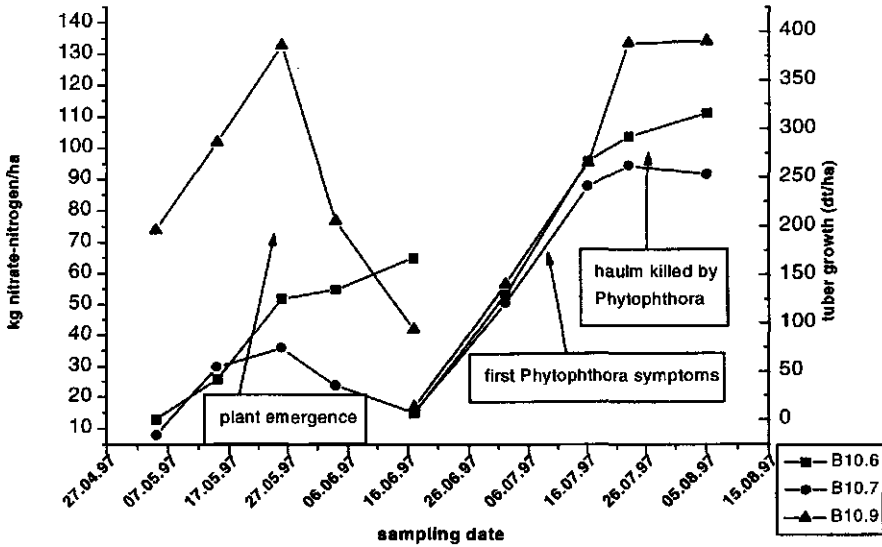
Field trial

Figure 7 represents the yield of the field trial in 1996: The differences between variant 1 and variant 3 (without and with additional nitrogen supply) were distinctly higher than the differences between variant 1 and variant 2 (without and with fungicides against *P. infestans*).

Figure 7. Yield response to nitrogen supply and Phytophthora disease, 1996 - cv. Agria.
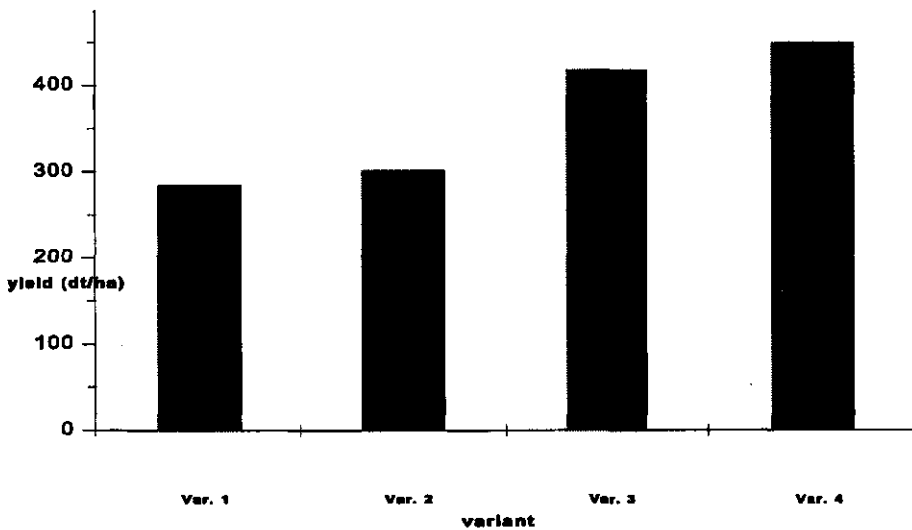
Figure 8 shows tuber growth curves of field trial in 1997. Nitrogen supply in variants without additional nitrogen fertilization was distinctly higher than in 1996. Only minor, no significant differences were recorded between the variants until the end of July, the date of foliage killing of the two variants without *Phytophthora* control. Tuber growth in variant 2 became very slow in the first two weeks of August and ceased completely in the middle of this month, while in variant 4 tuber growth continued until harvest date.

Figure 8.   Tuber growth curves in 1997.
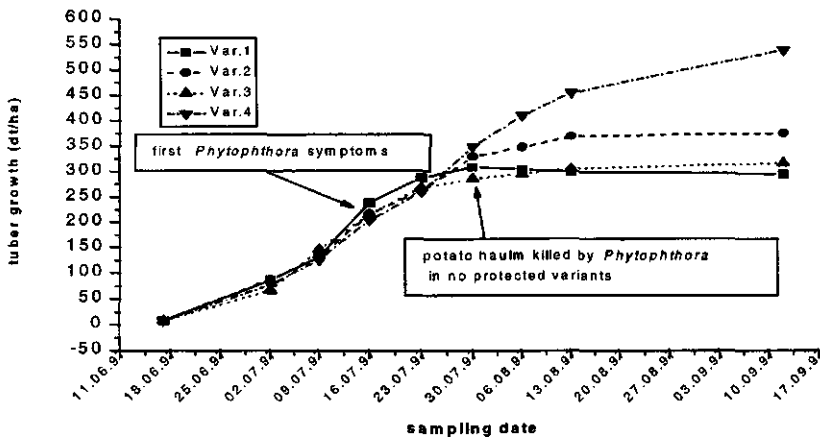
Discussion

The results show that in the years under investigation tuber growth ceased in the middle of July on nearly 50% of the test fields from organic potato growers in Southern-Bavaria, independent from *Phytophthora* disease on these fields. Results concerning nitrogen supply of the different fields show, that nitrogen status had greatly influenced yields. These results are hints, that other growing factors like nutrition supply are responsible for low yields. On the most fields low nutrient supply seems to be the first limiting factor for tuber growth, in these cases *Phytophthora* only killed very senescent plants, without affecting tuber growth. *Phytophthora* became responsible for yield losses only on fields with sufficient nitrogen supply; therefore *Phytophthora* control is able to increase the yields only in case of sufficient nitrogen in soil. On the lower leaves of plants with nutrition deficiencies chlorosis was build from the beginning of July, these chlorosis became netrotic.

Furthermore only little problems with tuber blight were recorded. Maybe the very fast foliage destruction caused by *Phytophthora* under favourable weather conditions limited losses by tuber blight.

Satisfactory yields are possible in organic potato production in spite of lack of an effective *Phytophthora* control: The combination of *Phytophthora* tolerant cultivars (at least a medium *Phytophthora* tolerance) with early start of tuber growth, presprouting of seed tubers to accelerate the early development of potato plants and a sufficient nitrogen supply secured the yields on a relatively high level in most cases.

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Main infection and sporulation periods (MISPS):

towards its use in an event-based DSS to control potato late blight

M. RUCKSTUHL, H.R. FORRER

Swiss Federal Research Station for Agroecology and Agriculture

Department of Farming Systems and Landscape Ecology

CH-8046 Zürich, Switzerland

Abstract

A simple combination of standard hourly measurements of three weather parameters (air temperature, precipitation, relative humidity) was used to formulate a set of meteorological conditions, crucial for the entire process to be completed from sporulation to successful infection of the asexual stage of *Phytophthora infestans* in potato crops.

Based on measurements from local weather stations and regional forecast data, it was checked in hourly intervals if these crucial weather conditions, defined as "main infection and sporulation period" or MISP, had occurred or were expected, respectively.

Accordingly, recorded "after MISP" situations and predicted "before MISP" situations were embedded in two different spraying schedules. In 1997, these two models were compared in small plot trials to the DSS plant protection schemes suggested by NegFry and PhytoPRE. With PhytoPRE and the two MISP procedures, the onset of the epidemics was delayed, the disease development retarded, and the final infection rate reduced. The NegFry model failed completely in terms of crop protection due to very long intervals between subsequent sprays, whereas MISP models recommended 7-10 fungicide applications, which reduced the final infection significantly even in small plots under heavy disease pressure.

Keywords: *Phytophthora infestans*; PhytoPRE; NegFry; advisory system; plant protection.

Introduction

Since 1994, the PhytoPRE advice system offers Swiss potato growers a plot-specific tool to optimise the control of *Phytophthora infestans* (Mont.) de Bary, the causing agent of potato late blight (Forrer *et al.*, 1993). PhytoPRE relies mainly on information on local infection pressure deriving from a fine-scale leaf blight observation network, and estimates the date on which the fungicide protection layer ought to be renewed, based on locally measured rain data and maximal intervals between sprays. Aspects considered for this decision are the current fungicide protection status of the crop, susceptibility of the cultivar, and agronomic factors that potentially influence the infection chances (e.g. growth stage, production technique). Due to the lack of precise local weather data, the influence of meteorological parameters in PhytoPRE is actually restricted to the use of accumulated precipitation.

However, single plant observations in experimental plots in 1995 and 1996 indicated that a rather simple combination of basic meteorological parameters may be useful to identify conditions crucial for both sporulation and infection of *P. infestans* (Cao *et al.*, 1997). These conditions were scrutinised in 1997 and used to run a preliminary version of PhytoPRE+2000, the future model of an event-based decision support system (DSS) that will ultimately replace the current PhytoPRE advice system.

This communication reports on our first experiences with a late blight control strategy that has evolved from a concept which we call "Main Infection and Sporulation Periods" (MISP). It is based on correlations of local meteorological conditions with late blight incidence and severity measures, respectively, found by Cao *et al.* (1997). At hourly intervals, the model determines if the weather was favourable in the last 24 hours or will be favourable in the next 24 hours for both infection and sporulation of *P. infestans* to occur.

Material & Methods

The validation of four DSS models for the control of potato late blight was carried out in 1997 in a multi-location field trial at three sites in northern (Reckenholz), north-eastern (Ellighausen), and eastern (Salez) Switzerland. The experiments at each site compared the four models with an unsprayed check treatment in a RCB design with 5 replications, using the two varieties Bintje and Agria, which are classified as highly and moderately blight susceptible, respectively, in Switzerland. Single plots consisted of 15 m², separated by rows planted with Panda, one of the most resistant variety so far released in the country. Agronomic prac-

tices were applied according to conventional standards.

Hourly meteorological data were recorded with automatic weather stations installed in the experimental fields, whereas hourly forecast data were kindly provided by the national meteorological institute, based on calculations for a national forecast grid with a mesh size of approx. 14 km. These data were employed to run the following DSS models.

NegFry: The NegFry system described by Hansen (1993) was slightly modified to account for the delay of the first recommendation as it was commonly observed in Switzerland, when the "negative prognosis" (Ullrich and Schrödter, 1966) was applied to determine the optimal moment for the first spray. Instead, the first national bligth observation was used to start all four models.

PhytoPRE: The spraying schedules for the PhytoPRE treatments were issued by the advisory system (Forrer *et al.*, 1993) to which about 800 farmers in Switzerland and Liechtenstein were subscribed in the growing season 1997.

MISP: MISPs were defined as periods of 24 hours with at least six consecutive hours during which the relative humidity is ≥90%, and at least six non-consecutive hours with precipitation at air temperatures ≥10°C (Cao *et al.*, 1997). At hourly intervals, we checked both the last and the future time frame of 24 hours for the occurrence of the MISP conditions. In the "before MISP" plots , fungicides were applied as soon as MISP conditions were announced, whereas in the "after MISP" treatments, the plots were sprayed right after the end of the rainfall.

Fungicides used in the NegFry and MISP models were 2.5 kg ha^{-1} Daconil combi DF® (chlorothalonil 60%, cymoxanil 6%). The PhytoPRE system however, suggested the use of both translaminar and protectant fungicides: again, Daconil combi DF® was used as the translaminar product, whereas 3 l ha^{-1} Daconil 500® (chlorothalonil 41%) was used as the protectant product. Fungicides were applied with a backpack sprayer in 500 l ha^{-1} water. Minimum intervals between two subsequent fungicide applications were 6 days in all tested DSS models.

Blight severity was estimated visually as the proportion of chlorotic and necrotic foliage in the two centre rows of each plot every three to four days. As the fungi passed along successive generations, the epidemics built up in the course of a single growing season. The polycyclic process of the untreated check plots was expected to follow the logistic growth model of a "compound interest disease" (Van der Plank, 1963), that is best described by plotting disease data against a time scale resulting in disease progress curves. Using the percentage data,

S-shaped sigmoid growth curves were drawn. The area under the disease progress curve (AUDPC) based on Julian days was calculated and subjected to standard statistical procedures.

Table 1. Comparison of potato late blight advice systems in 1997 at three locations in Switzerland, tested with two varieties Bintje (highly susceptible; upper half) and Agria (moderately susceptible; lower half). The area under the disease progress curve, relative to the untreated check plots, was employed to quantify the disease development under the different spraying regimes. In the right half of the table, the number of sprays are listed that were recommended by the various DSS models.

BINTJE	Relative Values of AUDPC[2,3]			No. of Fungicide Applications		
	Reckenholz	Ellighausen	Salez	Reckenholz	Ellighausen	Salez
untr. Check[1]	100.0 a	100.0 a	100.0 a	0	0	0
NegFry	97.4 a	91.5 a	70.6 b	2	3	3
PhytoPRE	45.2 b	28.0 bc	25.0 d	7	6	7
after MISP	41.5 bc	33.1 b	35.4 c	7	7	8
before MISP	38.8 c	12.6 c	9.5 e	7	10	10
AGRIA	Relative Values of AUDPC[2,3]			No. of Fungicide Applications		
	Reckenholz	Ellighausen	Salez	Reckenholz	Ellighausen	Salez
untr. Check[1]	100.0 a	100.0 a	100.0 a	0	0	0
NegFry	94.6 a	93.6 a	53.6 a	2	2	2
PhytoPRE	27.9 b	21.4 b	8.5 bc	6	6	6
after MISP	20.1 b	11.3 bc	16.9 b	7	7	7
before MISP	25.6 b	5.8 c	3.7 c	7	10	10

[1] untreated check did not receive any fungicide treatments during the whole season.
[2] relative AUDPC: area under the disease progress curve; figures are relative values of the untreated check plots.
[3] figures within a column followed by the same letter are not significantly different at P<0.01 (Fisher's unprotected LSD).

Results

In 1997, late blight was first detected at May 16 in the western part of the country. Within one week, all treatments at the three experimental sites received the first spray, which follows the common practice advised by PhytoPRE in the major potato areas of Switzerland.

The rainy weather in June and most of July, launched a rapid disease development in the untreated check plots, particularly in Bintje, where a total loss of green leaf material was recorded by July 15 in all the locations (figures 1-3). The 2-3 fungicide treatments recom-

mended by NegFry were in most cases insufficient to detect a significant difference to the untreated checks (table 1).

However, in all six trials (3 sites, 2 cultivars), the fungicide treatments suggested by Phyto-PRE and the two MISP models gave a significantly better protection to the crops (figures 1-3). Infection levels, expressed as AUDPC values relative to the untreated check plots, were always lower than 50% and even below 10% in three Agria and one Bintje treatment (table 1).

Discussion

Field trials at all three sites showed that the MISP models performed well. Considering the very high and even disease pressure and the small plot size, it cannot be expected that plots can be maintained blight-free. However, the disease progress curves recorded in PhytoPRE and MISP plots indicated an important delay of the disease onset and a much less vigorous blight attack at most sites, compared to plots treated according to the NegFry model. Obviously, the NegFry model would have to be adjusted to more continental conditions, i.e. shorter periods with high relative humidity, as they prevail in Switzerland.

PhytoPRE proved to be a safe and reliable system, both in four years of practical use by farmers and in field trials as presented here. If fungicide treatments are applied strictly according to PhytoPRE's recommendations, a sufficient protection is realised under most conditions. However, due to the system's low sensitivity towards actual weather data, dry and hot periods with low infection risks can hardly be exploited to postpone the next fungicide application. Therefore, a majority of farmers feels that in dry seasons, PhytoPRE recommends more treatments than required to keep the crop disease-free.

Figure 1. Comparison of potato late blight advice systems from May to August 1997 at Reckenholz, northern Switzerland, with variety Bintje (upper half) and Agria (lower half): For both varieties, crucial weather parameters and MISPs are displayed (top graph), followed by the diagram with the four different fungicide schedules (central graph), and the S-shaped disease development curves of all five treatments (bottom graph).
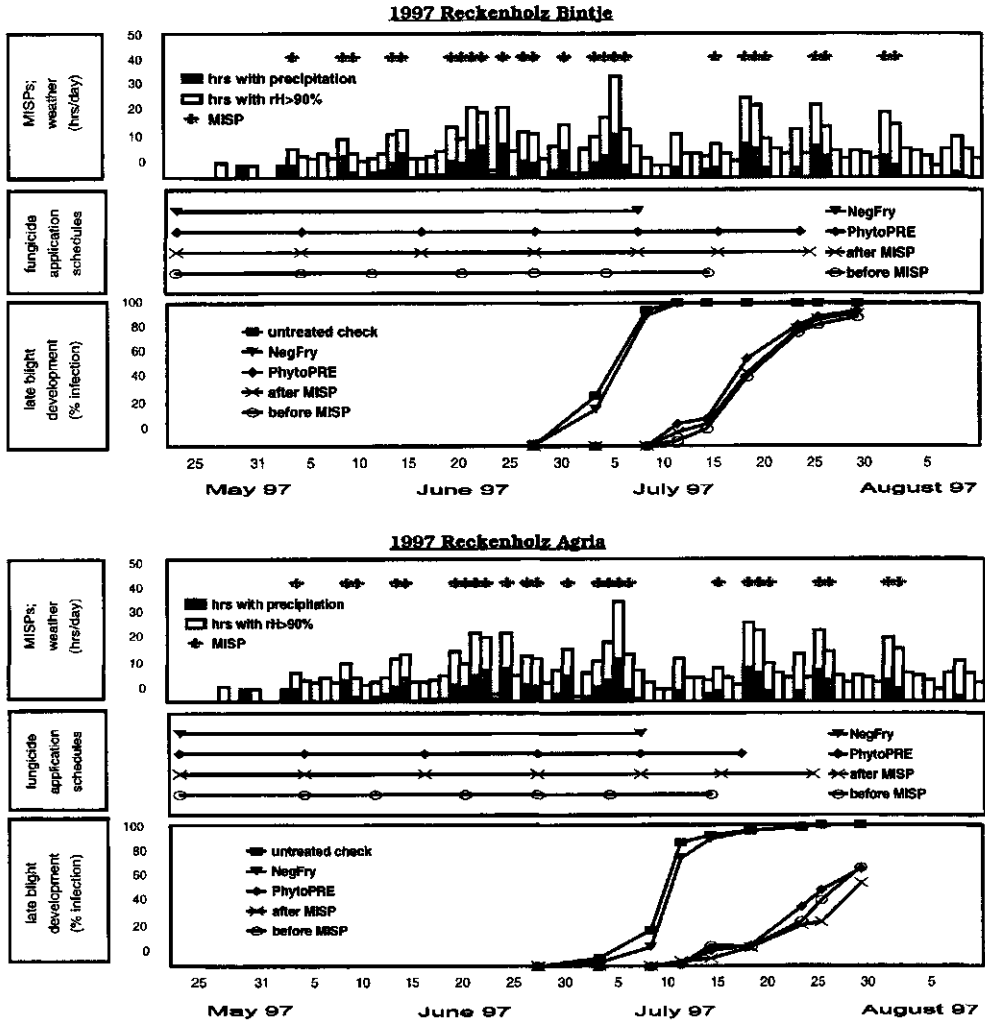
Figure 2. Comparison of potato late blight advice systems from May to August 1997 at Ellighausen, north-eastern Switzerland, with variety Bintje (upper half) and Agria (lower half): For both varieties, crucial weather parameters and MISPs are displayed (top graph), followed by the diagram with the four different fungicide schedules (central graph), and the S-shaped disease development curves of all five treatments (bottom graph).

1997 Ellighausen Bintje

1997 Ellighausen Agria

Figure 3. Comparison of potato late blight advice systems from May to August 1997 at Salez, eastern Switzerland, with variety Bintje (upper half) and Agria (lower half): For both varieties, crucial weather parameters and MISPs are displayed (top graph), followed by the diagram with the four different fungicide schedules (central graph), and the S-shaped disease development curves of all five treatments (bottom graph).
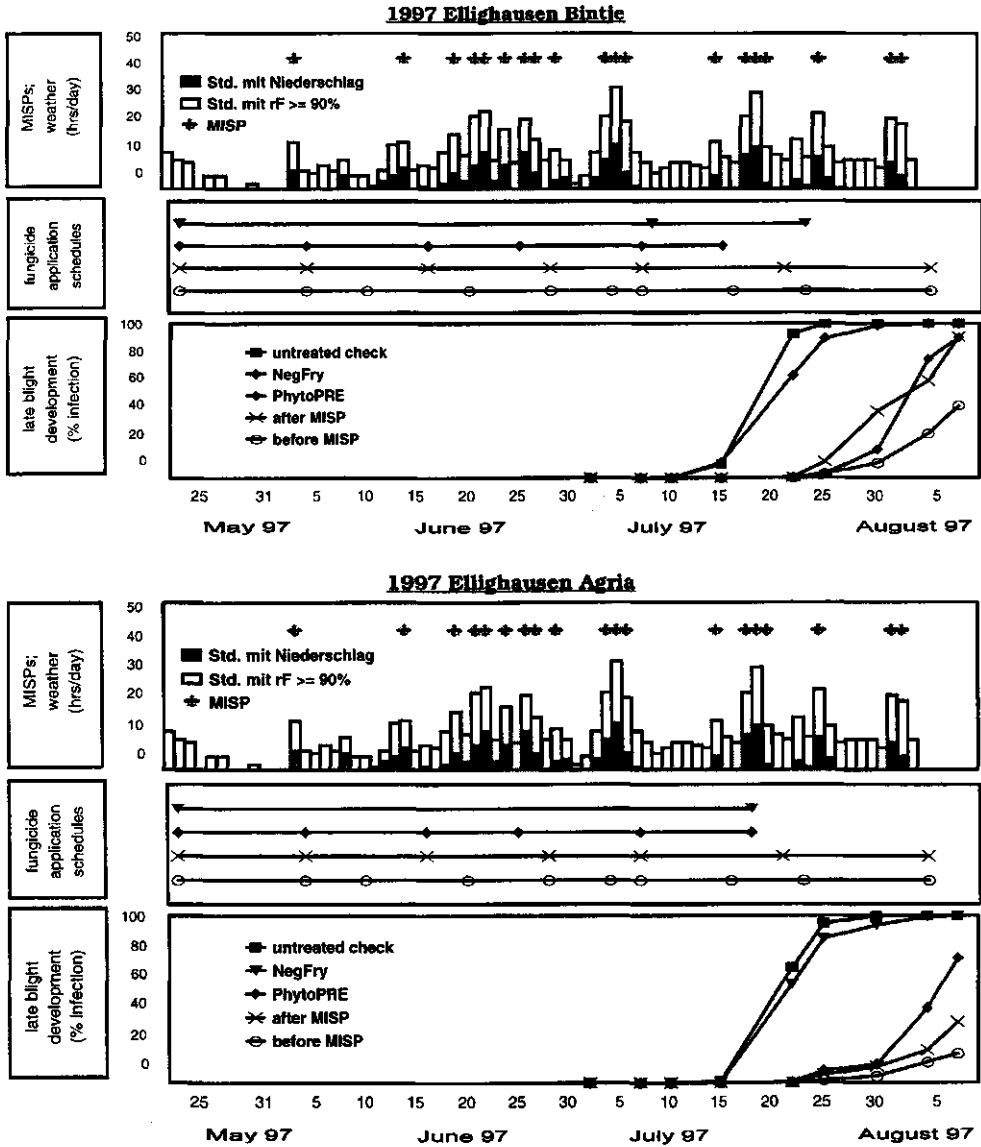

1997 Salez Bintje

1997 Salez Agria
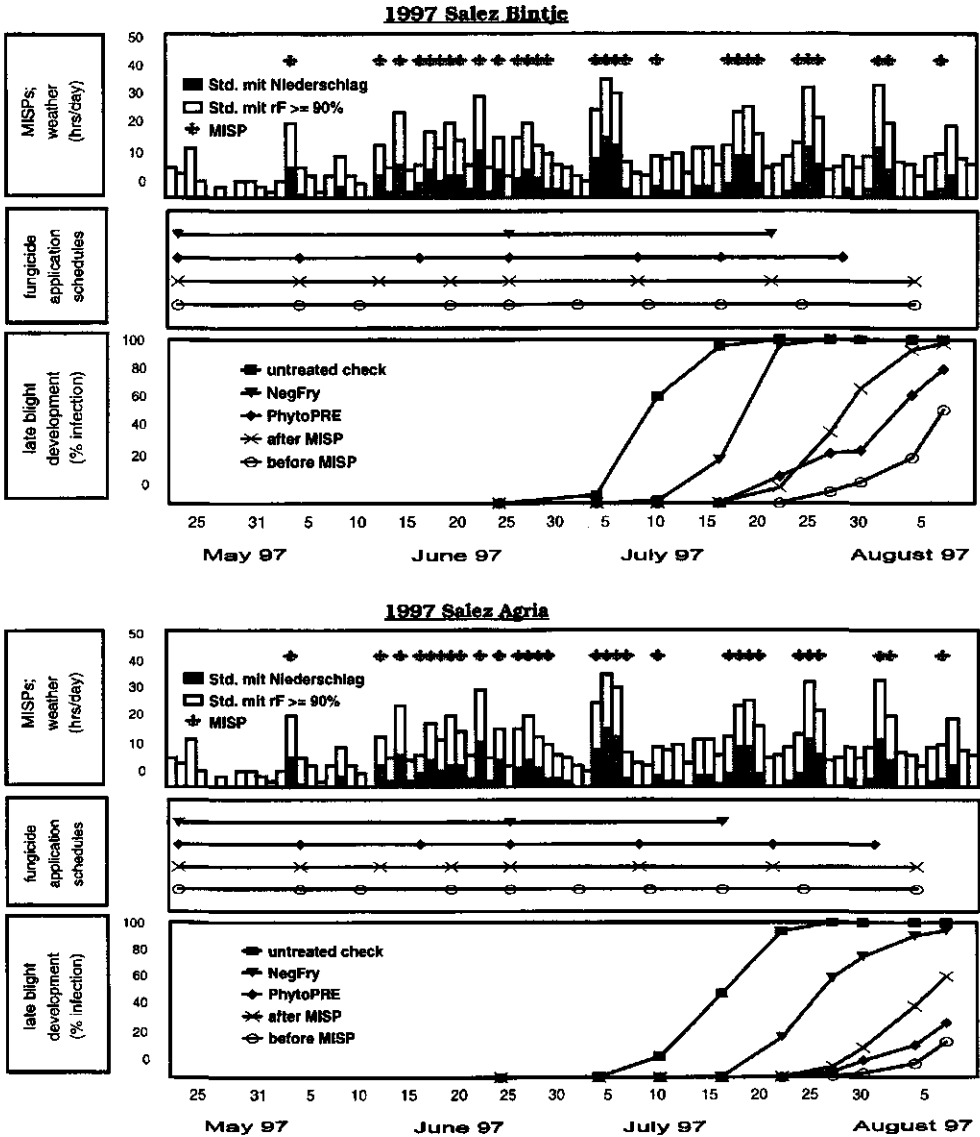
The MISP model now provides us with a tool to more reliably determine the periods of high infection risk. Unfortunately, the rainy weather in spring and summer 1997 was not helpful to further develop and elaborate on a more precise definition of MISP events. New blight symptoms developed almost continuously in the observation plots and could therefore not be traced back unambiguously to a specific infection period. Furthermore, the prolonged rainy period in 1997 might have masked a potential difference in the number of recommended fungicide treatments between PhytoPRE and the MISP models, which are designed to achieve pesticide savings during dry periods. In a field trial 1996, a clear reduction in the number of fungicide applications with the "after MISP" model was attained, in a year however, which was characterised by an unusual drought in June (Cao *et al.*, 1997; here called "CWC-model").

Nevertheless, the presented results suggest that a combination of measured local weather data with regional weather forecast will be useful to detect blight favourable conditions. The complex topography of Switzerland and the small scale farming systems ask for a DSS that functions with local weather data. We tried to develop our models with a very basic set of meteorological parameters, that can be measured with simple, rather inexpensive weather stations. However, we don't expect the current definition of the critical periods to fully cover all possible infection conditions, and we are aware of the necessity to fine-tune and probably permanently supervise these decision rules.

Obviously, both the "before MISP" and the "after MISP" models have to be combined and embedded in a field-specific advisory system such as PhytoPRE that further includes submodels for other parameters with influence on the host-pathogen-environment triangle:

host: varietal susceptibility
               production type
               crop growth

pathogen: inoculum sources
               fungicide resistances
               population characteristics

environment: fungicide characteristics
               dosage of active substance
               wash-off factor
               field conditions

Conclusions

Both MISP models tested in the presented experiments revealed a promising approach for an event-based control strategy of potato late blight, not only in terms of a reduced infection risk, but primarily as a protection strategy that suggests pesticide treatments only in situations where weather conditions are met that are crucial for a potential blight infection. The models help to identify periods with meteorological conditions unfavourable for the fungi to reproduce and spread, and can therefore support the farmers in decreasing the pesticide inputs.

The MISP models need to be further tested in years with lower disease pressure. Single infection events need to be found which allow the statistical analysis of many more meteorological data sets. Probably, the definition of MISP situations has then to be revised but we believe that much more sophisticated models either won't fit the complex topography of Switzerland or would economically be uninteresting for the generally small scale potato growers.

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Screening for resistance in leaves of potato-cultivars against *Phytophthora infestans* with use of biochemical markers

F. FLEISCHMANN [1], W. OSSWALD [2], J. HABERMEYER [1], V. ZINKERNAGEL [1]

[1] Inst. of Phytopathology, TU-Munich-Weihenstephan, D-85350 Freising, Germany

[2] Dept. of Forest-Botany, Inst. Phytopathology, LMU-Munich, D-85350 Freising, Germany

Abstract

For the development of a suitable screening-test against *Phytophthora infestans* in potato-foliage, several pathogenesis-related (PR) proteins and postinfectional produced ethene were tested for theire use as biochemical markers for late-blight resistence. All tested substances increased intensively after infection. Potato-cultivars with a high quantitative resistance showed significant different induction patterns compared to more susceptible cultivars. Resistant varieties induced higher levels of PR-proteins than susceptible ones, while ethene-synthesis was higher in susceptible varieties. Furthermore the influence of plant- and leave-age on PR-protein induction was studied and different growing-methods were compared.

Keywords: *Phytophthora infestans*, pathogenesis-related proteins, ethene, quantitativ resistance

Introduction

Potato-leaves show several biochemical changes after infection with Phytophthora infestans. So ethene usually is released in very small amounts under physiological conditions and regulates e. g. flower fading, senescence of leaves and fruit ripening as a phytohormone (Roberts and Tucker, 1985). A long known phenomenon is the increased postinfectional synthesis of ethene. In several studies it was shown that ethene synthesis is correlated with the quantitative resistance, whereby both cases are known: resistant varieties produce higher amounts of

ehtene than susceptible ones and vice versa (Montalbini and Elstner, 1977). Previous studies with potato-leave-disks exhibit that susceptible cultivars produce more ethene after infection than resistant ones, but a clear differentiation failed.

PR-proteins were discovered in tobacco after infection with TMV. Since now several sero-logical related families are described (Kombrink and Somssisch, 1997). PR-proteins are defined as small proteins with certain characteristics like relatively high resistance against proteases. Their constitutive level in healthy plant tissue usually is low and they are induced by pathogenes, but also by other stress-factors like wounding, ozone, salicylic acid etc.. The role of PR-proteins in plant defence is not quite clear jet, as the function of most of the proteins is unknown. Several family show hydrolase activity. The two most studied PR-protein families 2 and 3 belong to 1,3-ß-glucanases and chitinases. For these enzymes Schröder et. al.(1992) discovered differences of induction in compatible and incompatible interactions of potato leaves with *P. infestans.*

Here we studied the different postinfectional ethene synthesis and PR-protein induction in leaves of potato varieties with different quantitative resistance against *P. infestans.*

Materials & Methods

Growth of potato varieties

Potato-plants were grown in three different ways. One variant was grown in the field, with normal fertilisation and protection against insects, but no antifungal protection. The second variant was planted in potts and cultivated in the glasshouse; so was the last variant, but the potts were stored outside the glasshouse after emergence of the plants.

In detached leave tests, the resistance of a variety was measured as the leasion size compared to the leave area. The resistance in the field was evaluated as the progress of the intensity of infestation.

Isolates of Phytophthora infestans

Three isolates of *P. infestans* from different parts of Germany were used. Together they contained the virulence-genes 1.2.3.4.6.7.8.10.11.. For inoculation a sporangia suspension with 1×10^5 sporangia per ml was prepared and cooled for 1 hour to induce zoospore development. Leaves were inoculated by deeping them shortly into the suspension.

PR-protein measurement

For PR-protein measurement, the second well developed leave from the top of a plant was detached, inoculated and incubated in petridishes on waterager (16°C, 16 hours light, 200µE). Samples were taken every 24 hours up to 6 days post inoculation.

All PR-protein tests were done during summer 1996.

The leaves were rubbed to powder in liquid nitrogen and freezedried. Protein of 30 mg dry powder was extracted in 1 ml 0,1 N acetate buffer (pH = 5,5) and the extract was dialysed for 5 hours against destilled water.

With this extract glucanase and chitinase activity was measured using dye-labeled substrates form LOEWE Biochemica according to the method of Wirth and Wolf (1990).

Ethene measurement

For ethene measurement in summer 1997 very young leaves were detached. The leaves were inoculated and incubated in a gas-tight camber (about 8,5 cm Ø, 5 cm hight, total volume 260 ml) with the petiols standing in destilled water. Cambers were closed 20 hours before measurement and opened for 4 hours every day. Incubation conditions were 16°C and 16 hours light (400µE). 1 ml air was suck out of the chamber with a syringe and measured in a Varian 3300 gas chromatograph with an activated aluminia 60/80 column 1/8" and a FID.

Results

PR-protein induction

The activity of glucanase and chitinase is almost not measurable at the day of inoculation. It starts rising two days later and reaches a maximum four to five days post inoculation. (Figure 1). In general the activity in the resistant variety 'Bettina' reaches a higher maximum than in the susceptible variety 'Indira'. The activity in the moderate susceptible cv. 'Agria' was in between. The activity in uninfected control leaves also rose during the incubation time, but the level was lower and there were no real differences between the three tested potato varieties.

Figure 1. Induction of 1,3-ß-glucanase in potato leaves.
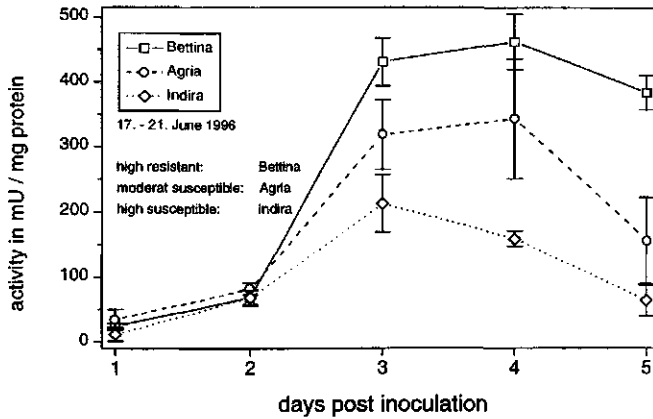
The induction of these PR-proteins is not always the same in one variety. It depends both on leave age and plant age. The maximum activity of 1,3-ß-glucanase in cv. 'Bettina' after infection is highest in jung leaves and lowest in old leaves, while the influenced on chitinase

	2nd leave form top		4th leave form top		6th leave form top	
	mean	sd	mean	sd	mean	sd
Glucanase ac-tivity (mU/mg dry powder)	**7,37**	0,44	**4,66**	2,5	**3,33**	1,87
Chitinase activity (mU/mg dry powder)	**358**	33	**353**	104	**315**	62

activity is only little (Table 1).

The induction of hydrolytic enzymes also changes during the vegetation period, so that the above shown differences between the cultivars are not so clear all the time (Figure 2). In all three tested varieties the induction was only low in plants about one week after emergence. The activity was high in plants four to six weeks after energence, but the differences were most significant in plants short before flowering. At the end of July 1996 heavy rainfalls took place and influenced the induction aswell.

A test with seven potato cultivars in 1996 confirmed that the induction of glucanases and chitinases in resistant cultivars is higher than in susceptible ones. A comparison of the hydrolytic activity in leaves 4 dpi and the corresponding leasion size gave a suitable correlation (-0,62 for glucnase and -0,73 for chitinase), even if the date for the test was not optimal.

Test with glasshouse grown potatoes during summertime exhibited low activities for all varieties and also no clear symptom development.

Figure 2. Change of glucanase activity during the summer 1996.
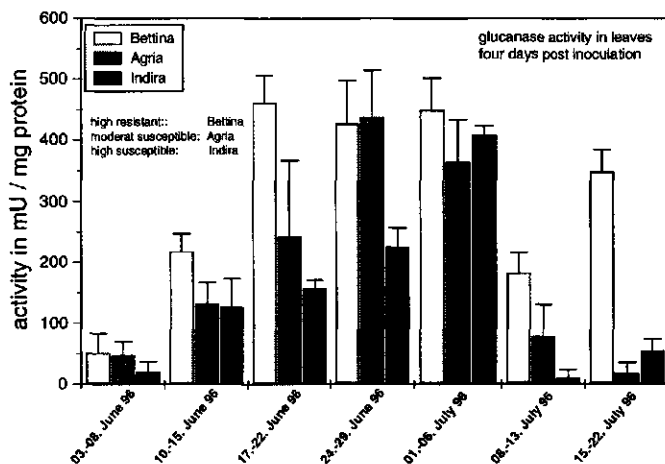
Postinfectional ethene synthesis

For the tests of ethene synthesis only the first well developed leave from the top could be used, because other leaves were to big for the gas thight chambers. Incubating the leaves or leave-disks on waterager for testing older leaves was little reproduceable.

Figure 3. Postinfectional ethene synthesis.
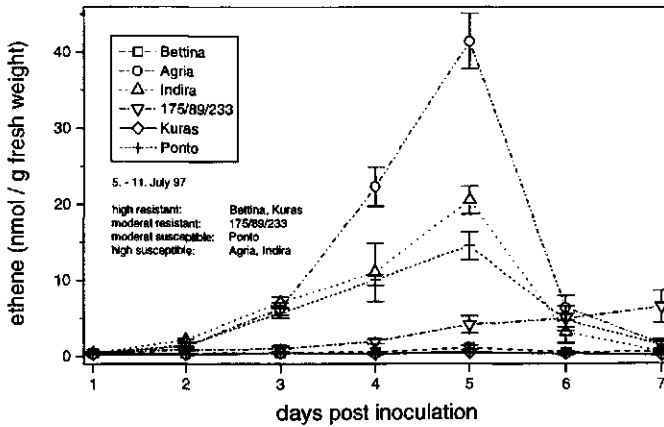
The ethene synthesis in infected leaves short after inoculation and in uninfected leaves during the whole incubation period was at the limit of detectability. Two to three dpi the synthesis rose in susceptible and moderat susceptible varieties while there was almost no increase in resistant ones. Five dpi susceptible varieties reached a maximum in ethene synthesis, followed by a sharp decrease. Moderat susceptible varieties reached a lower maximum but the decreas was the same (Figure 3).

The same results were obtained with plants of two different fields and potted plants grown in the field. Again potatos grown in greenhouse in summer reacted different.

Discussion

Both the results for postinfectional ethene synthesis and PR-protein induction showed that these factors were involved in the biochemical response of quantitativ resistance of the potato foliage against *P. infestans*. These factors differed only in their amount and not in their temporal apperance between the tested potato varieties. Resistant plants did not react faster on pathogen attack than susceptible ones like it was observed for ethene in beans infected with *Uromyces* (Montalbini and Elstner, 1977). This could also be a consequence of the relatively high inoculum concentration.

The higher amount of ethene in susceptible varieties indicated that it is more a stress symptom than a signal in the resistance induction pathway. The low level of ethene in uninfected control leaves compared to infected ones showed that the postinfectional ethen synthesis is not influenced by other factors like wounding.

In contrast to ethene PR-proteins seemed to be much more involved in the active resistance response of the plant. Although their was no real proof for a effectiveness of 1,3-ß-glucanases and chitinases against *P. infestans* (Schröder et. al., 1992), the induction correlates with the leasion size of the leaves in negative way. Later tests with only three varieties reached correlations of -0,8 (data not shown). The induction of the PR-proteins was caused both by pathogen attack and abiotic factors like wounding, as the rising activity in uninfected leaves indicated. Thus the PR-protein induction was not as specific to *P. infestans* as ethene synthesis, but it seems to be a quantitative factor for potato leaves to deal with stress situations.

So far ethene synthesis in very young leaves seems not to be influenced by plant age, but very young plants were not tested jet. The great influence of plant age on PR-protein induction restrict the samplingdate on two or three weeks during the vegetation period. The use of greenhouse grown potatoes - at least during summertime with high temperature inside- is not suitable for biochemical resistance tests.

Another interesting observation was the different susceptibility of variety 'Agria' in 1996 (PR-protein measurements) compared 1997 (ethene measurement), although the same isolates were used for inoculation. The results corresponded with the susceptibility observed in the field where 'Agria' was not more resistant than 'Indira' in 1997, a variety classified in our institute as a high susceptible variety. The PR-protein measurement for the year 1997 might give further information but is still in progress.

Acknowledgement

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Sporangia production on leaf and stem lesions in relation to cultivar resistance to potato blight (*Phytophthora infestans*)

J.W. LAMMERS[1], R.A. BAIN[2], G.L. LIGERTWOOD[2] & E.L. RAYNOR[2]

[1]Undergraduate at Wageningen Agricultural University,

Haarweg 333, NL-6709 RZ Wageningen, The Netherlands

[2]Department of Plant Biology, Plant Science Division, SAC, Auchincruive,

Ayr KA6 5HW, UK.

Abstract

In experiments using detached leaves and excised stem sections of eight cultivars, cultivar resistance to stem blight was closely related to resistance to leaf blight. However, in three field experiments using six of the cultivars there was a poor relationship between foliar and stem blight severity. The potential amount of inoculum produced on blighted leaves and stems of the cultivars was monitored during an epidemic by incubating diseased plants in a high relative humidity prior to counting the number of sporangia. Sporangia production per unit area of leaf lesion was greatest early on in the epidemic but declined significantly with time. In contrast the decline in sporangia production on stem lesions was more gradual. For most cultivars the number of sporangia collected from stem lesions exceeded that from leaf lesions but the relationship between sporangia numbers from stems and leaves was poor.

Key words: late blight, inoculum

Introduction

The importance of stem lesions as a source of inoculum for the infection of progeny tubers was demonstrated and discussed previously (Fairclough, 1995; Bain *et al.*, 1996). However, no account was taken of the influence of cultivar resistance and yet it is likely to have a marked effect on the amount of inoculum produced on the haulm and therefore the rate of

spread of the pathogen. This paper describes experiments that examined the influence of cultivar resistance on the production of sporangia on foliar and stem lesions at different times during the development of an epidemic. The relationship between leaf and stem blight for different cultivars was also examined.

Materials and methods

Seven maincrop cultivars, Brodick, Desiree, King Edward, Maris Piper, Pentland Hawk, Pentland Squire and Russet Burbank and one first early, Pentland Javelin, were selected for the experiments to give a wide range of cultivar resistance to foliar and tuber blight. The most susceptible cultivar was King Edward which had NIAB ratings of 4 and 1 for resistance to foliar and tuber blight respectively (9 indicates the highest possible resistance). Brodick was the most resistant cultivar used and had ratings of 7 and 9 for foliar and tuber blight (Anon. 1993). The seed tubers used were SE or VT grade in the Scottish Seed Potato Classification Scheme. In most experiments a mixture of seven *P. infestans* isolates was used. The isolates were obtained from UK potato crops and were maintained on detached leaves of cv. K. Edward. Inoculum for experiments was also bulked on detached leaves of cv. K. Edward.

Cultivar resistance to leaf and stem blight, laboratory experiment: In the glasshouse ten seed tubers of each cultivar were planted singly in pots containing Levington compost. Five weeks after planting, six *c.* 5 cm internodal lengths of stem were cut from one stem per plant. In addition, two leaves were removed from each stem. Either one leaf, with three leaflets, or three stem pieces were placed in a Petri dish. The leaves were placed adaxial surface uppermost and on damp paper tissue to maintain a high relative humidity. The leaflets and stem sections were challenged with 50, 250 or 1000 sporangia of *P. infestans* in a 20 µl droplet of water and the sealed dishes placed in a growth cabinet at 15°C with a daylength of 16 hours. There were 60 leaflets or stem pieces for each cultivar. Seven days after inoculation each leaflet was assessed for a sporulating blight lesion. The stem pieces were similarly assessed but 2 days later because stem lesions developed more slowly. This experiment was repeated once, approximately 2 weeks later. The same method was used except that the inoculum concentrations were 10, 50 and 250 sporangia per inoculation site.

Cultivar resistance to leaf and stem blight, field experiment: Seed tubers of six of the eight cultivars, P. Hawk and P. Javelin were not included, were planted in pots containing Leving-

ton compost and the plants produced were transplanted from the glasshouse to a field site at Auchincruive *c.* 3 weeks later on 10 July 1996. The field experiment was arranged as a randomised complete block with four replicate blocks, each containing a row of five plants of each cultivar. Three weeks after transplanting, each plant was sprayed from above with c. 4 ml of *P. infestans* suspension containing 2.5×10^4 sporangia per ml. High humidity at each inoculation site was achieved by enclosing the foliage in a polythene bag for 48 hours.

Foliar and stem blight and the potential production of sporangia were recorded twice. Sporangia production was assessed using four replicate lots of five stems per cultivar, incubated at c.20°C in a relative humidity close to 100% for 48 hours. Six counts of the sporangia washed from either 10 leaves or five stems with sterile distilled water were carried out using a haemocytometer slide. In order that sporangia production could be expressed as the number of sporangia per unit area of lesion, the area of all stem lesions in the sample was measured using a transparent grid of known area. The areas of foliar lesions were calculated from the percentage of leaf area that was blighted and leaf area measurements. This experiment was repeated once using the same procedure but three assessments were made. A similar, third, experiment was carried out at a different site but the plants were grown from seed tubers planted directly in the field and the inoculation process was more natural because inoculum was introduced from inoculated infector plants located close to the experimental plots. In the third experiment, only five of the six cultivars were used, Desiree was omitted, and no assessments of sporangia production were made.

Statistical analysis: Analyses of variance and regression analyses were carried out using Genstat 5. Where data were transformed prior to analysis this is indicated in the results table.

Results

Cultivar resistance to leaf and stem blight, laboratory experiment: Leaflets were generally more susceptible to infection by *P. infestans* than stem tissue and for three of the cultivars, K. Edward, P. Javelin and P. Hawk, differences were significant (Table 1). Only for M. Piper was stem infection greater than leaflet infection but this was not significant. The cultivar resistance of detached stems was closely related to that of leaflets (r=0.91, *P*=0.001).

Cultivar resistance to leaf and stem blight, field experiment: When six of the eight cultivars

were grown and spray inoculated in the field the resistance to lesion development for leaves and stems was not correlated (Table 2). In particular, the severity of stem blight on P. Squire was much greater than expected from its susceptibility to foliar blight. Similar results were obtained in the two other field experiments (data not presented). The results obtained with the spray inoculation and infector inoculation techniques were consistent.

Table 1. The susceptibility to infection by *P. infestans* of detached leaflets and stem tissue of eight potato cultivars (mean values of two experiments).

Cultivar	Incidence (%[1]) of infection	
	Leaflet	Stem
K. Edward	77.5	60.0
R. Burbank	76.7	69.2
P. Javelin	69.2	53.3
P. Squire	64.2	53.3
M. Piper	63.3	75.0
Desiree	60.8	50.0
P. Hawk	45.8	29.2
Brodick	15.0	3.3
LSD (*P*=0.05)	14.9	
Mean	59.1	49.2
LSD (*P*=0.05)	5.1	

[1] angular transformation

Table 2. Severity (%) of leaf and stem blight for six cultivars grown in the field.

Cultivar	Leaf	Stem
R. Burbank	81	4
K. Edward	52	13
M. Piper	64	3
P. Squire	54	44
Desiree	49	3
Brodick	1	0
LSD (*P*=0.05)	9.0	6.0

The potential for sporangia production per cm^2 of leaf lesion was greatest during the early phase of the epidemic, i.e. 11 or 12 days after inoculation, and was significantly lower as the

epidemic developed (Table 3). For all cultivars, except Brodick in experiment 1, the number of sporangia produced declined as the severity of blight in the plots increased. Significant reductions occurred for R. Burbank and P. Squire in experiment 1 and M. Piper, P. Squire and Brodick in experiment 2 (data not presented). In contrast, the number of sporangia collected from stem lesions increased slightly at the second assessment in both experiments and the only significant reduction in sporulation occurred 32 days after inoculation in experiment 2. For most cultivars sporangia production did not decline significantly, the exceptions were K. Edward and P. Squire in the second experiment (data not presented).

Table 3. Number of sporangia produced per cm^2 of leaf and stem lesions (mean values of six cultivars).

	Experiment 1		Experiment 2			LSD ($P=0.05$)
	Days after inoculation					
	11	19	12	21	32	
Leaf	114.7	73.7	151.2	121.2	84.9	
Stem	118.1	134.3	165.0	166.5	136.0	18.2
	Disease progress (% foliar blight)					
K. Edward	18.0	92.0	6.0	80.0	100.0	-
Brodick	0.6	1.0	0.9	1.0	3.0	-

For most cultivars significantly more sporangia were produced per unit area of stem than of leaf lesion (Table 4). Sporangia production on the stems of the six cultivars was not related to the numbers produced on leaves. Overall, significantly more sporangia were collected from Brodick leaves than any other cultivar except P. Squire. Significantly more sporangia were obtained from M. Piper stems than from the other five cultivars. There was a negative correlation (r=0.83, P=0.026) between the severity of leaf blight and the number of sporangia collected from the different cultivars (Tables 2 and 4). The number of sporangia produced on stems was not related to the severity of stem blight.

Table 4. Number of sporangia produced per cm^2 of leaf and stem lesions in relation to cultivar (mean values of experiments 1 and 2).

Cultivar	Leaf	Stem
R.Burbank	97.8	140.0
K. Edward	109.0	129.2
M. Piper	111.0	190.1
P. Squire	125.2	128.9
Desiree	102.7	131.6
Brodick	141.9	112.8
LSD (*P*=0.05)	18.2	

Discussion

The poor correlation between cultivar resistance to leaf and stem blight in the field suggests that potato breeders should screen separately for resistance to foliar and stem blight to accurately assess the resistance of clones. If this is not practical then a compromise combined assessment of foliar and stem blight should be made rather than one of foliar blight alone. It may also be necessary to assess the severity of both foliar and stem blight where estimates of the quantity of inoculum available for new infections of the haulm or tubers are required. Failure to do this could lead to misleading results, especially for cultivars such as P. Squire.

It could be argued that because both stems and tubers are modified stolons, cultivar resistance to stem blight may be closely related to tuber resistance, which is already assessed by breeders. However, the estimates of resistance to stem blight obtained for the six cultivars were not related to their NIAB ratings for tuber blight resistance (Anon., 1993).

It is difficult to quantify the relative importance of leaf and stem lesions as sources of inoculum for the spread of haulm blight. Which of the two is more important will depend mainly on the relative occurrence of both types of haulm blight, which will be affected by cultivar and the stage of the epidemic. However, it is clear that as the severity of blight on a plant increases, stem lesions will become relatively more important primarily because colonised leaves, unlike stems, cease supporting sporulation within a relatively short time of colonisation, due to tissue necrosis or leaf abscission. The relative importance of leaf and stem lesions as sources of inoculum is likely to differ for progeny tuber and haulm infection because of the relative ease with which inoculum produced on stem lesions, compared with leaf lesions, can reach progeny tubers (Lacey, 1967; Lapwood, 1966).

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Sexual reproduction of *Phytophthora infestans*
on potato in Sweden

B. ANDERSSON[1], M. SANDSTRÖM[1] & A. STRÖMBERG[2]

[1] Dept. of Applied Plant Protection, Swedish University of Agricultural Sciences, Uppsala,

Sweden

[2] Dept. of Cell Research, Swedish University of Agricultural Sciences, Uppsala, Sweden

Introduction

Phytophthora infestans (Mont.) de Bary, the causal agent of potato late blight, was first discovered in Europe in 1845. Until the 1980's, only isolates of the A1 mating types were known to occur in Europe. The absence of A2 mating type isolates restrained the fungus from sexual reproduction. In 1984, A2 mating type isolates were discovered in Switzerland (Hohl *et.al*), and in 1987 it was discovered in Sweden (Kadir & Umaerus 1987). Sexual reproduction means enhanced ability to exchange and rearrange genetic material. Furthermore, sexual reproduction results in the formation of oospores, (resting structures with thick walls) which gives the fungus a possibility to survive adverse climatic conditions and long-time survival in soil.

In this paper, we present observations of sexual reproduction of *P.infestans* in a naturally infected potato crop in Sweden.

Background and observations
1994

In 1994, a potato field trial located at Uppsala, Sweden was inoculated with field isolates of *Phytophthora infestans* on two separate occasions. The first inoculation was made on August 10 by planting infected plants taken from the south of Sweden (Kristianstad). At the second inoculation on August 17, a suspension of sporangia (10^4 sporangia per ml) was sprayed on

healthy plants. The inoculated plants were covered with plastic bags over night to ensure favourable condition for infection. The isolate used for this second inoculation was taken from an allotment garden in Uppsala and propagated on potato slices. On both occasions, the inoculations were done in a grid pattern to give an even infection pressure. The field was treated with different dosages of Shirlan (fluazinam). The aim of the trial in 1994 was to study the effect on late blight of different dosages of fungicides. The first fungicide application was done before inoculation. A thorough assessment of the amount of disease was made in a pattern of one meter by four rows.

The weather was favourable for late blight, and the disease spread quickly from the points of inoculation. In the beginning of September, all the crop that had been left untreated or had been treated with very low dosages was infected. At the end of September, the haulm in these areas of the field had been destroyed by late blight. In the areas treated with higher dosages there were no or very light attacks. Fifty percent of the tubers were infected in the areas with heavy attacks on the haulm, whereas in the areas with low attacks only one percent infected tubers were found. Due to wet weather and the high amounts of tuber infection, the crop was left in the field without harvesting. The field was later treated first with a rotary cultivator and after the first frost, the field was plowed.

1995

In 1995, a cereal crop was grown on the field. The field was checked for volunteer potato plants in the spring and summer of 1995, but no over wintering plants were found.

1996

On June 7, 1996, a similar potato trial was planted in the same place. The trial overlapped most of the area of the trial in 1994 (see figure 1). The cultivars Bintje and Matilda were planted. The weather was unusually cold and wet in the spring and there were very high amounts of rain between planting and crop emergence, especially during the week of emergence. The rest of the season was unusually dry and hot. Crop emergence occurred in the first days of July, and on July 19 infections of late blight could be found all over the part of the field planted with Bintje. In some parts of the field, all plants were killed by late blight. These areas were located at the same places within the trial as the heavily infected areas in 1994 (figure 1). The cultivar Matilda with a higher resistance for late blight was also infected, but

at a later date. Most of the symptoms were found on the stems with very few lesions on the leaves. Samples of dried haulm were examined for occurrence of oospores. Five to ten stems from each sample were first soaked in water for two days and then cut to pieces and treated in a household blender (Tur-mix) at high speed for 2-3 minutes. A total 150 µl of the solution was examined under a light microscope looking for oospores. These samples of haulm (18 in total) were collected in a matrix pattern in the trial. Both treated places with low amount of disease and untreated places with high amounts of disease were sampled. In all the samples of dried haulm only one oospore was found. The number of infected tubers was low.

Figure 1. Areal photo of the potato trial at Ultuna 1996 showing areas of potato heavily attacked by late blight. Dotted line shows the location of the trial in 1994. The attacked areas in 1996 corresponds closely to where severe attacks were observed in 1994.

1997

In 1997, half of the area that was used in 1996 was planted with the cultivars Bintje and Matilda. The planting was done on 2 June. Half of the trial was irrigated between planting and emergence to ensure high soil humidity. At plant emergence the plants were studied one by one. The first plants with symptoms of late blight were taken into the laboratory and the

seed tubers were sliced and kept in a moist chamber to check for infection. During this period (24 June to 10 July) ca. 25 isolates of *P. infestans* were collected from the field for mating type investigations.

Figure 2. An oospore of *Phytophthora infestans* found in a potato plant from a potato trial at Ultuna, Sweden 1997.

All work with isolation and mating type testing was performed on 90 mm. petri dishes on rye agar with fungicide. The cultures were isolated from stems and leaves and incubated at a temperature of 17 °C in darkness. Cultures CBS 430.90 (mating type A1) and CBS 429.90 (mating type A2) from CBS (Centraalbureau voor Schimmelcultures) in Baarn, Holland were used to determine mating type. This was done by inoculating the unknown isolates on different agar plates together with an A1 and an A2 isolate from CBS. After ten days oospore formation was determined. The unknown isolates where considered the opposite mating type of that with which it produced oospores.

On June 24 the first plant with symptoms of late blight was found. This plant had probably been infected before emergence. On June 27 a second infected plant was found and the week after that infected plants where found in many places. The first two infected plants sprouted from healthy tubers. Most of the symptoms were found on the stems with very few lesions on the leaves. Both mating types A1 and A2 were found among the isolates that were collected from the field. July 28 the first oospores were detected (figure 2). They were found in tissue above ground, in leaves and stem in areas of the field where the attacks started early.

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Blight forecast and chemical control in Finland

A. HANNUKKALA

Agricultural Research Centre (MTT),

Institute of Plant Protection

FIN- 31600 Jokioinen, Finland

Abstract

Blight forecast in Finland is based on NEGFRY system tested and partly developed in Nordic collaboration. Cumulative risk values in 1997 were calculated using weather data from 25 meteorological stations maintained by the Finnish Meteorological Institute. The forecast was distributed through internet and printed in local agricultural newspaper in July and August. Chemical blight control has been based on maneb, mancozeb and metalaxyl + mankozeb. In the average 3-5 applications of fungicide are needed in Finnish conditions to control late blight. As a result of excessive use of metalaxyl- product, majority of *P. infestans* strains were insensitive to the fungicide in the beginning of 1990's. Propamocarb-HCl + mancozeb, fluazinam and dimetomorf + mancozeb were recently registered for blight control. In 1995-97 the proportion of metalaxyl resistant strains had diminished. Metalaxyl fungicides gave excellent control of blight in 1997.

Key words: *Phytophthora infestans*, late blight, chemical control, NEGFRY

Introduction

Potato is grown on 35 000 hectares in Finland. The potato growing area has been very stable for last three years. Potato is grown throughout the country for home consumption. The professional production is concentrated along the western coast of the Gulf of Bothnia. Early potato is produced in the southernmost areas, often under plastic cover. Potato for processing industry is grown in central and seed potato in the northern parts of the potato region. Organic

potato is grown mainly in eastern parts of southern Finland.

Late blight is a serious problem on potato production. The epidemic usually starts in the end of July in southern and in the end of August in the northern regions. Naturally there is considerable variation in the onset of the epidemic between years and regions (Seppänen 1971, Hannukkala 1997a).

Chemical blight control is normal practice in professional potato production, but practically no fungicides are used in home gardens. In northern climate blight risk is relatively low. Usually 3-5 applications are needed to control blight. Under heavy disease pressure during rainy and warm summers susceptible cultivars must be sprayed up to 7-8 times (Hannukkala 1997a).

The blight control used to based totally on mancozeb (Dithane DG), maneb (Maneba) and mixture of metalxyl and mancozeb (Ridomil MZ). The mixture of metalaxyl and mancozeb (Ridomil MZ) was registered for late blight control in 1985 (Hynninen and Blomqvist 1997). Although metalaxyl resistance risk had been recognised, many farmers used Ridomil MZ curatively and did not use any other products in their spraying program. Consequently blight population had become totally resistant to metalaxyl by the beginning of 1990's. An anti-resistance strategy campaign was then initiated. (Kankila et al. 1995, Hannukkala 1997b). Also new systemic and translaminar fungicides have been registered for blight control (Hynninen and Blomqvist 1997).

Table 1. Fungicides registered for potato late blight control in 1997 in Finland.

Active ingredient	Commercial product	Waiting period	Dosage	Registered
Fluazinam	Shirlan	7 d	0.4 l/ha	1996
Copperoxychloride	Kuprijauhe	1 d	5-8 kg/ha	<1980
Mancozeb	Dithane DG	21 d	2 kg/ha	<1980
Mancozeb+metalaxyl	Ridomil MZ	21 d	2.5 kg/ha	1985
Mancozeb+propamocarb-HCL	Tattoo	21 d	4 l/ha	1995
Mancozeb+dimetomorf	Acrobat MZ	21 d	2 kg/ha	1997
Tolylfluanide	Euparen M	14 d	1.5- 2 kg/ha	1993

In Scandinavia there has been a public demand to reduce use of fungicides. Late blight warning and forecasting systems have been intensively developed (Hansen et al. 1995, Kaukoranta et al. 1993).

The blight forecast and warning system in Finland is based on NEGFRY- system (Hansen 1997). Negative prognosis is used to estimate the risks of primary attacks (Ullrich & Schrödter 1966) and the timing of subsequent fungicide applications is based on model of Fry et al. (1983). The validity of NEGFRY system has been tested in all Scandinavian countries and the results indicate that the number of fungicide treatments can be reduced considerably (Hansen et al. 1995).

Materials and methods

The NEGFRY prognosis in 1997 was run on meteorological data obtained from 25 synoptic weather stations maintained by the Finnish Meteorological Institute. The measurements were done at three hour's intervals, and the data was transferred through network to the central computer unit of the Agricultural Research Centre every 24 hour.

The weather data was checked manually for missing observations and other inaccuracies. The blight warning was updated only twice a week due to time consuming manual work before running NEGFRY- program. Running the NEGFRY will be automatised for the next season.

The negative prognosis was validated for 10 weather stations, which are situated close to Research Stations of Agricultural Research Centre. The appearance of first blight symptoms was surveyed from unsprayed potato plots (cv. Bintje). In addition there was one field trial, where fungicides were sprayed according to NEGFRY- system using HARDI metpole as the source of weather data (Hansen 1997).

The efficacy of fungicides, mancozeb (Dithane DG), metalaxyl + mancozeb (Ridomil MZ), propamocarb + mancozeb (Tattoo), dimetomorf + mancozeb (Acrobat) and fluazinam (Shirlan) was compared in a field trial. The trial was managed according to standard fungicide trial procedures in Finland (Kurtto et al. 1996).

The application programs were

1.)   4x Dithane + Shirlan (7-10 day's intervals)

2.-3.) 2 x Ridomil MZ + 2-3x Shirlan (7-10 and 10-14 day's intervals)

4.-5.) 2 x Tattoo + 2-3x Shirlan (7-10 and 10-14 day's intervals)

6.-7.) 2 x Acrobat MZ + 2-3x Shirlan (7-10 and 10-14 day's intervals)

8.)   4x Shirlan (10-14 day's intervals)

First fungicide application in all programs was done at 16.7. The occurrence of leaf blight was observed 2-3 times a week by estimating percentage of leaf area infected. Tuber blight was assessed after harvest as percentage of diseased tubers.

Results and discussion

The blight prognosis in 1997 was distributed through Finnish agricultural network, Agronet (http://www.agronet.fi; direct address to forecast: http://www.mtt.fi/ksl/ajankohtaista/ rutto-ennuste.html). The cumulative NEGFRY risk value was shown on map as figures and symbols indicating location of each weather station. The map was also printed every Saturday in agricultural newspaper ('Maaseudun tulevaisuus'; circulation 100 000 copies) in July and August.

In 1997 the blight risk accumulated in southern Finland somewhat faster than in 1996. In northern Finland the risk accumulation was considerably faster than in 1995 or in 1996 (Fig. 1). Negative prognosis did underestimate the blight risk at certain locations especially in southern Finland. Blight was observed when the cumulative risk value was 140-150 though no blight should be present before the cumulative risk value reaches 150 points.

Figure 1. Cumulative blight risk values run by NEGFRY- model in southern and northern Finland in 1995-1997.
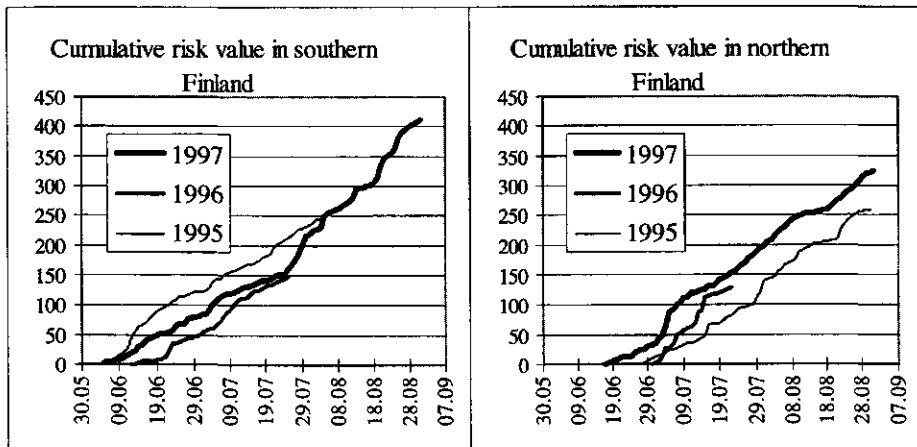
The failure of the prognosis is probably due to the difference in the micro climate between weather stations and observation fields. Therefore it is important in future to improve the

quality of weather data.

In fungicide efficacy trials leaf blight was found at the end of the season in all fungicide programs. First symptoms were found in Dithane/Shirlan program ten days after first fungicide application. The epidemic spread very fast after 10.8. and 80% of the foliage was destroyed at he end of the season. Potato yield was considerably lower than in other treatments. In spite of heavy leaf blight no tuber blight was observed after harvest.

Programs Started with Tattoo or Acrobat tended to fail at the end of the season. First blight lesions were observed 28.7. The disease progress remained slow until 20.8 where after disease increased rapidly and in the end 50-70% of the foliage was killed.

Programs started with Ridomil and the program with Shirlan alone gave the best control of leaf blight. First blight lesions were observed 10.8. and the disease progress was slow until 28.8. In the end of season 30-40% of foliage was destroyed. Also the yields were highest after these programs, though they were not statistically significantly higher than in programs started with Tattoo or Acrobat (Figure 2).

Figure 2. The effect of different fungicide application programs on potato yield and leaf blight expressed as the area under disease progress curve (AUDPC) on cv. Bintje in 1997. Bars indicated with the same letter do not differ statistically (TUKEY- test; 5% confidence level).
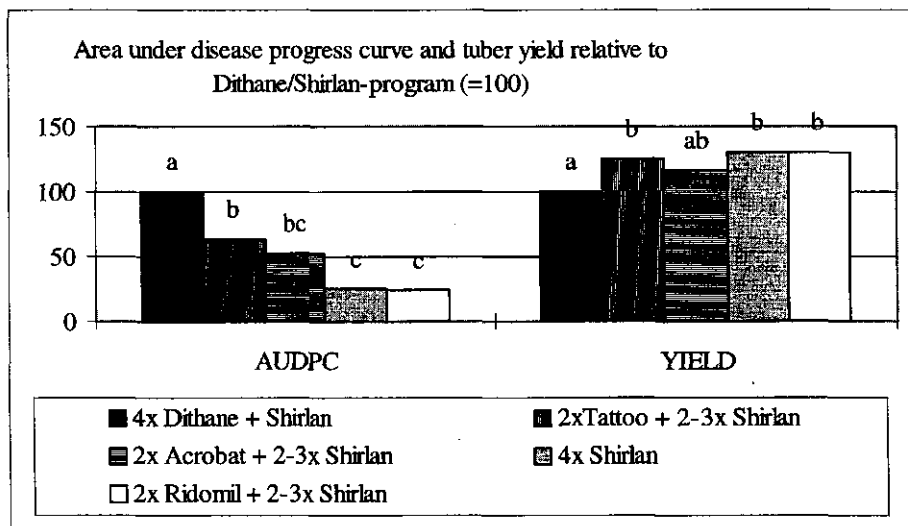
Conclusions

NEGFRY- system gives a reasonable estimate of blight risk in Finland. Improvements in the quality of weather data, further automatisation in data control and running the model are needed. Scandinavian collaboration has started to create a Scandinavian data bank for crop protection and disease warning systems in internet.

New fungicides Tattoo, Acrobat and Shirlan are effective in blight control compared to Dithane. Ridomil still gives excellent control if metalaxyl insensitive strains are not dominating. Further studies are needed to adjust optimal timing of applications in blight control.

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Second Workshop of an European Network for Development of[7]
an Integrated Control Strategy of potato late blight
Carlow, Ireland, 24 - 27 September 1997

Usage of model SIMPHYT in frame of the project PASO
in Germany from 1994 to 1997

V. GUTSCHE

Federal Biological Research Centre for Agriculture and Forestry,

Stahnsdorfer Damm 81,D-14532 Kleinmachow, Germany

Model structure of SIMPHYT 1 and 2

The prediction model consists of two parts. SIMPHYT 1 starts with the emergence of potatoes and calculates the outbreak of epidemics for two risk groups, predicting it 8 days ahead. SIMPHYT 2 starts with the beginning of the higher risk group and simulates the further course of the epidemic, as needed for the model to determine an optimal fungicide strategy (interval between two sprays, choice of optimal fungicide group). If dry periods occur during a late blight outbreak, the model recommends to interrupt spraying and determines the date for starting spraying again.

Figure 1 shows the structure of model SIMPHYT 1. When the potatoes emerge, the permanent inoculum generator of the model is switched on. At intervals of 3 h, it supplies the model with a very small rate of inoculum. The amount of this inoculum depends on the following parameters:

(1) a classification of the precipitation of the last two weeks on the basis of the corresponding longterm mean;

(2) an assignment of general inoculum into one of 2 classes, on the basis of late blight infection of planting material or late blight infection of the previous year;

(3) a so-called regional factor

Interval by interval, the primary inoculum fills the model compartment 'primarily latent'. Its duration in the compartment is calculated via a temperature function. Having reached a cer-

tain age, the inoculum goes over to model compartment 'primarily infectious'. Its duration there is also calculated via a temperature function. Having reached a certain age, its value falls back to 0.

Figure 1. **The structure of model SIMPHYT I.**

Basic structure SIMPHYT I
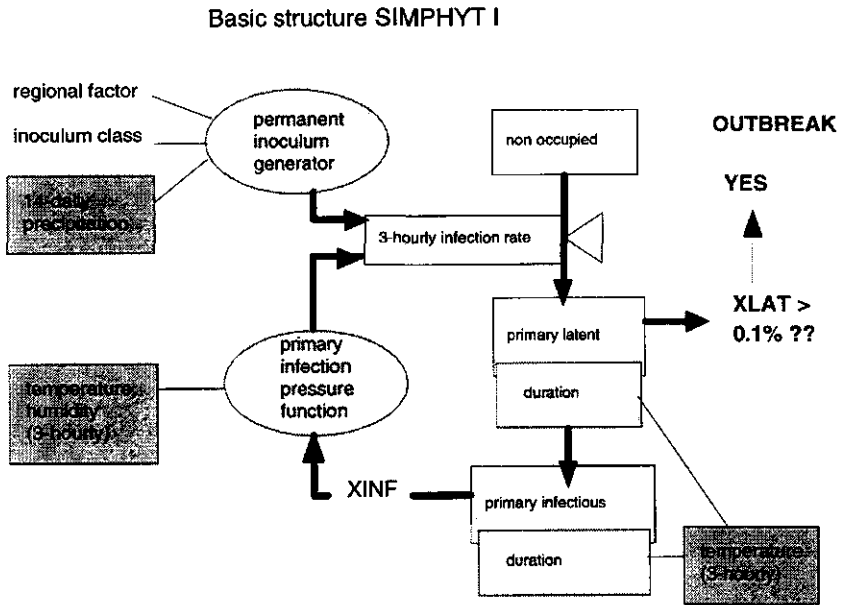
As long as it remains in compartment 'primarily infectious', the inoculum can cause primary infections. The primary infection rate depends on temperature, relative humidity and of course the quantity (XINF) of inoculum existing at that time in the compartment 'primarily infectious'. Consequently, the model compartment 'primarily latent' is fed by two sources: a permanent inoculum rate and a primary infection rate which can be of value 0 depending on temperature and relative humidity. If the content (XLAT) of the compartment 'primarily latent' exceeds value 0.1, the model predicts the outbreak of an epidemic.

Figure 2 shows the structure of model SIMPHYT 2. At the beginning of model calculation, the compartment 'latent leaflets' is filled with disease incidence 0.1%. Inoculum rates are evenly distributed over the age groups. The development function calculates, depending on temperature, the holding time and generates a flux of infected leaflets through the age groups. Having reached the last age group, the leaflets go over to model compartment 'infectious

leaflets'. Again, a development function controls the flux through the age groups. Having reached the last age group, the leaflets are set to 0.

Figure 2. The structure of model SIMPHYT II.
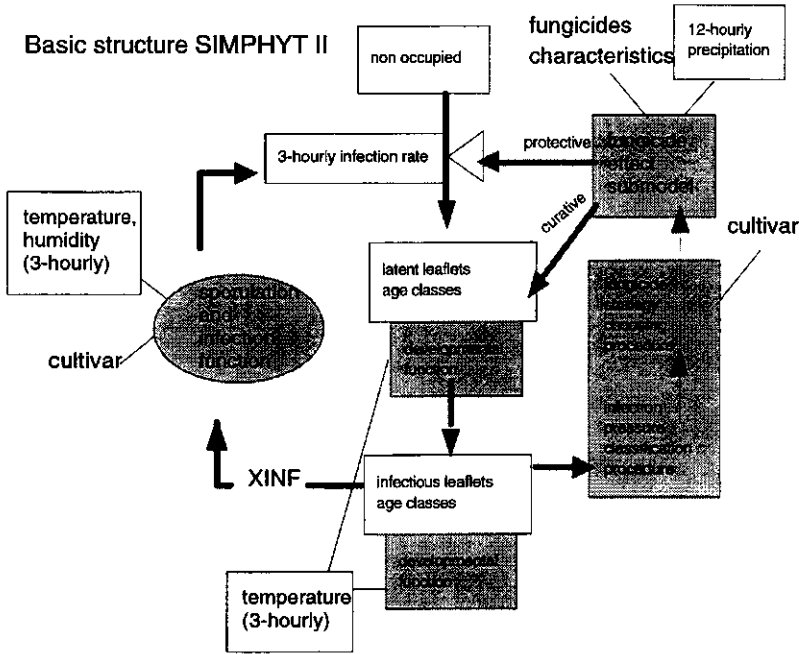
The model calculates for each age group of the compartment 'infectious leaflets' a so-called 'reinfection rate'. It depends on temperature, relative humidity, cultivar and the age group itself (quantity and age reached). The parameters of the sporulation and infection function were assessed partially on the basis of catch crop experiments in the field, partially on the basis of climate-chamber experiments. The function determines according to the intervals a balance of sporulation and infection.

To determine the optimal fungicide strategy, the contents of compartment 'infectious leaflets' (XINF) are analysed. The infection pressure is assigned to one of 4 classes (see table 1)
A day is regarded as a dry day if SIMPHYT 2 calculates for it a reinfection rate of 0.

Depending on this classification of infection pressure, potato cultivar and additional information for the region (see table 1), the procedure chooses the appropriate fungicide group and

the optimum interval after the preceding application. In case of at last 7 dry days the model recommends to interrupt spraying. The fungicide submodel contains the characteristics of the fungicide groups with respect to protective and curative efficiency. Furthermore, each group has a spray deposit by rain. Consequently , model SIMPHYT 2 does not only choose the optimal fungicide strategy, but also simulates its effect on the course of epidemics.

Results

The model SIMPHYT was checked in frame of the project PASO supported by the German Federal Ministry for Food, Agriculture and Forestry. 10 Bundesländer took part in this project. In 1994 56 field trials were investigated, in 1994 86 field trials, in 1996 87 field trials and in 1997 89 field trials.

The results of SIMPHYT 1 obtained in 1994-1996 is shown in figure 3.

Figure 3.   The results of SIMPHYT 1 obtained in 1994-1996.

SIMPHYT I
correct forecast of epidemic start of Phytophthora*

* prognosticated date before or at the same date of first occurence of Phytophthora in region

(n: number of observations)
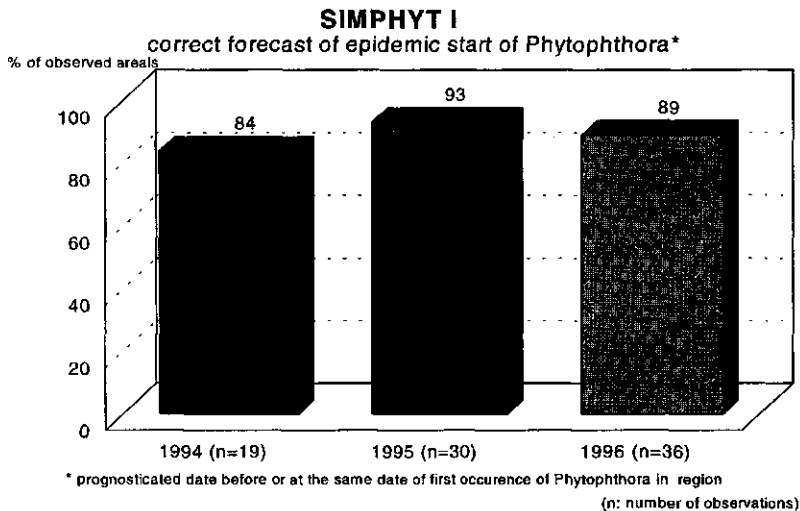
Figure 4.   The results of SIMPHYT 1 obtained in 1994-1996, analysed more in detail.

SIMPHYT I
forecast of epidemic start
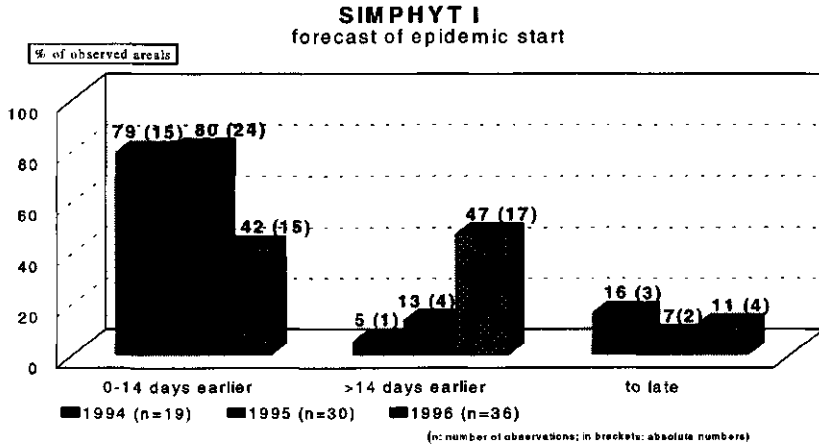
The reasons of the wrong predictions (to late forecastings) were the following:

1. The weather station used by the model did not represent the conditions of the region.

2. There were to much fields under foil in the region. They caused a higher inoculum pressure than assumed by the model.

3. There were to much fields under irrigation in the region. They also caused a higher inoculum than proposed by the model.

Figure 5.   Results of the second part of the forecasting system SIMPHYT for the years 1994 - 1996.

SIMPHYT II
number of treatments
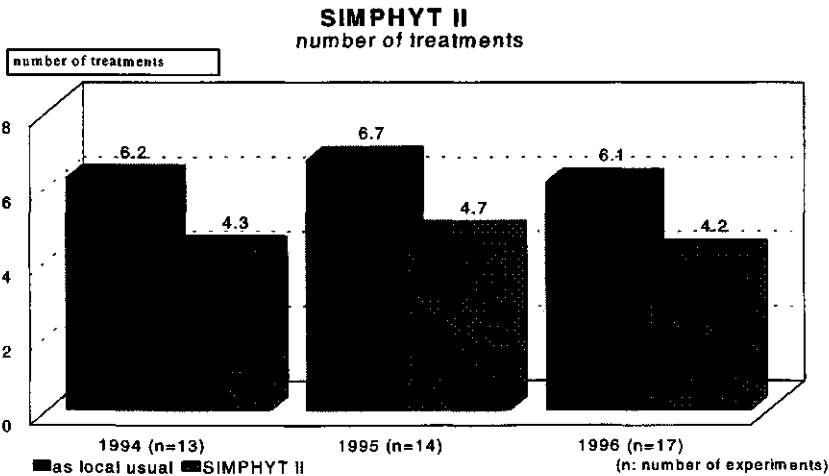
It is obviously to see that the fields managed by the SIMPHYT system are about two times less treated with fungicides against *Phytophthora inf.* in comparison with the local usual number of treatments.

This lower number of treatments, however, did not lead to a higher infestation by the disease as shown in figure 6.

Figure 6. **Percentage of infested leaflets before harvest.**
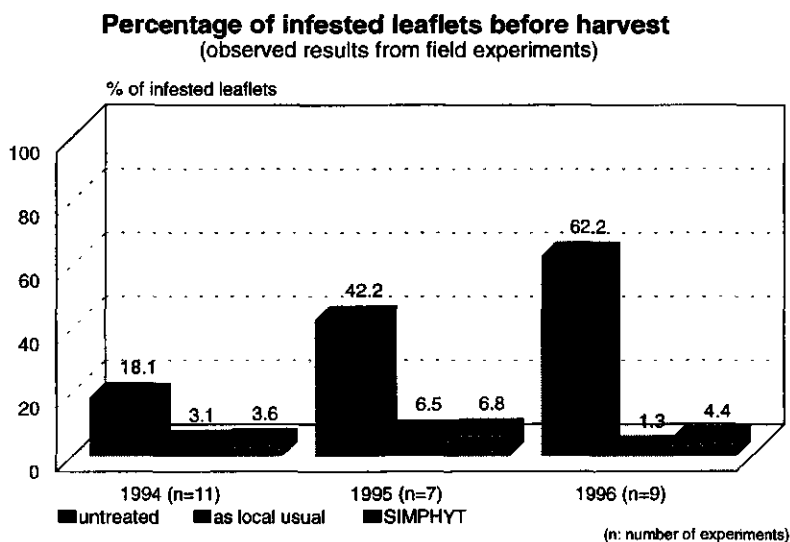
In 1997 the model SIMPHYT 1 gave not so well results. In some regions (mainly in the northern part of Germany) the predicted outbreak of the epidemic was to late. In these regions very heavy rainfalls happened in June. Often the fields were under water for some days. Immediately after this period a lot of primary attacked plants were observed in the fields. There were no single small patches as it is typical for the „normal" outbreak of the epidemic.

In total SIMPHYT 1 failed in about 25% of the cases in 1997. In opposite, Simphyt 2 worked well also in 1997.

The conclusion is, that SIMPHYT 1 needs a further improvement to manage such situation as in 1997. Long heavy rainfall events will better be taken into account by the model in future.

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Second Workshop of an European Network for Development of[1]
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Discussion on validity of decision support system

for potato late blight in Wallonia

J-L. ROLOT (*), D. MICHELANTE (*), A. VERLAINE (**)

(*) Assistant, CRAGx, Station de Haute Belgique,
Rue du Serpont 100, B-6800 Libramont, Belgium
(**) Agricultural scientist, asbl pameseb, Station de Haute Belgique,
Rue du Serpont 100, B-6800 Libramont, Belgium

Abstract

The Station de Haute Belgique in Wallonia (Belgium) warning service makes use of disease forecasting model of Guntz-Divoux. The basic principle of blight control consists of spraying before the emergence of lesions of a previous infection. The Station de Haute Belgique employs a network of 30 automatical weather stations. In 1996, the number of sprays were reduced by 3-4 compared to routine treatments. In 1997, a year particularly favourable to blight, 1-3 have been reduced.

Keywords : warning, potato, late blight, fungicides, agrometeorological stations

Introduction

The phytophthora warning set up by the Station de Haute Belgique is based upon the method worked oud by Guntz and Divoux and adjusted to the particular conditions of the Station. The elements taken into account simultaneously are: temperature, hygrometry, added up pluviometry, former infection conditions and plant phenology.

This paper presents results about late blight warning in 1996, a year unfavourable to the disease and 1997, a year particularly favourable to the blight.

Operation of the warning service in 1996 and 1997

Near of 75% of potato areas is cultivated with the variety Bintje. These variety is very susceptible to Late Blight for leaves and tubers. The others main cultivars are Nicola, Charlotte

and Désirée with reduced susceptibility to the disease.

Situation of potato in Wallonia

Tabel 1. Areas cropped by potato.

	Early		Bintje		Others		Total	
	ha	%	ha	%	ha	%	ha	%
Consumption	968	5	13763	73	3183	17	17914	95
Plants					953	5	953	5
Total Wallonia							18867	100
Belgium	9593		39252		7001		55846	

Average yield : Early cultivars= 32 to/ha Others= 39 to/ha

Tabel 2. Susceptibility of cultivars.

	% Area	Leaves	Tubers
Bintje	+/- 70%	3	3
Désirée		6	7
Nicola		5	8
Charlotte		6	8

(2 : very susceptible - 9 : very good resistance)

Climatological summary of the year

Climatological parameters

Monthly total precipitation at Uccle (mm)

Figure 1. Normal and absolute extremes from 1833 (IRM : Institut Royal Météorologique).
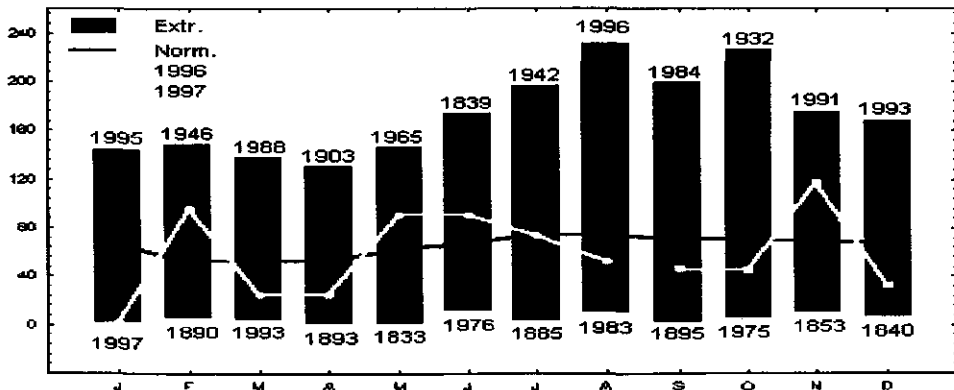
Monthly mean of air temperature at Uccle (°C)

Figure 2. Normal and absolute extremes from 1833 (IRM : Institut Royal Météorologique).
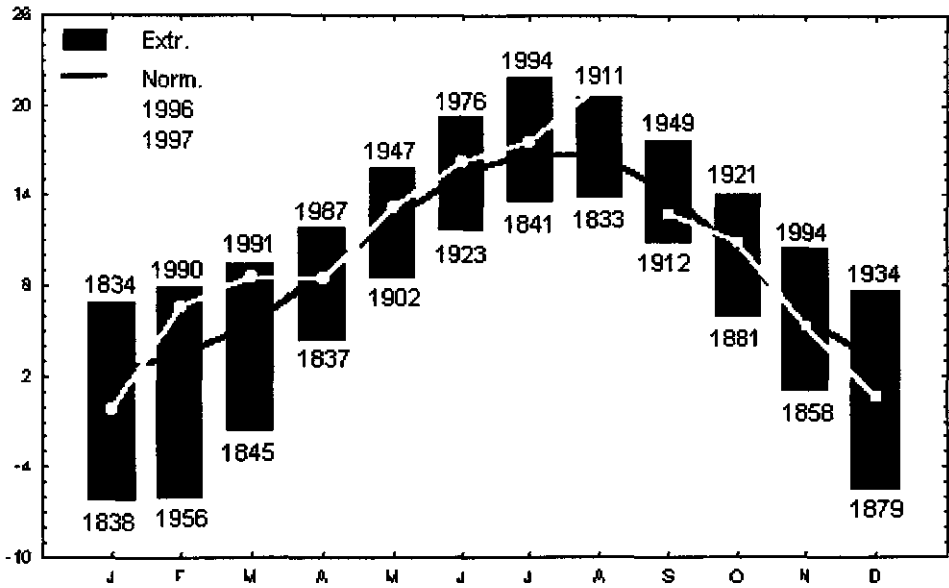
1996

The first trimester was colder than average and there was a long period of weak pluviometries. April was warmer allowing a good plantation. The dry period we knew since October 1995 was interrupted by exceptional downfalls in the second half of August.

Tabel 3. Monthly total precipitation and average monthly temperature for Libramont.

	apr-96	may-96	jun-96	jul-97	aug-96	sep-96
Rain	18	76	46	68	148	28
Number of day	7	21	9	13	17	13
Average T°	8,2	9,2	14,5	14,6	15,6	10,6

Tabel 4. Monthly total precipitation and average monthly temperature for Sombreffe.

	apr-96	may-96	jun-96	jul-97	aug-96	sep-96
Rain	7	38	24	34	241	25
Number of day	6	18	11	12	13	13
Average T°	9,5	10,2	15,5	16,2	16,7	11,8

1997

The beginning of the season (March-April) was relatively warm and dry allowing a good start of growth of cultures. May and June were marked by a strong pluviometry, particularly in the south of the country, with an exception from the 22/5 to the 6/6. These rains, often stormy, continued for some time in July but at a reduce rate; they completely stopped on the third of August. Then, they were followed by three weeks of hot weather with very high temperatures. At the end of August, beginning of September, the rain was back.

Tabel 5. Monthly total precipitation and average monthly temperature for Libramont.

	apr-97	may-97	jun-97	jul-97	aug-97	sep-97
Rain	46	138	210	76	54	
Number of day	11	15	23	15	12	
Average T°	6,2	11,5	14,1	15,7	19,4	

Tabel 6. Monthly total precipitation and average monthly temperature for Sombreffe.

	apr-97	may-97	jun-97	jul-97	aug-97	sep-97
Rain	26	90	71	53	53	
Number of day	12	13	20	19	10	
Average T°	7,9	12,8	15,6	17,1	20,8	

The late blight warnings

PAMESEB weather stations network in Wallonia

In Wallonia, almost 90% of potatoes areas are located in the loamy region in which there are 10 weather stations with an average range of 12 km.

Régions	Total area	Cropped area	Area cropped with potatoes (1995) ha	%	Number of stations	Total area per station (ha/Poste)	Average range (km/poste)
Royaume	3051871	1368136	57416	4,2			
Wallonie	1684550	748698	18867	2,5	30		
Flandre	1351143	618929	38545	6,2			
Limoneuse	481000	329398	16857	5,1	10	48100	12
Condroz	265200	133977	1430	1,1	5	53040	13
Famenne	163000	61871	178	0,3	4	40750	11
Ardenne	435800	132234	349	0,3	7	62257	14
Gaume	102900	30717	166	0,5	4	25725	9

PAMESEB network

Automatic network

- Places where Pameseb stations are to be found

Potato Late Bligt Warning Service
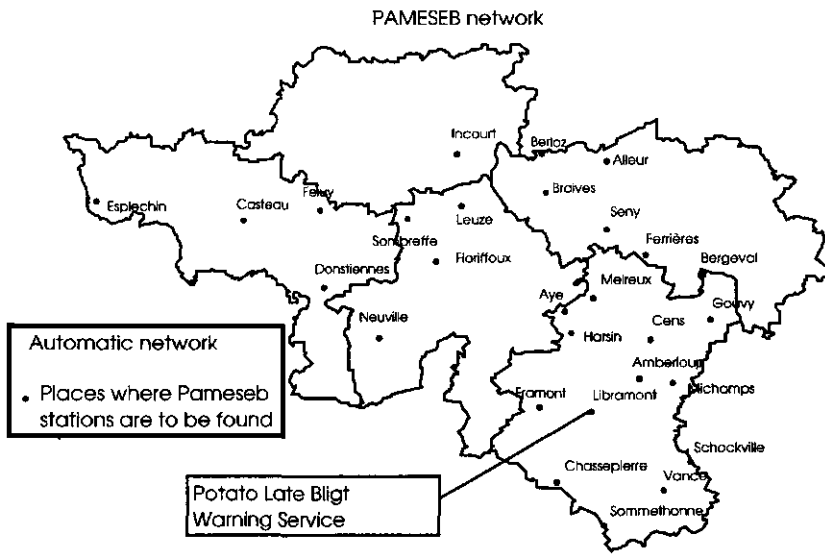
Tabel 7. General overview of activities.

	1993	1994	1995	1996	1997
Number of recommendation for treatment					
Sablo-limoneuse	7	8	7	8->9	10->11
Condroz	7	8	7	8	10
Famenne	8	8	7	7->8	9->10
Ardenne	7	9	10	7	9->10
Gaume	7	9	9	7	9->10
Number of systematic treatments	11->13	11->13	11->13	11->13	12->15
Reduction	3->4	3->4	3->4	3->4	1->3
Number of messages	26	62	45	38	32
Number of weather stations	23	27	27	28	30

Figure 3. Assessment of infection level in Sombreffe.
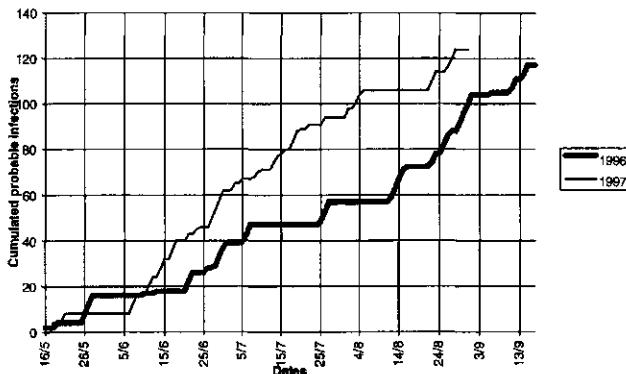
1996

In the North, the first fungicide application was requested on the 13th of June, during the 3rd cycle of potential infection. Lower temperatures in the South brought about later growths. In this region, climatic conditions at the beginning of the season don't bring about serious potential infections. In these conditions, the first treatment was requested on the 27th of June. Many rainfalls at the End of June or beginning of July brought risks of infections and necessitate repeated treatments to protect young plant growth. According to the moderate intensity of the rain, only contact products are prescribed. The rain at the end of July and then in mid-August brought about serious potential infections, cultures were no longer protected: treatments are recommended (the 30/7 and the 16/8). Contact products are prescribed as the plants have finished their period of growth. At the End of August severe rains brought about repeated potential infections and leaching of fungicides. Treatments were indicated for the 26/8 and the 3/9.

Tabel 8. Recommendations for treatment in 1996.

Year : 1996   Station : **LIBRAMONT**   Region :   **ARDENNE**

Crop emergence 30/05/96   End of season 14/09/96

Treatment				Infection		Rain
N°	Date	Fungicide	Days	Type	Date	
				Moderate	18/05/96	
				Very serious	26/05/96	
				Minor	09/06/96	
1	27/06/96	contact		Very serious	21/06/96	
2	05/07/96	contact	8	Very serious	01/07/96	32,9
3	11/07/96	penetrating action	6	Very serious	06/07/96	26,6
4	30/07/96	contact	19	Very serious	25/07/96	15,6
5	16/08/96	contact + stannic	17	Very serious	10/08/96	48,7
6	26/08/96	contact + stannic	10	Very serious	21/08/96	34,5
7	03/09/96	stanninc	8	Very serious	30/08/96	65,4

Year : 1996   Station : **SOMBREFFE**   Region :   **LIMONEUSE**

Crop emergence 20/05/96   End of season 15/09/96

Traitement				Infection		Rain
N°	Date	Fungicide	Days	Type	Date	
				Moderate	18/05/96	
				Very serious	26/05/96	
1	13/06/96	contact		Moderate	09/06/96	
2	26/06/96	contact	13	Very serious	21/06/96	7
3	05/07/96	contact	9	Moderate	31/06/96	13,9
4	11/07/96	penetrating action	6	Very serious	06/07/96	18,1
5	30/07/96	contact	19	Very serious	25/07/96	7,7
6	16/08/96	contact + stannic	17	Very serious	11/08/96	69,1
7	26/08/96	contact + stannic	10	Very serious	21/08/96	49,7
8	03/09/96	stannic	8	Very serious	30/08/96	123

1997

Strong rainstorms over the whole region accompany the potatoes emergence and the beginning of growth. They stimulate a series of infections considered as heavy to very heavy (14, 18, 21/5). The first treatment was requested everywhere at the outbreak of the 3rd cycle of infection (the 11/6). This later date for the first treatment was justified because of weak inoculum in the beginning of the season: previous year without blight and severe winter.

But unremitting rains of June- July generate repeated potential infection cycles and breaks out of infections mainly correspond with rainy periods. These weather conditions brought about the explosion of the epidemic.

A permanent protection was requested and advice of treatment were given weekly (between the 16/6 and the 23/7). These advice keep account of the risk of leaching according to the meteo forecast. Systemic and penetrating fungicides are recommended in the rainy period which also corresponds to the active growth period of the plants.

The hot and dry period in August stops the development of the illness. No treatment was requested until the 26/8. An advice of fungicide application was spread 27/8 following a potential heavy infection caused by a small amount of rain observed on the 22/8.

There was more rain at the end of August - beginning of September: the last two treatments were requested in order to avoid a comeback of the epidemic and to protect the tubers.

The haulm-killing is recommended at the same time as the last treatment (on the 3/9) as the cultures have reached sufficient maturity.

Tabel 9.   Recommendations for treatment in 1997.

Year :   : **1997**   Station   **LIBRAMONT**   Région :   **ARDENNE**
Crop emergence   25/05/97   End of season   05/09/97

Treatment				Infection		Rain
N°	Date	Fungicide	Dayss	Type	Date	
				Very serious	06/05/97	
				Very serious	11/05/97	
				Very serious	14/05/97	
				Very serious	21/05/97	
1	11/06/97	contact		Very serious	07/06/97	
2	16/06/97	penetrating action	5	Very serious	11/06/97	22,5
3	23/06/97	systemic action	7	Very serious	17/06/97	67,7
4	02/07/97	contact	9	Very serious	29/06/97	90,6
5	09/07/97	contact	7	Very serious	05/07/97	16,2
6	24/07/97	contact+penetrating action	15	Very serious	18/07/97	26,5
7	04/08/97	penetrating action t	11	Very serious	01/08/97	34,1
8	27/08/97	contact+stannic	23	Very serious	22/08/97	6,6
9	01/09/97	contact+stannic	5	Very serious	27/08/97	34,2

Year :	**1997**		Station	**SOMBREFFE**	Region:	**LIMONEUSE**	
Crop emergence	20/05/97		Levée	05/09/97			

Treatment				Infection		Rain
N°	Date	Fungicide	Days	Type	Date	
				Very serious	06/05/97	
				Minor	14/05/97	
				Very serious	18/05/97	
				Very serious	21/05/97	
1	11/06/97	contact		Very serious	07/06/97	
2	16/06/97	penetrating action	5	Very serious	11/06/97	15,5
3	25/06/97	systemic action	9	Serious	21/06/97	30
4	02/07/97	contact	7	Very serious	29/06/97	18,8
5	09/07/97	contact	7	Moderate	03/07/97	6,6
6	17/07/97	contact	8	Moderate	13/07/97	11,6
7	23/07/97	contact+penetrating ac-tion	6	Very serious	18/07/97	24
8	04/08/97	penetrating action	12	Very serious	01/08/97	28,3
9	27/08/97	contact+stannic	23	Very serious	22/08/97	5,3
10	01/09/97	contact+stannic	5	Very serious	27/08/97	28,2

Assessment of efficiency of warnings

Reference plots, Description

Reference plots are planted on the land of approximately ten farmers at different places in Wallonia. These plots make it possible to check the efficiency of the warning in each of the areas. In potato crops where classic plant protection schemes are carried out, farmers apply the recommendations made by the Warning system to a part of the area in a very strict way. In this time of geographic extension of the Service the plots also act as an ideal instrument with a view to informing farmers.

1996

No Late Blight was observed, either in the crop treated following warnings, or in the part treated systematically. The saving was between 2400 BEF/ha to 3600 BEF/ha (2 or 3 treatments at 1200 BEF/ha per unit).

1997

The farmers who followed advices of warning service saved 1 (sometimes 2) fungicide application. The other farmers began to spray potatoes one week earlier.

But the weather conditions of 1997 were particularly clear for blight control:

– the unremitted rains of June and July obliged farmers to maintain a permanent protection with weekly spraying

– the dry and warm period in August clearly didn't require treatment.

Control platforms

Description

Untreated check plots may possibly enable the expert in charge of the warning to verify the concordance between the possible infection resulting from the model and the actual infection of the fields. It also allows the determination of the onset of the epidemic, thanks to the presence of untreated plots: from the moment that symptoms become easily detectable, the protection of cultures in the region becomes necessary.

The choice of the date of the first treatment may be checked. These check plots also make it possible for the expert to try to improve the system by working out solutions for possible deficiencies of the model (infections in the presence of low temperatures, value attributed to the incubation evolution units according to the temperatures and especially to low temperatures, to recorded average temperature that are higher than those taken into account when defining the model (7 to 18 °C, ...).

Figure 4.   Libramont 1996 - Control platforms.

Variety :   BINTJE
Calibre :   25/28
Space :   0.75 X 0.32
Preceding :   cereal
Fertilizer :   1.000 kg de 9-9-15
Planting :   10 may 1996
End of season: 6 September 1996
Area of platforms: 20 plots, 9 ares
Area of plots :   6 lines de 10m, 45 m²
+ treated - untreated

N° plot	T1	T2	T3	T4	T5	T6	T7
1	-	-	-	-	-	•	•
2	-	+	+	+	+	+	+
3	-	-	+	+	+	+	+
4	+	-	+	+	+	+	+
5	+	-	-	+	+	+	+
6	+	+	-	+	+	+	+
7	+	+	+	-	+	+	+
8	+	+	+	+	-	+	+
9	+	+	+	+	+	-	-
10	+	+	+	+	+	+	+

<u>1996</u>

In 1996, three platforms were established : two at Gembloux under the supervision of the « Station de Phytopharmacie » and one in Libramont.

The analysis of data for Libramont shows that:

- in check plots that are non-protected, the first signs of blight only start from the 16th of July. At this moment, the quantity of inocculum present in the area is sufficient at last to provoke these symptoms. This shows that winter and spring conditions were not favourable to the conservation or hasty multiplication of the inocculum.
- applied protection up till then is sufficient, even excessive.
- after mid-August however, the amount of infection becomes important and even so, the protected parts become slightly infected.

In these control trials, we observed greater level of infection on parts close to the non-protected check. In order to avoid these difficulties, a buffer plot totally protected has been installed between control part and others.

Tabel 10. Productivity and level of infection of tubers.

N° plot.	Treatment	Gathering of crops (kg/ 50 plants)	Gathering of crop (% sample)	% tuber blight
1	0	45,7	100	18,6
5	5 (T2, T3)	55,1	121	2,4
6	6 (T3)	58,5	128	0,8
3	5 (T1, T2)	59,5	130	9,2
9	5 (T6, T7)	60,8	133	1,0
4	6 (T2)	61,6	135	4,4
8	6 (T5)	63,7	139	0,3
2	6 (T1)	64,3	141	7,4
10	7	64,6	141	1,3
7	6 (T4)	64,8	142	1,7

The absence of treatment on the check brings about a net deficit in productivity (about 10 to/ha). The total yield of the other parts varies from 46 to/ha to 54 to/ha.

1997

In Libramont, the plantation was made, late, on the 17th of May 1997.

The fist symptoms were observed on the 7th of July (following the very serious infection of the 29th of June) on all parts that were untreated twice in June.

Among these parts, the Late Blight was reduced in all the ones that received every following treatments in accordance with advice of Warning Service (2 to 5% infection at the haulm-killing).

The illness evolved rapidly in the non-protected check plot : the leaves was destroyed by 10% on the 17th of July and on the 6th of August the destruction was total (after the sporulation of the very serious infection of the 1 of August).

Parts not having received at least one treatment in July were severely damaged in the beginning of August and following treatments were not able to reduce the progression of infection (15% of infection at haulm-killing).

Situation in organic crops

The most common varieties are Charlotte, Désirée and Nicola. This choice results mainly from demand of consumers and also from lower susceptibility to Late Blight.

In normal years, farmers specialised in this production treat about once a month according to symptoms or in rainy periods. Fungicides most widely used are « Bouillie Bordelaise » and copper oxychloride applied at normal doses. But a lot of farmers growing potatoes in smaller areas use no treatment. Some use « homeopathic » products that stimulate the growth of the plant.

Fertilisation-based manue or compost sometime with organic fertilizer added to it gives a limited vegetation drying quickly. Mechanical weeding can bring about wounds that facilitate the installation of Late Blight.

The mechanical haulms-killing is effected from the 20-25 August. It allows a homogenous maturation, weeding and, when necessary, to reduce the impact of Late Blight at the end of the season.

Cultures are affected every year by blight. But the infection usually develops at the end of the season with limited consequences. The yield reach 20-25 to/ha for Charlotte, 25-30 to/ha for Bintje and 25-35 to/ha for Desirée. Tubers are often stocked until May/June of the following year in ventilated conditions or sometimes in fridges. Only a few problems of conservation have been reported.

In 1997, there was a favourable development of Late Blight that brought about the complete destruction of crops at the end of July. The haulms-killing was done one month on advance (20th of July) despite an intensive protection (spraying every 6 days), having started 10-15 June, from the onset of the first visible symptoms. Despite of the importance of the infection,

not many problems of rotting were reported.

Conclusions

During the 1996 season 38 messages have been worded and spread as well as 7 to 9 recommendations for treatment, the operation being carried out from 30 April to 11 September. In the course of the 1997 season 32 messages have been worded and spread. The operation was carried out from 12th of May to 15th of September. According to the observation posts 9 to 11 recommendations for treatment have been spread. In a year unfavourable to the disease as in 1996, recommendations permitted to reduce 3 to 4 treatments, while in 1997, a year particularly favourable to blight, 1 treatment has been reduced.

The check plots disseminated in the main potatoes cropped region have the same level of infection as the fields protected following the schedule of treatments by farmers.

These results showed the efficiency of the DSS based on Gunz and Divoux model used at the Station de Haute Belgique. As the recommendations resulted in considerable saving (at approximately 1000 BEF per ha and per treatment), the farmers are greatly satisfied with the service.

The control platforms are very useful to check the efficiency of the system but the unequal effects of various plots between them make the interpretation of results difficult.

The control platforms showed that each treatment recommended by the Warning Service following the Gunz and Divoux model is unavoidable. Nevertheless, following the results of control platforms, we can observe that it could be possible to save one more treatment : the first of August in 1996 and the second of July in 1997. Moreover, in the particular conditions of Libramont with low pressure of inoculum, it could be possible to save the first fungicide application of the season because of the late onset of blight (16 days after treatment in 1996 and 20 days after treatment in 1997). But these reductions of treatments could probably bring about an accelerated progression of the disease.

The system showed its efficiency for highly susceptible culivars like Bintje. But it will be necessary to modulate the advice for the best resistant varieties.

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Availability and use of meteorological data for

disease forecasting in Denmark

JENS GRØNBECH HANSEN

Danish Institute of Agricultural Sciences
Department of Agricultural Systems and Landscape
Research Centre Foulum
8830 Tjele, Denmark

Abstract

This paper describes the availability and use of meteorological data in decision support systems in Denmark. In 1998 farmers have access to meteorological data from local on-farm weather stations and via the Internet from the Danish Meteorological Institute. Import of data from different sources are handled by a Climate data Interface (CDI). For a discussion on models sensitivity to non-accurate data a small test was carried out on the NegFry system. This test showed that threshold models like NegFry are particularly sensitive to systematic deviations in relative humidity compared to reference data.

Keywords: DSS, weather data, late blight, NegFry, sensitivity analysis, Internet.

Introduction

In Denmark farmers are under societal and political pressure to reduce the amount of pesticides. For example in 1998 the taxes on pesticides will be raised and the use of pesticides will not be allowed in areas that are important with respect to the formation of groundwater for human use. In order to reduce the use of pesticides while still maintaining high yields and quality, farmers increasingly rely on decision support systems (DSS's). Several systems are now being used by Danish farmers and extension services: PC-Plant Protection based on PC (Secher et al., 1995), PI@nteinfo based on internet applications (Jensen et al., 1996; Jensen et

al., 1997; Hansen, 1996) and NegFry for control of potato late blight (Hansen et al., 1995). These DSS's all require access to operational weather data on a daily and hourly basis. This paper will describe the availability and use of meteorological data in decision support systems in Denmark. Examples will be given using the NegFry system.

Network of meteorological stations

The Danish network of meteorological stations comprises 45 synoptic stations with measurements every three hours, 36 automatic stations with hourly measurements and approximately 500 manual precipitation stations. The location of the synoptic and automatic stations are given in figure 1.

The synoptic stations were established for use in weather forecasting and are mainly located along the cost lines and at airports. During the mid-eighties 36 automatic stations were established in major agricultural areas, some of them at research stations owned and managed by the Danish Institute of Agricultural Sciences (DIAS). Local meteorological data are now available for such purposes as evaluation of field experiments at DIAS.

Cooperation with the Danish Meteorological Institute

The Danish Institute of Agricultural Sciences (DIAS) and the Danish Meteorological Institute (DMI) has made a cooperative agreement concerning weather information in three parts:

A: Operation and service of meteorological stations located at research stations owned by DIAS.

B: Delivery and transmission of meteorological observations from DMI to DIAS.

C: Production and dissemination of meteorological information for agriculture.

According to this agreement most of the data from the network of meteorological stations in Denmark are transferred on a daily basis to a database at DIAS for use in research and development projects. Primary data are not allowed to be given to a third party, however the data may be used in Pl@nteinfo products e.g. maps with risk indices for pest and diseases (http://www.planteinfo. dk). Until now all products in Pl@nteinfo have been free of charge. In the future products that operates on the local scale e.g. the irrigation management system in

Pl@nteinfo, will include charges for use of local meteorological data from the Danish Meteorological Institute.
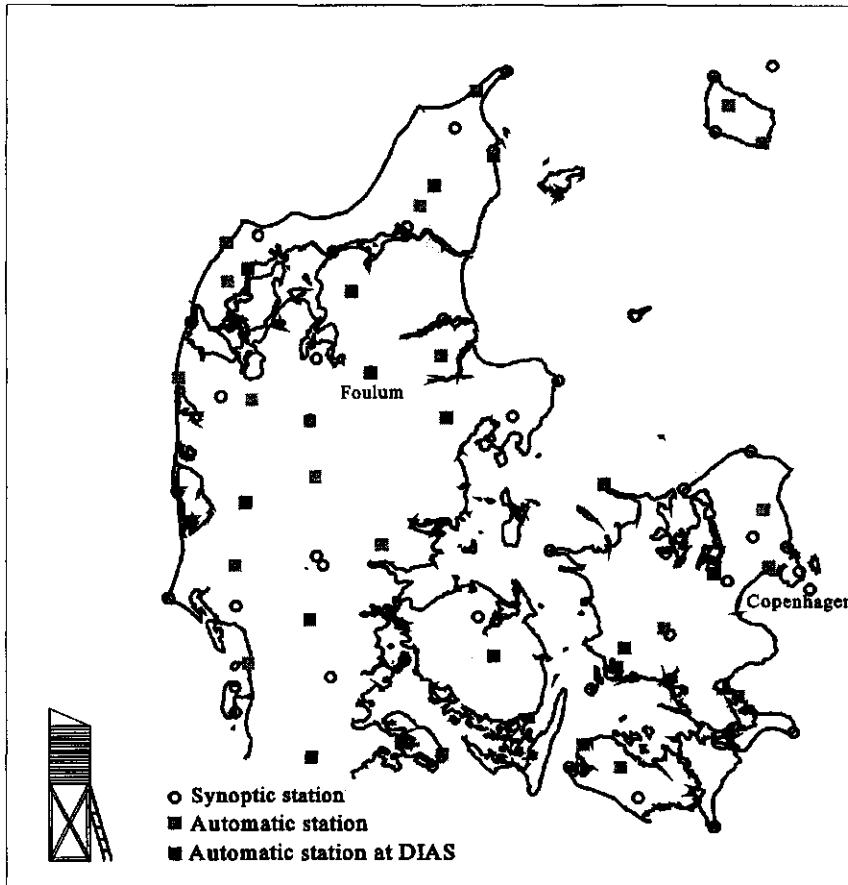

Figure 1. Meteorological station network in Denmark. Synoptic stations measure every three hours. Automatic stations measures every hour. Several of the automatic stations are located at DIAS research stations.

AMIS - Agricultural Meteorology Information System

Since 1997 historical and forecasted weather data have been available via the Internet from DMI. Data are given as interpolated grid values of 10 * 10 km. The basis for the grid values are data from all synoptic and automatic stations as well as some of the manual precipitation stations. Available data from AMIS are given in Table 1.

Table 1.   Interpolated grid data available via AMIS.

Historical data	Prognosis data (5 day)
Air temperature every three hours	Daily maximum temperature
Relative humidity every three hours	Daily minimum temperature
Wind speed every three hours	Daily maximum wind speed
Daily precipitation	Daily precipitation
Daily potential evapotranspiration	Daily potential evapotranspiration

Data from AMIS are transferred from DMI to a local PC via the Internet using a programme called DM1Vejr3. With this programme farmers can access AMIS data and weather radar pictures for precipitation events in steps of 10 minutes. AMIS data can be exported to an ascii file for use in decision support systems. Starting in 1998, a significant portion of weather-based products in Pl@nteinfo will be based on AMIS data. Advantages of using AMIS data are: i) products in Pl@nteinfo will be updated at least once a day, including weekends and ii) as AMIS data are interpolated data from the stations shown in figure 1, there will be a minimum of missing data in the data series for each grid. Major tasks for the near future will be to evaluate the quality of interpolated data as well as to evaluate the sensitivity of models and methods to data that are not entirely accurate.

Local weather data from the Hardi Metpole

In 1995 an on-farm weather station was introduced by Hardi International (Høstgaard, 1993). The NegFry system has until now been the only DSS in Denmark that is fully integrated with the Hardi Metpole. In 1997 approximately 8 local extension services operated local weather information systems based on the Hardi metpole. For approximately 2-3000 Dkr farmers could gain access to Hardi metpole data from the extension service via a modem and run NegFry on their own computers. Therefore 30-50 farmers could share the cost of 5-8 metpoles located in

the region. A number of farmers did not have computers and advice on late blight risk and spraying strategy was therefor passed on from the extension service to the farmers via fax transmissions. The advice was based on NegFry calculations using field specific data and weather data from a metpole near the farmers field. The modem solution for transmission of Hardi metpole data however turned out to be problematic. This was primarily due to difficulties in modem-to-modem connections and thus starting in 1998 the transmission of metpole weather data will be based on e-mail via the Internet.

Availability and quality of meteorological data from different sources

In order to cope with the difficulties of using weather data in PC-models and DSS's from many different sources, the Danish Institute of Agricultural Sciences has developed a Climate Data Interface (CDI) that can be used as a standard component (DLL) in PC-programs, DSS's and Internet applications (figure 2).

Data from the Hardi metpole are imported directly from the Hardi paradox database, and ascii files can be imported in any format described by the user via the CDI interface. AMIS data from DMI are imported automatically via the Internet. After transformation, quality control and interpolation of missing data, data from any source are stored in a database as hourly data and/or as daily means, minimums or maximums. A data source may have missing values for several days, which implies that interpolation in time is problematic. A MERGING function makes it possible to merge data from different sources, e.g. if data for two days are lost for a Hardi metpole, the user can specify substitution of AMIS data for the lost sequences of data. The CDI will be a standard component in NegFry and in PC-plant protection in Denmark.

Given the new possibilities of using AMIS data from DMI, farmers and the extension services have naturally asked whether or not 10* 10 km grid interpolated AMIS data can be used instead of local data from the Hardi Metpole in DSS'S. We have only made a preliminary test of the quality of AMIS data and only some general answers can be given at the moment:

1. For models and systems driven by temperature AMIS data may be an alternative to local metpole data. Humidity and rain can be very local and use of local precipitation may be necessary.

2. For grids containing an ordinary meteorological station, the interpolated grid value will be highly influenced (>90%) by the local meteorological station. If the farmer's field is located

near an ordinary meteorological station all variables from that specific grid may be an alternative to local metpole data. In areas between meteorological stations the quality of interpolated data may however differ more significantly when compared to local measurements.

3. For models and methods using microclimate data as input AMIS data are not an alternative to Hardi metpole data.

In 1998 the Danish Institute of Plant and Soil Science, the Danish Agricultural Advisory Centre and the Danish Meteorological Institute will initiate a project with the following objectives:

1. Evaluation of the sensitivity of selected weather-based models and methods for systematic and random deviations (precision and accuracy) in the climate variables used.

2. Obtain empirical-based estimations for the systematic and random variation in the differences between measured and calculated (e.g. spatial interpolated) values of important climate variables, e.g. variation in local climate are compared with 10* 10 km grid interpolated values.

3. Evaluation of the advantages and constraints in scenarios for future weather information systems including improved quality and accessibility to local climate data. In addition to create a report on necessary future investments for new ordinary and/or different kinds of local climate stations, techniques for communication and the need for research and development of calculation methods, e.g. spatial interpolation.
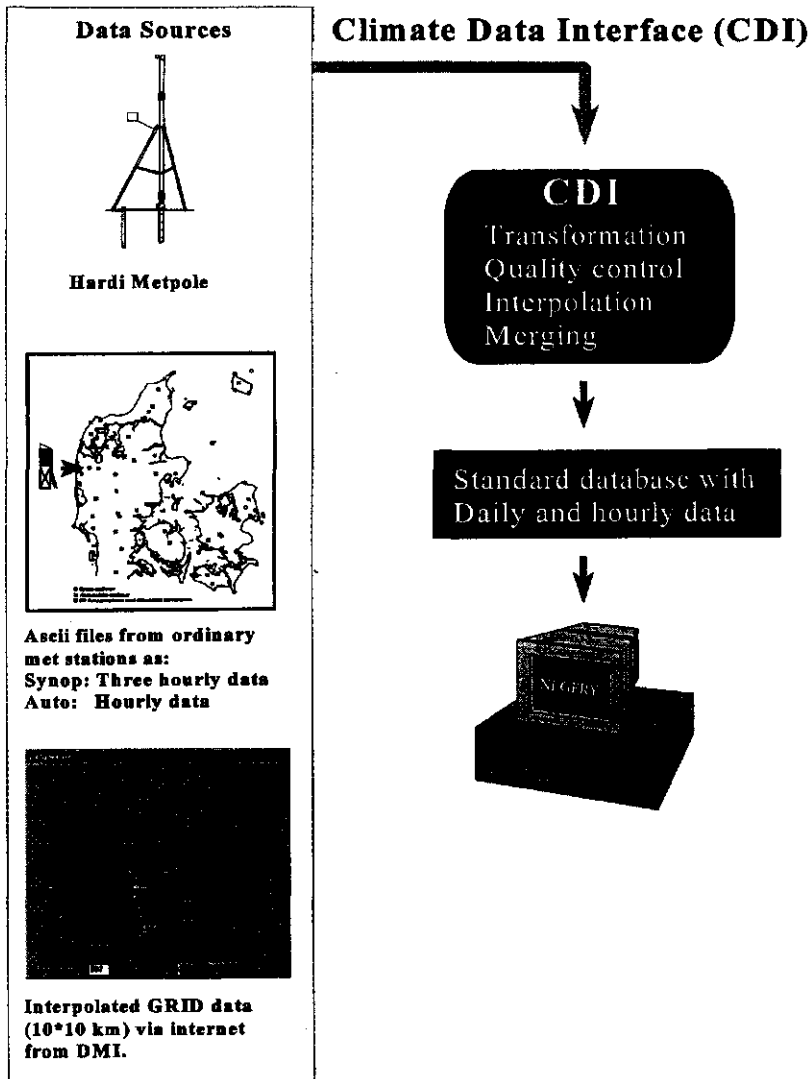
Figure 2. Data sources and functions of the Climate Data Interface. Data sources from the Hardi metpole, Synoptic stations (Synop), Automatic stations (Auto) and Grid data from the AMIS system, Danish Meteorological Institute (DMI)

NegFry sensitivity to systematic deviations in temperature and humidity data

In many late blight forecasting systems methods are based on thresholds for temperature and humidity (Ullrich & Schrödter, 1966; Försund, 1983; Smith, 1956; Winstel, 1993; Krause,

Massie & Hyre, 1975; Hansen, Andersson & Hermansen, 1995). A list and a short descriptions of late blight models and DSS's can be found on the Internet:

http://axp.ipm.ucdavis.edu/DISEASE/DATABASE/potatolateblight).

Such threshold models and methods may be sensitive to the use of non-accurate weather data, but sensitivity tests are seldom found in the literature. A small test was consequently carried out on the NegFry system (figures 3 and 4, and tables 3 and 4). Hourly weather data from 1996 were modified to simulate systematic deviations in temperature and relative humidity from reference data. Non-accurate weather data may be caused by: i) sensors not being calibrated correctly, ii) relative humidity sensor drifting (often down) during the season, or iii) local climate differing from interpolated data based on the nearest ordinary meteorological stations.

In the NegFry system the first part is nearly identical with the Negative prognosis (Hansen, Andersson & Hermansen, 1995). In this method the end of the epidemic free period is calculated with a value of 150 accumulated risk values. Only those hours where the temperature is between 10 and 24°C and where Rh>90% are included in the calculation of risk values.

In this analysis temperature was lowered and raised 0.3, 0.5, 1.0 and 1.5°C respectively. Model outputs with the modified data were compared with outputs using the reference data (figure 3 and table 3). Similarly relative humidity was lowered and raised with 2, 3, 5 and 8% respectively (figure 4 and table 4).

Accumulated risk values were calculated for the period June 6 (crop emergence) - August 30. Definitions of risk indices are given in table 2.

Table 2. Definitions of risk indices used in table 3 and 4.

Risk indices	Definitions
DRV	Daily risk value according to the Negative prognosis
ARV	Accumulated risk value according to the Negative prognosis
Infection hours	4 or more consecutive hours where the temperature is between 10 and 24°C and Rh>90%
Sporulation hours	10 or more consecutive hours where the temperature is between 10 and 24°C and Rh>90%

Generally it appears that the Negative prognosis is highly sensitive to systematic deviations in both temperature and relative humidity (figures 2 and 4). Temperature sensors are relatively easy to calibrate with accuracy levels of ± 0.1-0.3°C and this calibration is often stable for several years. Calibration and measurement of relative humidity however, is very difficult and most of the sensors used specify an accuracy of ± 3-5%. If Rh is calibrated too low or has drifted downwards, calculation of risk values will be particularly influenced (figure 3).

In 1996 a primary attack of late blight was observed on July 25 at Foulum. The date for the accumulated risk value of 150 was July 9 and the NegFry system recommended the first spray on July 10.

If the temperature had been 1°C higher (+1.0) than the reference data, NegFry would have recommended the first spray on July 2. If the temperature had been 1°C lower (-1.0) than reference data, NegFry would have recommended the first spray on July 26 approximately one week too late. Based on this data set a systematic deviation of ± 0.5°C is acceptable for a correct late blight prognosis. The number of fungicide applications recommended in this case is identical to the recommendation when reference data is used.

Systematic deviations in Rh are much less acceptable than deviations in temperature. The prognosis for primary attack would fail with a systematic deviation of -2% or more. Rh deviations of only -2 to +3% seem to be acceptable in this test.
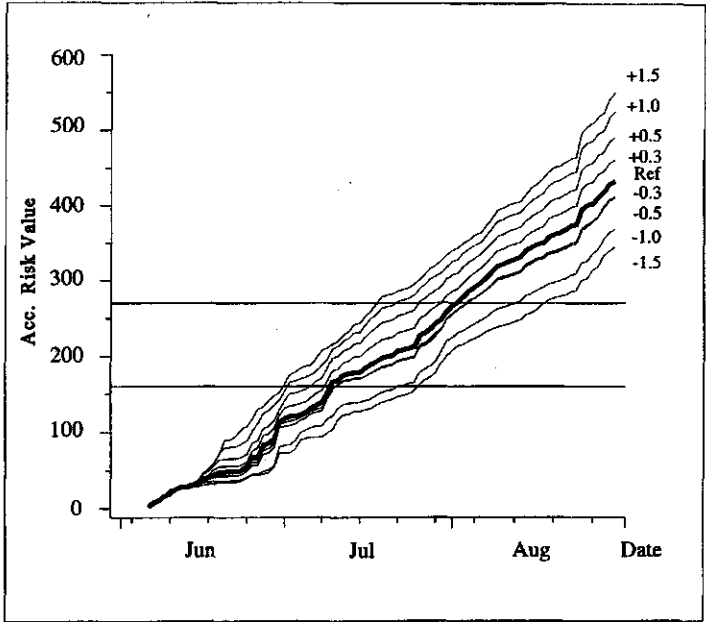
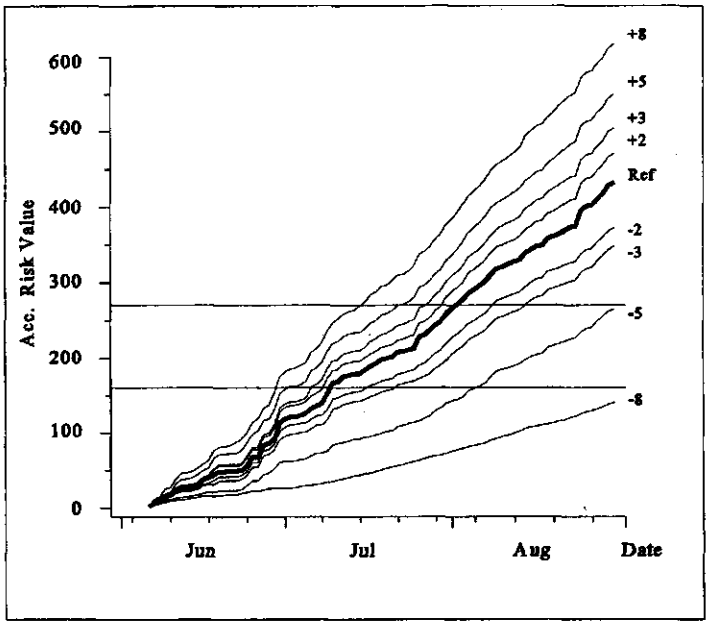Figure 2. Negative prognosis sensitivity to systematic deviation of temperature [°C]

Figure 3. Negative prognosis sensitivity to systematic deviation of Rh [%]

Generally humidity data should be carefully evaluated because Rh is difficult to calibrate in the area above 90% and the calibration is often unstable during a growing season. It is very important that data for relative humidity be accurate because models such as NegFry with Rh thresholds seems to be particularly sensitive to too-low measurements of Rh.

Table 3. NegFry sensitivity to systematic deviation of temperature [°C]. Accumulated values are given for the period June 6- August 30. Primary attack was observed on July 25. See text for further explanation.

	-1.5	-1.0	-0.5	-0.3	Ref.	+0.3	+0.5	+1.0	+1.5
Data ARV=150	+16	+10	+1	+1	07.09	-2	-7	-8	-10
Days DRV>8	-4	-2	-2	-3	13	+4	+7	+11	+16
Infection [hh]	-60	-44	-13	-18	249	+18	+37	+56	+70
Sporulation [hh]	-10	-7	0	-2	60	+6	+13	+23	+24
First spray (NegFry)	07.26	07.26	07.11	07.10	07.10	07.09	07.09	07.02	07.01
No. of sprays (NegFry)	3	3	4	4	4	4	5	6	6

Table 4. NegFry sensitivity to systematic deviation of relative humidity [%]. Accumulated values are given for the period June 6- August 30. Primary attack was observed on July 25. See text for further explanation.

	-8	-5	-3	-2	Ref.	+2	+3	+5	+8
Data ARV=150	+59	+26	+9	+3	07.09	-2	-3	-8	-10
Days DRV>8	-	-7	-4	-3	13	+5	+7	+9	+15
Infection [hh]	-249	-130	-63	-48	249	+28	+51	+81	+133
Sporulation [hh]	-60	-46	-27	-20	60	+13	+15	+44	+63
First spray (NegFry)	-	08.08	08.01	07.31	07.10	07.09	07.06	07.06	06.30
No. of sprays (NegFry)	0	2	3	3	4	5	5	6	8

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Experiences of running late blight models on Adcon

network weather data in the UK

H. HINDS

DMA Crop Consultants,
Unit 5, Beacon Court,
Ollerton.Notts. NG 22 9QB, U.K.

Abstract

Spray timings generated by late blight models (Ullrich Schrödter & Plant Plus) using local weather data from Adcon weather station networks were compared with 15 routine spray programmes carried out by growers in the East Midlands.

Blight disease pressure in the area was severe during June and most crops developed some late blight symptoms by mid July. The worst infections in the network crops were seen in blight sensitive varieties and or where only 1 spray had been applied in June. Most growers applied 3 sprays in June and subsequently had no or low blight infection. The use of phenylamide fungicides predominated in June, once infection was observed a switch to local systemic products was made. All disease isolates tested from the network were A1 mating type and resistant to metalaxyl.

The Ullrich Schrödter model (7 day product duration) and Plant Plus generated more spray recommendations in June (3.5 & 4.0 respectively) than growers achieved with routine programmes (2.5). Routine sprays were missed in June because of the limited spray windows available. Actual grower sprays increased significantly in July and August, but after infection had already occurred. Total sprays to the end of August for routine and Plant Plus were the same, Ullrich Schrödter (7 day) was one spray less.

Fungicide recommendations made by the Plant Plus model were more likely to coincide prior

to an infection period than Ullrich Schrödter, thus aflowing a greater chance of preventative spraying. Plant Plus incorporates a 5 day weather forecast in the model, an important practical consideration for growers with large potato areas.

The experience from 1997 is that models can be effective in protecting potato crops even under extreme disease pressure, but technical support is necessary to help interpret model output and in agrochemical choice.

Introduction

DMA Crop Consultants are an independent specialist vegetable and root crop consultancy company based near Wisbech. Their clients range from marketing organisations to individual growers covering most of the UK vegetable producing regions.

As part of the DMA service, advice on integrated crop management accounts for an increasing area of the business. DMA identified that information technology has an important role to play in successful implementation of ICM. With this in mind Adcon weather stations were used by DMA in 1997 to offer growers weather data collection from their own field situations. Several weather station networks were set up for potato growers to observe risk assessments by late blight models compared to their own routine spray progranunes. The foflowing details experience from the Midland network of weather stations.

Adcon Weather Stations

The Adcon weather stations used by DMA customers comprise of a light weight portable mast and a receiver / transmitter and data storage unit. Sensors for measuring temperature, huniidity, precipitation, leaf wetness, solar radiation, wind direction and speed are attached. The stations are powered by a small solar panel linked to a battery. Real time weather data is measured in field by the sensors every 15 minutes and transmitted via radio frequency to receiver linked to an office PC.

The stations have a nominal transmission range of 20 km. Stations can be centred around the receiver base or linked in chains to form networks covering large growing areas.

Integral advantage software process the weather data and provides disease forecasting and irrigation models. Adcon software provides two late blight disease models, Ullrich Schrödter

and Winstel. The model used in the Midland network was the Ullrich Schrödter which calculates blight risk using Negative Prognosis. Basically this means risk periods are accumulated until a limit value is reached. An infection chance is then assumed to be possible. The next significant rise in the risk index will thus trigger a spray recommendation. When this occurs, the user then needs to input the chemical and its duration period (eg 7 days). Variety sensitivity to late blight is also configured by the user. After the duration period of the first treatment ends, a rise over 8 in the index will then cause the next spray to be recommended.

In the Midland network two Ullrich Schrödter models were run. Chemical control duration was set at 7 and 1 0 days. In addition to this the Plant - Plus system from Dacom was also evaluated.

UK Adcon Weather Station Networks

Six Adcon weather station networks were set up in 1997, involving over 40 individual weather stations. Three of the networks were sited with potato growers in the Midlands, West Midlands and East Anglia.

The largest of these potato networks was based in the Midlands and covered an area from Nottingham, north to Retford and east to Lincoln. The eight growers involved in the network grow between 80 - 800 ha of potatoes mainly for processing. Varieties included: Saturna, Lady Rossetta, Hermes, Russet Burbank, Morene and Shepody.

Spray details from 15 separate grower blight programmes were compared to 15 virtual model programmes run from the nearest weather station. The target potato area for each programme was 50 ha, however this varied depending on the potato area within the vicinity of a station.

Late Blight Infection in the Midland Network

1997 was arguably one of the worst late blight years in living memory for Midland growers. The weather pattern was ideal for the development of an epidemic, cool and very wet in June (140 mm of rain), warm and humid in July and finishing with a wet end to August. The area was badly hit by late blight, with some growers burning off significant areas of crop in July.

Generally growers crops involved in the Network were not affected as bad as some, however most experienced low levels of infection. Disease symptoms were first seen in early July and

reached a peak by mid July after which intensive spraying helped keep the disease at bay. June was therefore the critical month for the diseases inoculation. The most severe infection occurred from programmes where only 1 spray was applied in June (Table 1). Programmes with 3 June sprays mostly avoided all but a trace of infection, except where very susceptible variaties were grown.

The problem facing growers in June was that, not only was there a shortage of good spray days but rapid haulm development, combined with chernical wash - off, almost certainly reduced fungicide persistence to less than the nornimal 10 day control duration.

Table 1. Blight Infection Levels in Midland Network Crops.

Programme Sprays	Variety Resistance	Disease Infection	June
1	Moderate	1	3
2	Moderate	1	3
3	Susceptible	3	3
4	Moderate	1	3
5	Moderate	0.5	2
6	Moderate	1	3
7	Moderate	1	2
8	Susceptible	2	3
9	Susceptible	0.5	3
10	Moderate	1	3
11	Moderate	3	1
12	Moderate	1	3
13	Susceptible	2	3
14	Susceptible	3	1
15	Moderate	0.5	4

Key   0 = no infection

0.5 = trace

1 = odd plants found

2 = small patches found & burnt off . Did not develop further.

3 = small patches, developed into larger arcas. 10% of field affected 5 = 50 % of field with severe infection.

10 = 100 % of field with severe infection.

Network fungicide choice

Table 2 shows phenylamide systemic products were used extensively in June to help protect

new growth. Tests from 6 infected sites have now shown partial and full resistance to metalaxyl. This helps explain why at least one programme with 3 sprays in June still resulted in significant blight infection.

Translaminar products (local systemics), with some curative action were generally not used until infection symptoms had occurred in July. A period of panic spraying then followed where these products were alternated with tin. With hindsight earlier use of fungicides with both protectant and curative action would have been more appropriate in this season.

Table 2.   Midland Network - Number of Sprays by Fungicide Type.

| Month | Product Type | | | |
	Contact (Protectant)	Local Systemic (Translaminar)	Systemic (Phenylamide)	Total
May	5	2	0	7
June	7	11	21	39
July	26	50	2	78
August	59	15	0	74

Routine Programmes compared to Model Output

The total number of sprays applied came to just under 200. Table 3 analyses these into the three months, June, July and August. In June growers applied an average of 2.5 sprays (range 1-3), however in July & August this rose to 5.0 & 4.5 respectively. Total average spray/ programme was 12 to the end of August.

The average number of sprays generated by the 1 0 day Ulrich Schrödter model was similar to actual sprays in June, however both the 7 day Ullrich Schrödter and Plant Plus generated more sprays in June (3.5 & 4 respectively) than growers applied during this critical period. Only one grower managed 4 sprays in June and interesting kept virtually blight free. During July output from all models was less than actual sprays applied but then increased in number during August. By the end of August the 1 0 day Ullrich Schrödter had averaged 8.9 sprays and the 7day Ullrich Schrödter 1 1 sprays and Plant Plus 12 sprays.

When the number of Ullrich Schrödter risk days (index rises of more than 8) are added up for each month, June & August recorded the highest (14.8 & 13.8 respectively). The model,

therefore concentrated more sprays in these periods as can be seen in Table 3., unlike the actual sprays which were highest in July.

Table 3.   Average Actual Sprays / Month compared to average model recommendations.

| Month | Average Sprays Generated | | | | U.S. |
	Actual	7D model	10D model	P/Plus	Index Risk days
June	2.5	3.5	2.6	4	14.8
July	5.0	3.0	2.4	4	10.6
Aug	4.5	4.6	3.9	4	13.8
Total	12.0	11.1	8.9	12	

June Spray Windows

There were actually six spray windows in June, based on the dates when grower sprays application were recorded. Table 4 shows that over 25% of sprays applied by growers were applied between 6th - 8th June, nearly week before either Plant Plus or Ullrich Schrödter recommended the first June spray (programme 1 1). Critically many growers missed the two late June spray windows 23rd - 24th and 28th - 30th June. Rainfall was particularly high prior to and during this period and most early infection was recorded within 7 days of the end of June. The reasons for the lack of spraying in late June were generally because the spray windows were so short or the land was too wet travel, however some felt the conditions were too cold to get infection. Both models highlighted severe risk during this period.

Spray recommendations generated by Plant Plus coincided with 4 of the June spray windows, two of which were the late June dates (Table 4).

Table 4. June Spray Windows.

| Spray Window Periods | % Grower Applications | Model Recommendation Dates (programme 11) | |
		U.S. (7day)	Plant Plus
4 - 6 June	25.6		
8 - 11 June	12.8	12th June	11th June
13 - 17 June	28.2		15th June
20 June	5.0	20th June	
23 - 24 June	12.8		24th June
		27th June	
28 - 30 June	15.4		29th June

Comments on Ullrich Schrödter compared to Plant Plus

The 1997 season was a good test of any late blight model. Model success did not depend on saving sprays, as we have come to expect, but on maintaining a blight free crop.

The severe infection conditions exposed weaknesses in assumptions made by the Ulrich Schrödter negative prognosis model. During June & early July high blight pressure was also accompanied by rapid new leaf growth. The Ulrich Schrödter model assumes that product activity is complete for the period of its duration (chemical label interval). In reality protection declines with new growth, especially for contact products. Plant Plus does account for unprotected new growth, and product degradation with time. Table 4 highlights this difference, for example the Ulrich Schrödter model triggered every 7 days during the severe infection period, whereas Plant Plus spray intervals varied from 4 to 9 days during the same time. It has to be noted, however that manipulation of Ulrich Schrödter to give lower initial limit value and short chemical duration would have given better results than routine spraying.

Models like Ulrich Schrödter tend to trigger recommendations during or after an infection period and therefore can advise a spray in a wet period of weather. Plant Plus is more successful at timing sprays before or shortly after infection periods, because the model incorporates a 5 day weather forecast, thus allowing more time to plan a preventative spray prior to infection periods. This is particularly important for network growers as it is not uncommon for one sprayer to cover more 150ha of potatoes (2 - 3 days spraying).

The Plant Plus model also allows for infection sources already present and evaluaties infection risk correspondingly to the level of disease in the area. The Uflrich Schrödter assumes there is no infection possible until the a limit index is reached. One programme in the network did not reach this limit valuc until the 20th June and would have been at extreme risk from nearby infection sources.

Experience this year has taught DMA that disease models will work in the UK but only if farmers are given guidance and technical backup for decision making based on model recommendations. Models such as Plant Plus require routine field visits to record crop growth and scout for infection. Advice on spray timing and fungicide choice will also be necessary especially when using a weather forecast. Interactive communication between farmer and adviser is essential for model success. In 1998 DMA plan to run Plant Plus as a late blight forecasting service for users of Adcon weather stations.

Decision support systems for the control of *Phytophthora infestans* under Irish conditions - problems and progress

R. LEONARD[1], L. DOWLEY[1], B. RICE[2] & S. WARD[3]

[1] Crop Protection & Breeding Department, Oak Park Research Centre, Carlow, Ireland

[2] Crop Production & Engineering Department, Oak Park Research Centre, Carlow, Ireland

[3] Department of Agriculture & Food Engineering, University College Dublin, Ireland

Abstract

Routine fungicide application for the control of late blight was compared with two decision support systems in field trials during 1996 and 1997. 1996 was a normal blight year while 1997 was a severe blight year. There was no significant difference in disease control or yield between routine fungicide application and the Negfry blight system in both 1996 and 1997. The reduction in fungicide use was 56% and 22% respectively. Within the Negfry system, Fluazinam tended to give better disease control than mancozeb.

The Meteorological Service warning performed well in 1996 but the disease control was unacceptable in 1997 when the blight pressure was very high. This is consistent with previous results for this system.

Air-assisted application of fungicides has not given significant benefits in these trials, but further trials are planned to examine the effect of air assistance on the incidence of stem blight.

Keywords: Decision support system, late blight, validation trials.

Introduction

The Republic of Ireland grows approximately 18,000 ha of potatoes per annum. The area has been increasing over the last few years but has now stabilised. The value of the potato pesticide market is approximately £3.5 million of which 63% (£2.2 million) is spent on fungicides for the control of late blight caused by *Phytophthora infestans*. If there are to be reductions in

the amount of pesticides used on Irish potatoes, the most obvious starting place is with the fungicides used to control late blight.

The use of decision support systems to determine when fungicide treatments should be applied for the control of *Phytophthora infestans* (Mont.) de Barry are becoming more acceptable across Europe. This has been helped by legislation that is aimed at reducing pesticide inputs. Ireland has no legislation in place and there is none envisaged in the immediate future. As a result, decision support systems used in Ireland must produce a direct benefit to the grower.

The results achieved in Ireland with decision support systems in conjunction with air-assisted spray application technology in 1996 and 1997 are presented in this paper.

Materials and Methods

Trials were conducted at Oak Park Research Centre, Carlow, on the maincrop cultivar `Rooster` during 1996 and 1997. This cultivar is susceptible to late blight having ratings of 4 and 6 for foliage and tuber blight resistance respectively (Dowley, 1995). The design for each trial was a randomised complete block with four replications per treatment. Each replicate consisted of 6 drills 7.69 m long. The drill width was 81.28 cm and the distance between tuber centres was 31.75 cm. The total replicate size was 37.5 m^2 from which 25 m^2 were harvested across the centre 4 drills. Weed control consisted of paraquat (600 g a.i./ha) and simazine (600 g a.i./ha) applied pre-emergence.

Routine fungicide application commenced in mid-June when the plants were beginning to meet along the drill and was repeated at prescribed intervals throughout the season. The spray volume was equivalent to 250 l/ha and the spray pressure was 3 bars.

Fungicide treatments and application

Details of the spray treatments used in 1996 and 1997 are given in tables 1 and 2 respectively. Air-assisted application was included in the 1997 trial only.

Decision support systems

Two decision support systems were evaluated:
>   1) Negfry in conjunction with the Hardi Metpole,

The Metpole is a portable in crop weather station for the recording of weather data in an individual crop. It collects such weather data as rainfall, air humidity, air temperature, windspeed, soil temperature, and soil humidity amongst others. The data collected by this pole was used by the Negfry model to predict the fungicide treatment timings. The Negfry model uses only air temperature, air humidity, and rainfall to predict the fungicide application times. The data from the Metpole can also be used for other disease forecasting systems or timing of irrigation or any other weather dependant procedure.

Negfry is a computer based programme for scheduling chemical control of late blight. It was developed by the Danish Institute of Plant and Soil Science and is based upon a combination of two prediction models. The first is the 'Negative prognosis' (Ullrich & Schrödter, 1966) which forecasts the date of disease outbreak and the first fungicide application. The second is the FRY-method (Fry *et al*, 1983) for calculation of weather and cultivar dependant spraying intervals.

The first part of the programme calculates the epidemic free period before spraying is required. This interval depends on the time of emergence of the crop and the subsequent weather patterns. Once the first spray has been triggered, the second part of the programme is then initiated and this calculates subsequent spray intervals. The weather for disease development is expressed in blight units as set out by the FRY- method.

The Irish Meteorological Service bases its forecasts on the following rules:-
a) A 12 hour period with temperatures of $10^{\circ}C$ or greater and relative humidity not less than 90%. b) Free moisture on leaves for up to two hours. c) Effective Blight Hours (EBH's) begin on the 12th successive hour as in (a) if there is rain between the 7th and 15th hour. Otherwise they do not start until the 16th hour. d) If two spells with blight conditions, the first as in (c) and the second as in (a), follow each other, within 5 hours or less between the ending of the first and the beginning of the next, no lead in period of 11 or 15 hours need be deducted for the second spell.

Crop assessment

During the growing season, disease levels were assessed at weekly intervals up to desiccation

using the British Mycological Society foliage blight assessment key (Cox & Large, 1960). Disease outbreak was recorded as the date when the first blight lesions were observed in the centre 4 drills of each replicate. Delay in the onset of disease was the number of days by which the disease outbreak was delayed by each fungicide when compared with the unsprayed control for each block. The crop was desiccated with diquat at the end of September and harvested in October/November using an elevator digger. The produce was stored at a temperature of over $10^\circ C$ for at least two weeks to allow tuber blight symptoms to develop and was then graded into the following grades:- < 40 mm, 40-60 mm, 60-80 mm, > 80 mm, blighted and other diseases. After grading the produce was weighed and the yields expressed in tonnes per hectare.

Data analysis

The results of each year were analysed separately using analysis of variance procedures and differences between treatments were evaluated using the Student's t-test.

Results

1996 results

Late blight was first observed on unsprayed plots on July 31st, which is about normal for the area. During 1996, the Negfry programme reduced the number of fungicide applications by 56% while the Irish Meteorological Service warnings reduced fungicide applications by 66% when compared with routine fungicide applications at 10-day intervals. Results for disease development and yield during 1996 are presented in Table 3. It can be seen that all sprayed treatments were significantly better than the untreated control in terms of delay in disease onset, area under the disease progress curve and marketable yield.

No significant differences were observed between the routine fungicide applications (Dithane DF and the routine Ridomil MZ programme) and the three reduced input programmes in terms of delay in disease onset, area under the disease progress curve and marketable yield. In terms of tuber blight control the Negfry programme based on Shirlan was significantly better than the Negfry programme based on Dithane DF.

1997 Results

Late blight was first observed on unsprayed plots on June 25th, which is about one month ear-

lier than normal. Disease pressure continued to be high during the year. During 1997, the Negfry programme reduced the number of fungicide applications by 22% while the Irish Meteorological Service warnings reduced fungicide applications by 56% when compared with routine fungicide applications at 10-day intervals. The Negfry model failed to suggest the first spray early enough in this season, as by the 23rd of June the blight attack had already commenced.

Results for disease development and yield during 1997 are presented in Table 4. It can be seen that all sprayed treatments (except the Irish Meteorological Service) were significantly better than the untreated control in terms of delay in disease onset and area under the disease progress curve.

Within the sprayed treatments, the routine fungicide treatments tended to delay disease onset more than the fungicides applied as per the Negfry programme. However, these differences were not significant. Disease progress as measured by the area under the disease progress curve would also suggest that the routine fungicide applications gave better disease control in 1997 compared with the Negfry programme, however, these differences were not significant.

Problems

A number of problems have been encountered with the Negfry/Metpole combination, stemming mainly from the Metpole.

The Metpole battery housing became water logged on two occasions and this resulted in the loss of 3 days of weather data. Inserting missing data is time consuming and difficult and may insurmountable for many farmers. The Metpole receiver can be put out of action by an electrical storm. This was easily rectified by temporarily disconnecting the power from the receiver. However, data can be lost if the problem is not noticed immediately.

The Negfry model would not calculate blight units after the updating of missing data in the Metpole programme. This problem was only over come by installing the windows version of the Negfry programme. This resulted in the second spray in 1997 being applied 4 days late. In general, it was found that the Negfry model was not very user friendly.

Discussion

1996 was an average blight year and the Negfry model performed well, giving a greater delay in disease onset and better foliage blight control than the routine fungicide treatments. The Negfry system did not control tuber blight as well as the routine sprays but levels of tuber blight were low and this resulted in a higher marketable yield than with routine spraying. The Meteorological Service warnings also performed very well giving a good level of control of late blight.

1997 was a very severe blight year and the results were different to 1996. The Negfry model did not perform as well as the routine application of fungicides, but it did perform better than the Meteorological Service warnings which gave very poor levels of control. However, there was no significant difference in the level of disease between routine and Negfry spray programmes.

The Negfry probably did not perform as well in 1997 as in 1996 due to two main reasons. These are that the initial warning was triggered about 3 days late and also that the second spray was applied 4 days late. The second spray was four days late due to problems that had been encountered with the system as explained earlier. The four days between when the spray warning was given and the spray was applied were four days of blight conducive weather.

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Table 1. Details of spray treatments 1996.

Code	Commercial Name	Iso Name	Rate of Product/ha	Grams a.i./ha	Number of applications	Dates of applications
A	Unsprayed	None	None	None	None	None
B	Dithane DF	Mancozeb	2.25 kg	1688	9	21/6, 1/7, 11/7, 22/7, 1/8, 12/8, 22/8, 2/9, 12/9
D	Ridomil MZ 72	Metalaxyl + Mancozeb	2.50 kg	200 + 1600	3	21/7, 1/7, 11/7
	fb Dithane DF	Mancozeb	2.25 kg	1688	6	22/7, 1/8, 12/8, 22/8, 2/9, 12/9
E	Dithane DF on Met. Warnings	Mancozeb	2.25 kg	1688	3	9/7, 23/7, 2/9
H	Dithane DF as per Negfry	Mancozeb	2.25 kg	1688	4	23/7, 6/8, 20/8, 2/9
R	Shirlan as per Negfry	Fluazinam	0.40 l	200	4	23/7, 6/8, 20/8, 2/9

Table 2. Details of spray treatments 1997.

Code	Commercial Name	Iso Name	Rate of Product/ha	Grams a.i./ha	Number of applications	Dates of applications
A	Unsprayed	None	None	None	None	None
B	Dithane DF	Mancozeb	2.25 kg	1688	9	17/6, 27/6, 7/7, 18/7, 28/7, 7/8, 18/8, 28/8, 8/9
C	Dithane DF (air-assisted)	Mancozeb	2.25 kg	1688	9	17/6, 27/6, 7/7, 18/7, 28/7, 7/8, 18/8, 28/8, 8/9
D	Ridomil Gold	Metalaxyl + Mancozeb	2.50 kg	200 + 1600	3	17/6, 27/6, 7/7,
	fb Dithane DF	Mancozeb	2.25 kg	1688	6	18/7, 28/7, 7/8, 18/8, 28/8, 8/9
E	Dithane DF on Met. Warnings	Mancozeb	2.25 kg	1688	4	6/6, 7/7, 15/8, 1/9
H	Dithane DF as per Negfry	Mancozeb	2.25 kg	1688	7	23/6, 18/7, 28/7, 8/8, 18/8, 26/8, 5/9
K	Dithane DF as per Negfry (air-assisted)	Mancozeb	2.25 kg	1688	7	23/6, 18/7, 28/7, 8/8, 18/8, 26/8, 5/9
P	Ridomil Gold	Metalaxyl + Mancozeb	2.50 kg	200 + 1600	3	23/6, 18/7, 28/7,
	fb Dithane DF as per Negfry	Mancozeb	2.25 kg	1688	4	8/8, 18/8, 26/8, 5/9
R	Shirlan as per Negfry	Fluazinam	0.40 l	200	7	23/6, 18/7, 28/7, 8/8, 18/8, 26/8, 5/9
S	Shirlan as per Negfry (air-assisted)	Fluazinam	0.40 l	200	7	23/6, 18/7, 28/7, 8/8, 18/8, 26/8, 5/9

Table 3. Effect of fungicide treatment on delay in disease onset, AUDPC, marketable yield and tuber blight (Oak Park, 1996).

Treatment code	Delay in disease onset (Days)	AUDPC	Marketable Tuber yield (tonne/ha)	Tuber blight (tonne/ha)
Unsprayed	0	1782.3	39.16	0.01
Dithane DF	12.75	214.7	47.78	0.05
Ridomil MZ 72 fb Dithane DF	25	11.2	50.76	0.00
Dithane DF on Met. Warnings	15.5	198.2	51.86	0.02
Dithane DF as per Negfry	17	33	49.02	0.18
Shirlan as per Negfry	25.5	10.9	49.64	0.00
L.S.D. (0.05)	11.19	333.54	5.11	0.11

Table 4. Effect of fungicide treatment on delay in disease onset and AUDPC (Oak Park, 1997).

Treatment Code	Delay in disease onset (days)	AUDPC
Unsprayed	0	2980.78
Dithane DF	24.5	363.65
Dithane DF (Air-assisted)	26.25	420.35
Ridomil Gold fb Dithane DF	29.75	299.25
Dithane DF on Met. Warnings	3.5	1505.09
Dithane DF as per Negfry	15.75	777.53
Dithane DF as per Negfry (Air-assisted)	10.5	591.50
Ridomil Gold fb Dithane DF as per Negfry	17.5	827.05
Shirlan as per Negfry	12.25	596.05
Shirlan as per Negfry (Air-assisted)	12.25	761.95
L.S.D. (0.05)	10.10	430.17

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Distribution of metalaxyl resistance, mating type and physiologicalraces in Irish populations of *Phytophthora infestans*. a preliminary report

D. GRIFFIN[1], E. O'SULLIVAN[1], M.A. HARMEY[2] & L. J. DOWLEY[1].

[1] Crop Protection & Breeding Department, Oakpark Research Centre, Carlow, Ireland.

[2] Department of Botany, University College Dublin, Belfield, Dublin 4, Ireland.

Keywords: *Phytophthora infestans*, phenylamide resistance, mating type, virulence genes, Ireland.

Abstract

Irish populations of *Phytophthora infestans* are monitored annually for phenylamide resistance and mating type. Phenylamide resistance has remained reasonably static over the last seven years following the introduction of an anti resistance strategy. The incidence of the A_2 mating type has decreased from 35% in 1988 to 2.6% of the population in 1996. The physiological race structure of the population was surveyed in 1996 and was found to be diverse. The population contained 17 different races of the fungus. All isolates were avirulent to R8 and R9. Isolates virulent to R1 and R2 were found but at very low levels.

Introduction

The appearance of phenylamide resistance (Dowley & O'Sullivan 1981) and the subsequent arrival of the A_2 mating type (O'Sullivan & Dowley, 1991) indicates that the Irish population of *P. infestans* is in a dynamic state. Metalaxyl resistance was first confirmed in 1980 when some crops sprayed with metalaxyl were observed to have higher levels of foliage blight than mancozeb sprayed crops. The following year all phenylamide products were withdrawn from the Irish market and a monitoring programme was initiated to detect changes in the distribution of phenylamide resistance. Resistance was at its highest immediately after the withdrawal

of the phenylamide products and fell rapidly to 6% in 1983. In 1985 phenylamides were re-introduced to the Irish market as pre-pack combinations with mancozeb. An anti-resistance strategy aimed at limiting the build up of resistance was developed for their use (Dowley *et al*, 1995). Phenylamide resistance monitoring has been reviewed up to 1989 by Dowley & O'Sullivan (1991). The results from 1990 to 1997 are presented here.

It was generally accepted that the A_2 mating type was confined to Mexico (Gallegly & Gallindo 1958). The A_2 mating type began to appear around the world in the early 1980's (Hohl & Iselin, 1984). The A_2 mating type was first confirmed in Ireland in 1987 (O'Sullivan *et al*, 1995). Due to the possibility of mating crosses between the A_2 and indigenous A_1 mating types, fears arose that the European population of *P. infestans* could produce fitter and more resistant strains which in turn would lead to greater control problems. Monitoring of populations for mating type is carried out each year.

Experience from other countries has shown that populations of *P. infestans* tended to become more complex with respect to race specialisation (Malcolmson 1969). Previous work in Ireland has borne this out. In the early 1960's Races 4 and 1.4 were the most common (Anon. 1963). By the early 1980's however races were found to be significantly more complex (O'Sullivan & Dowley, 1983). A survey of physiological race specialisation was carried out using isolates from samples received for phenylamide resistance monitoring in 1996

Materials and Methods

Crops in the main potato growing areas of the country were sampled at random. Four individual samples of 100 infected leaflets were taken per crop except where the crop size was less than 1 ha. Phenylamide resistance was determined for each sample using the leaf disc method (Dowley & O'Sullivan, 1985). *P. infestans* was isolated into pure culture from randomly selected lesions using the methods of O'Sullivan *et al.* (1995). The cultures were maintained on rye A agar (Caten & Jinks, 1968). Mating type was determined by pairing each isolate with reference A_1 and A_2 isolates on V8 agar (Ribeiro, 1978).

Races of *P. infestans* were determined by their reaction on leaf discs of indicator plants possessing R genes 1 to 11. Suspensions in sterile distilled water containing approximately $1*10^6$ sporangia per ml were prepared from 3 week old cultures. These were incubated at 10°C for

2h to induce zoospore formation. Leaf discs, floating on distilled water (5 per petri dish, 1 petri dish of each indicator for each isolate) were inoculated on the abaxial surface with a 20µl drop of each zoospore suspensions. The leaf discs were then incubated in a lighted incubator simulating daylight hours at 18-20°C and examined after one week. Races were determined by the production of hypersensitive reactions or necrosis with sporulation on the differential indicator discs.

Results

Phenylamide Resistance

A total of 807 leaf samples were collected from 349 crops over the period 1990 to 1997. Average resistance over the eight years was 50.75% (Table 1). Resistance varied from 38% in 1992 to 71% in 1995. The number of crops with resistance present appear to have levelled off in recent years to about 50% of crops sampled.

Table 1.   Frequency of phenylamide resistance in populations of *P. infestans* 1990-1997.

Year	No. Samples	No. Crops	Resistant %	Intermediate %
1990	122	50	57	0
1991	90	40	40	0
1992	96	43	38	0
1993	112	49	55	1.8
1994	116	37	49	0.9
1995	41	26	71	0
1996	124	50	51	2.3
1997	106	54	45	1.8
Totals	807	349	50.75%	6.8%

Mating type

Over the period 1988 -1997, 447 isolates of *P. infestans* were collected from 220 crops in the Republic of Ireland and tested for mating type. Twenty two (10%) were of the A_2 mating type and 2 (1%) were self fertile (Table 2). The level of the A_2 mating type was highest in 1988-89, (35%) and decreased substantially in subsequent years. In 1993 and 1994 the A_2 isolates were found only in a single crop each year. All the A_2 isolates found in the Republic of Ireland were metalaxyl sensitive.

Table 2. Frequency of the A2 mating type of *P. infestans.*

Year	Isolates			
	No. tested	A2	Self-fertile	A2 (frequency %)
1988-89	26	9	1	34.6
1990	13	3	0	23.1
1993	71	2	1	2.8
1994	139	4	0	2.9
1995	114	0	0	0
1996	153	4	0	2.6
Total	447	22	2	11

Physiological race specialisation

In 1996 physiological races were determined for 148 isolates of *P. infestans*. Race 3.4.7.10.11 was the most common (Table 3). Race 4.10 was the most simple and race 1.2.3.4.5.6.7.10.11 the most complex detected. All isolates from the 1996 population of *P. infestans* were avirulent to R8 and R9 while all isolates tested were virulent to R4. Virulence to R10 and R11 was also confirmed in 97% of isolates.(Table 4).

Table 3. Frequency (f) of races of *Phytophthora infestans* in 1996 as percentage of total.

Race	f	Race	f
4.10	0.7	4.6.7.10.11	0.7
3.4.7	2.7	1.3.4.7.10.11	1.4
4.10.11	14.2	3.4.5.7.10.11	10.8
1.4.5.11	0.7	3.4.6.7.10.11	0.7
3.4.10.11	3.4	3.4.5.6.7.10.11	3.4
4.7.10.11	4.1	1.2.3.4.6.7.10.11	1.4
3.4.7.10.11	54.1	1.3.4.5.6.7.10.11	0.7
4.5.7.10.11	0.7	1.2.3.4.5.6.7.10.11	0.7

Table 4. Frequency of virulence to R genes in the 1996 population of *P. infestans.*

R genes	R0	R1	R2	R3	R4	R5	R6	R7	R8	R9	R10	R11
Virulent isolates (%)	100	5	2	79	100	17	7	81	0	0	97	97

Discussion

The results presented show that the Irish population of *P. infestans* has altered significantly over the last fifteen years. The level of phenylamide resistance appears to be linked to the use of phenylamide products. Resistance was at its highest in the 1981-82 and 1988-89 seasons, just after the withdrawal of phenylamide products from the Irish market and following their subsequent re-introduction (Dowley & O'Sullivan, 1991). The stabilisation in the distribution of phenylamide resistance in crops to about 50% over the last seven years may be attributable to the adherence of potato growers to the use of phenylamide products according to an anti-resistance strategy (Dowley *et al.,* 1995).

The A_2 mating type was first detected in Ireland in 1989 (O'Sullivan & Dowley. 1991). The frequency of its occurrence was initially high (35%), but decreased steadily until 1995 when no A_2 was found. In 1996 however the A_2 was again confirmed in 2.7% of isolates. Prior to 1996 the A_2 was found only on the cultivars Cara, Kerr's Pink and Golden Wonder. The 1996 A_2 isolates were found on differential blight indicators grown as part of a cultivar field resistance screening trial at Oak Park. The occurrence of all the A_2's at one site combined with the steady decline in its occurrence and its absence from sampling in 1995 may suggest that the A_2 is present at a much lower level than 2.7% of the population. The steady decline of the A_2 suggests that A_1 strains present in Ireland may be fitter or better adapted to climatic conditions. The low level of the A_2 also suggests that sexual recombination does not take place regularly if at all and hence oospore inoculum is not a significant factor in the epidemiology of the disease at present in Ireland.

The extensive variability and increasing complexity of *P. infestans* for virulence genes has been demonstrated by many workers (Malcolmson, 1969; Schöber & Turkensteen, 1992). Malcolmson reported the existence of over 70 pathotypes of *P. infestans* in Britain as early as 1960. Dowley & O'Sullivan (1983) identified 4 different races, two of which were complex. This was in contrast to earlier investigations which showed that race 4, and 1.4. were the most abundant in the population (Anon. 1963). In 1996 seventeen races were identified with 4.10 being the most simple and 1.2.3.4.5.6.7.10.11 the most complex. Race 3.4.7.10.11 dominated the population with over 54% of the isolates tested carrying this genotype. No isolate tested was able to infect the R_8 and R_9 differentials. This was confirmed in 1997 when the R_8 and R_9 differentials sown in the field remained uninfected. All isolates were able to infect the R_4 dif-

ferential while 97% of isolates were able to infect the R_{10} and R_{11} differentials. Of great interest was the low level of isolates virulent to R1 and R2 in the population. Race 1 has been one of the most commonly found races in the previous surveys mentioned but appears to be very rare at present. Also race 2 was present at a very low level. It has been noticed that breeders clones carrying the R_2 gene in Ireland remain uninfected for 2-3 weeks after the initial outbreak of late blight. This may prove useful for breeding programmes in the future. For many of the races present in the Irish population, corresponding R genes were not found in commonly grown Irish cultivars. R_1 and R_2 are the most commonly found R genes in Irish cultivars, yet the corresponding virulence genes were only found at a very low level. It has been found by many workers that populations of *P. infestans* carry virulence genes which may not exert any influence on infectivity (Andrivon 1995).

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Second Workshop of an European Network for Development of[6]
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Problems with forecasting potato blight in
England and Wales, 1994-1997

N.J. BRADSHAW[1]

M.C. TAYLOR[2] & N.V. HARDWICK[2]

[1]ADAS, St Agnes Road, Cardiff CF4 4YH, UK

[2]Central Science Laboratory, Sand Hutton, York YO4 1LZ, UK

Summary

Using frequently recorded in-crop weather data from each of five widely dispersed locations during 1994-1997, the Blitecast™, NEGFRY, Sparks, Schrödter & Ullrich and Smith Period potato late blight forecasting systems were evaluated. Comparisons were made with respect to time of first blight warning, the first occurrence of blight and the number of sprays recommended compared to a routine programme. No single system proved effective at all sites in all years. The schemes varied widely in their ability to predict the date of blight infection and the number of recommended fungicide sprays even when challenged with the same meteorological data. Of all the systems evaluated only the Smith Period was consistently successful in triggering spray applications prior to blight appearing in the crop. It is concluded that the Smith Period is still an effective forecasting scheme despite often warning of infection too early, as it is the least likely to fail.

Key words: potato blight, forecasting

Introduction

The forecasting of potato late blight caused by *Phytophthora infestans* (Mont.) deBary by use of meteorological data was first undertaken in England and Wales in 1931 using the 'Dutch Rules' (Beaumont, 1947; van Everdingen, 1926). Subsequently only two schemes have been

in widespread use in the UK, the Beaumont Period (Beaumont, 1947) since 1950 and the Smith Period (Smith, 1956) since 1975. The forecasts are based on data received from the network of synoptic weather stations. These stations, frequently sited at airfields, are not necessarily close to the major potato growing areas (Figure 1). The advent of inexpensive dataloggers linked to sensors capturing weather data can be used to provide in-field data which may improve the precision of forecasting schemes (Hims *et al.*, 1995). This paper compares selected forecasting schemes under UK conditions.

Materials & Methods

Five existing programs were compared over four years - Smith (1956), Sparks (1984), Schrödter and Ullrich (1967), Blitecast™ (1975) and NEGFRY (1995). Data were collected from in-crop meteorological stations via cellphone analogue networks at six sites: Starcross in Devon, Trawsgoed in Dyfed, Harpenden in Hertfordshire, Arthur Rickwood in Cambridgeshire, Stockbridge House and High Mowthorpe in North Yorkshire. These sites were chosen in order to provide a range of disease pressures and crop development relative to infection date. The cultivar chosen was King Edward which is susceptible to both foliar and tuber blight (NIAB rating of 3 and 2, respectively, Anon., 1997).

The number of days between the actual date when blight was found in the crop and the time to initiate the spray programme as dictated by the various forecasting schemes was examined. The ideal number of days was judged to be fourteen. Such a gap would allow growers using the forecasting scheme enough time to make up to two protective fungicide applications before the disease would otherwise enter the crop (Large, 1957). Additionally the number of sprays ap-

Figure 1. Distribution of potato fields and weather stations.

plied under each system in the absence of blight was recorded.

Results

Figures 2-5 show the relative performance of each of the schemes at the sites where field experiments were held. The zero day represents the date of blight outbreak in untreated foliage so bars to the left are first warnings before blight appeared while those to the right are warnings after the disease entered the crop. The dotted vertical line is the ideal fourteen day interval between the first warning and a subsequent blight outbreak, bars terminating close to the line have performed best for that site/year combination.

In 1994, all schemes except Smith failed to predict the first occurrence of blight at Trawsgoed. At High Mowthorpe, Sparks and NEGFRY predicted the outbreak too close to be practical and Blitecast™ failed to predict blight by a day. At Arthur Rickwood all schemes warned before the blight attack but only the NEGFRY and Schrödter & Ullrich systems were close to the fourteen day interval. At Starcross, a traditionally high risk blight location, all schemes warned well in advance of the actual outbreak (Figure 2).

In 1995, all systems except Smith and Sparks failed at Starcross, but even Smith and Sparks, at 10 days were below the 14-day optimum. Trawsgoed exhibited a reverse from the previous year with all schemes warning in advance but by too much in all cases. High Mowthorpe exhibited the most consistent results although Smith was too premature and Blitecast™ below the fourteen day optimum (Figure 3).

In 1996, the ability of the schemes to predict accurately the first outbreak showed a great degree of inconsistency. At High Mowthorpe only Smith and Sparks gave a warning well before the outbreak while NEGFRY and Schrödter & Ullrich were too close to the outbreak day and Blitecast™ failed altogether. At Trawsgoed all schemes gave a warning too far in advance, apart from Blitecast™ which on this occasion was very close to the ideal. At Starcross all the systems were too safe, giving warnings ranging from 35 days (NEGFRY) to 53 days (Smith and Sparks) in advance of the blight outbreak (Figure 4).
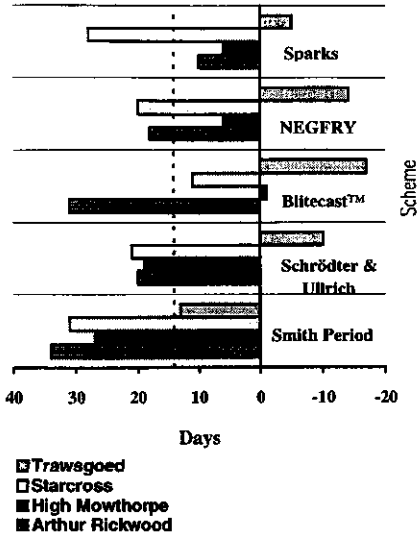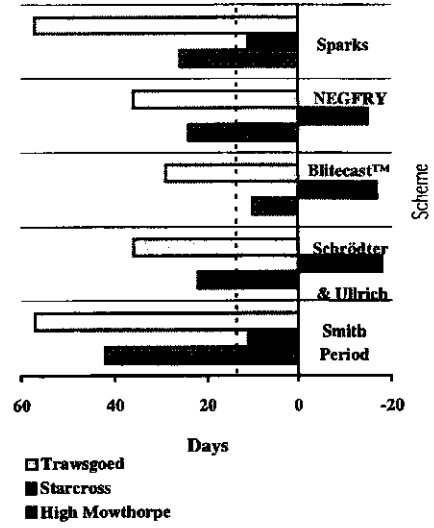
Figure 2. Forecasting scheme performance, 1994.

Figure 3. Forecasting scheme performance, 1995.
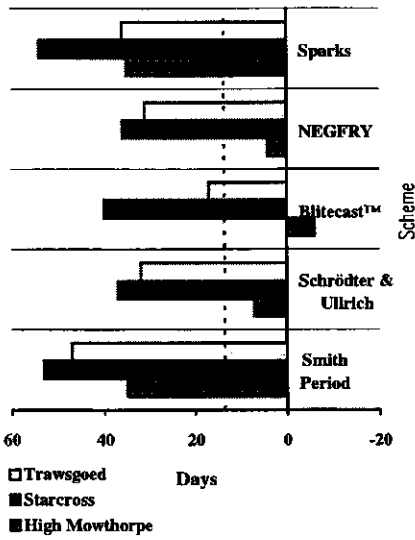

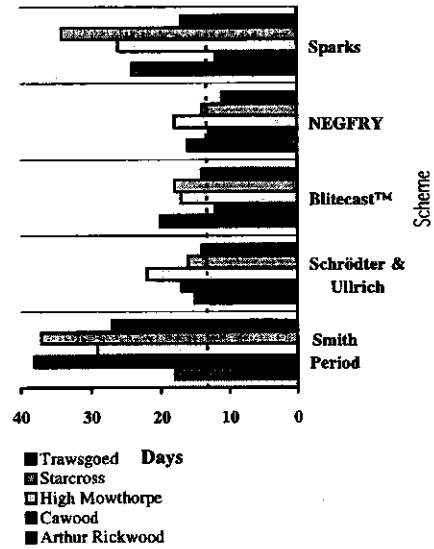**Figure 4. Forecasting scheme performance, 1996.**

Figure 5. Forecasting scheme performance, 1997.

In 1997, considered to be a major blight year, all schemes successfully predicted blight at all sites. NEGFRY, Blitecast™ and the Schrödter & Ullrich schemes performed better than in the previous years getting close to the ideal warning at Cawood and Trawsgoed in particular. Sparks and Smith gave more advance warnings in general apart from Sparks at Cawood and Smith at Arthur Rickwood. Despite the overall improvement in timing of the advance warning there were still large variations in the interval between forecast and first recorded blight outbreak, ranging from 38 days with Smith down to 10 days with NEGFRY (Figure 5).

A comparison of the number of sprays that would have been applied under the warning schemes at sites where blight was not recorded shows that Smith and Schrödter & Ullrich use the most sprays, up to eight at Harpenden in 1995. Blitecast™ and Sparks recommended the least number overall with never more than two unrequired sprays. Blitecast™ was the only scheme that accurately predicted no applications, interestingly at the Harpenden 1995 site. NEGFRY was inconsistent, ranging from one unnecessary application at Arthur Rickwood in 1995 to six at Harpenden in 1994 and 1996 (Figure 6).
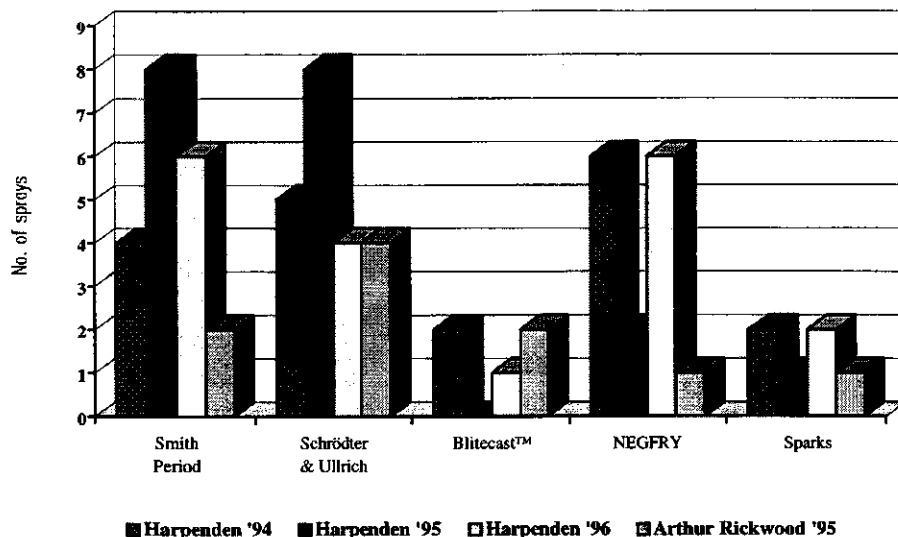

Figure 6. Number of sprays advised despite the absence of blight.

Discussion

The results for 1994 to 1996 represent years when blight was at low levels and crops were not considered to be at great risk. There was great spatial and temporal variation in the performance of the schemes, with some indicating blight almost 60 days prior to its occurrence and

others 18 days afterwards. The variability in the performance of the schemes is a cause for concern. Microclimatic variation is likely to play a part in causing problems for the schemes, damp hollows, tree shading and differential rates of foliage growth would influence the in-field conditions and even in-crop sensors could not account for such complexity (Bourke, 1953). Additionally, information regarding the sources and amount of blight inoculum is not taken into account by any of the forecasting schemes. Such information would obviously be vital for the success of a forecasting system but is difficult to measure and use in compiling spray advice. The current schemes prefer to assume that blight inoculum is never limiting which is the safest option but this clearly leads to disease warnings occurring too early.

To be acceptable to farmers a blight forecasting scheme must aim to achieve a 100% success rate. The schemes tested in this study were at their least reliable in drier years when low or intermediate blight risk occurred. Spray programmes were either initiated too far in advance of blight infection, including instances where disease did not occur, or failed to give sufficient warning for growers to protect their crops adequately. These were the years when the potential for forecasting schemes to reduce unnecessary fungicide applications was at its greatest. Conversely, in a high blight risk year the schemes were more reliable but less likely to recommend fewer fungicide sprays than a routine programme and improve the economics of production.

Forecasting systems designed to be used with in-crop weather data taken from a single meteorological station may be too precise and therefore subject to failure. Only the Smith Period did not fail to warn of forthcoming blight infection. It is concluded that more generalised but robust systems are likely to be of more practical value to potato growers.

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Experiences with PLANT-Plus in 1997

J. HADDERS

Dacom Automatisering bv, Postbus 2243

NL-7801 CE Emmen, The Netherlands

Introduction

The situation with Phytophthora was very critical in 1997. The DSS PLANT-Plus observed a possible infection period in late may and partially due to that period one of the most difficult Phytophthora years began. PLANT-Plus turned out to be a great help under those difficult circumstances. In the relative easy years 1995 and 1996 savings up to 40% occurred. In 1997 PLANT-Plus kept Phytophthora out of the fields where other fields were infected. In 1997 the savings in money were less, but the quality of the yield was a lot higher.

PLANT-Plus is based on a communication system that takes care of exchanging relevant (crop) data all over the world. Farmers record their fields and crop characteristics such as cultivar and date of emerge. During the season the farmer only has to record the sprayings, the fungicide and the applied dose. All other necessary information is brought into the system automatically.

The central, integrated Climate Interface (CI) guarantees the use of any type of weather station located anywhere in the world. This CI also adapts the regional weather forecast for use with PLANT-Plus. Infected plots in the area define the possible spore pressure on the fields. The farmer or his scout observe the crop growth and crop state for an exact calculation in that specific crop. All gathered data is worked up and presented in one graph that shows when to spray and the type of product to use.

Infected spots

In 1997 the weather conditions in the Netherlands for Phytophthora were very favourable for a long period. The first infected plots were found in the beginning of June and the number

rose quickly during the season. All fieldworkers involved in potato growing have agreed to record the infected plots in PLANT-Plus. Based on this information weekly reports in journals and magazines inform farmers about the infected plots in their region (Figure 1).

Figure 1.   Observed infections of Phytophthora in the Netherlands on july 3th.
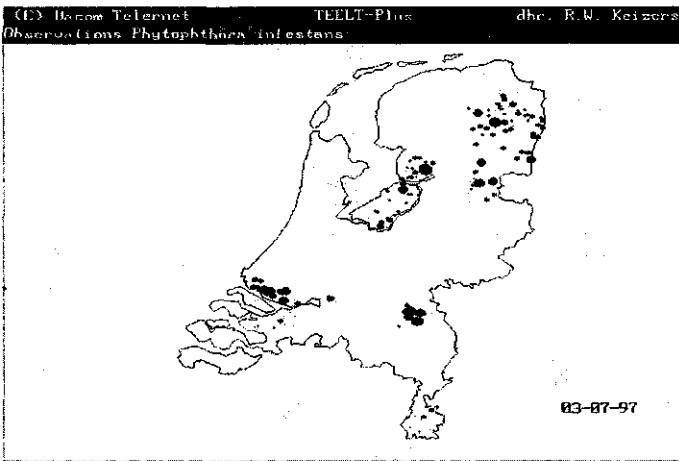

With PLANT-Plus the farmers can also see the infected plots around their fields in more detail. By running through the days the development of the infections can be monitored. The fieldworkers record various sources of infection, such as volunteers, waste piles, normal and organic fields and hobby gardens.

Climate interface

Weather data play a very important role in PLANT-Plus. The development of Phytophthora is calculated based on temperature, relative humidity, wind speed, wind direction, radiation and rainfall. The different stages in the life cycle are influenced in different ways by those factors. The CI can work with any type of weather station. In 1997 PLANT-Plus worked with approximately 50 weather stations in the Netherlands (Figure 2).

These weather stations are manufactured by Pessl (AU), Skye Instruments (UK), ELE (UK), DELTA-T (UK), Adcon (AU) and Opticrop (NL). The type of weather station is not very important, it is more important that the sensors are accurate and frequently calibrated.

Figure 2. Use of weather stations with PLANT-Plus in the Netherlands in 1997.
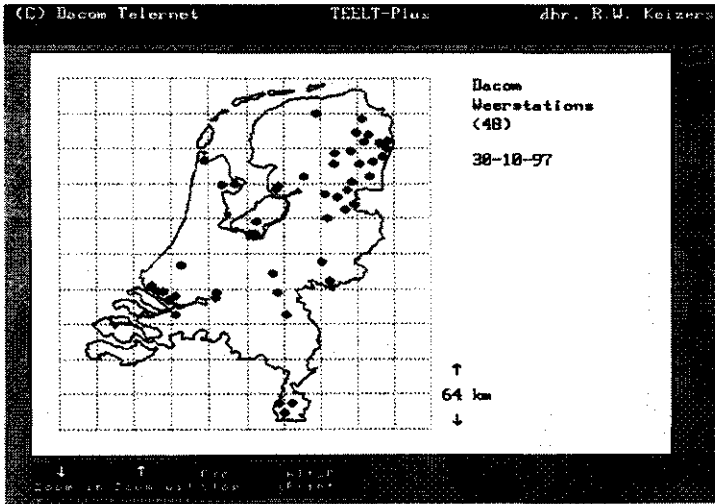

For use with PLANT-Plus the stations have to be installed outside the crop. The crop climate is calculated with the crop data that is recorded by farmer or his scout. This way one weather station can be used for calculations in more than one crop.

Advice

The spraying advice in PLANT-Plus is mainly based on one graph that shows all the information the farmer needs. With just a quick glance the farmer knows what to do. An example of such a graph is shown in figure 3.

Figure 3. Spraying advice in PLANT-Plus.
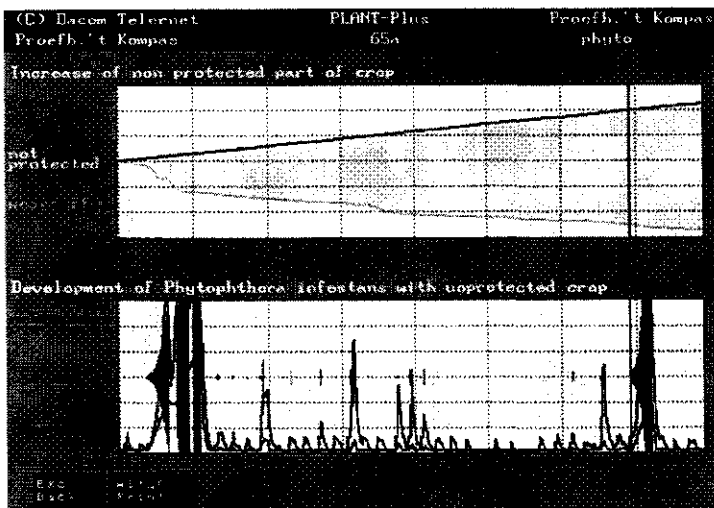
This graph shows the situation for the specific crop and starts with the date of the last spraying. Historical data of the connected weather station is used to calculate until the present moment (purple line). The weather forecast is used to calculate up to five days ahead. The top half of the graph shows the unprotected part of the crop. Unprotection is caused by growth of new leaves or degradation of the used prod-

uct. The unprotectiveness of the crop is related to the infection possibilities of Phytophthora that are shown in the bottom half of the graph. Three stages of the fungus are visualised here: the formation of spores, the airborne of spores and the germination of spores. When the last step is completed successfully with a substantial amount of spores, PLANT-Plus indicates an infection possibility. When there is also a great amount of unprotected leaves PLANT-Plus advises to spray. When there was an infection last day a local systemic of semi-curative product will be adviced. If the forecast indicates a infection a protectant of contact product will be advised. In PLANT-Plus the development of the fungus is more or less independent of the last treatment. When there are great infection possibilities a new spraying can already be recommended after four days. If there are no infection possibilities at all, the interval can go over four weeks.

Fieldtrial

In 1997 field trials were conducted at Research Centre 't Kompas to compare the effect and the costs of standard practice (weekly treatments with contact) in relation to use of PLANT-Plus. Figure 4 shows the leaf infection of Phytophthora (red line) and the costs of the strategy. Weekly treatments (15) are fairly cheap, but could not manage to keep Phytophthora out of the crop in 1997. PLANT-Plus advised 12 treatments.

With PLANT-Plus different product strategies were compared, but all strategies managed to keep the infection severity to the acceptable level of a few leaves. Compared to Weekly Maneb-Tin and additional sprayings with Ridomil to cure infections, PLANT-Plus with Shirlan as contact and Curzate as local systemic product saved about Hfl. 150,- per hectare.

Farmers will be very interested in the results of field trials, but even more in results of farmers who worked with PLANT-Plus for a few years. Figure 5 shows the results with PLANT-Plus in starch potatoes from 1995 to 1997.

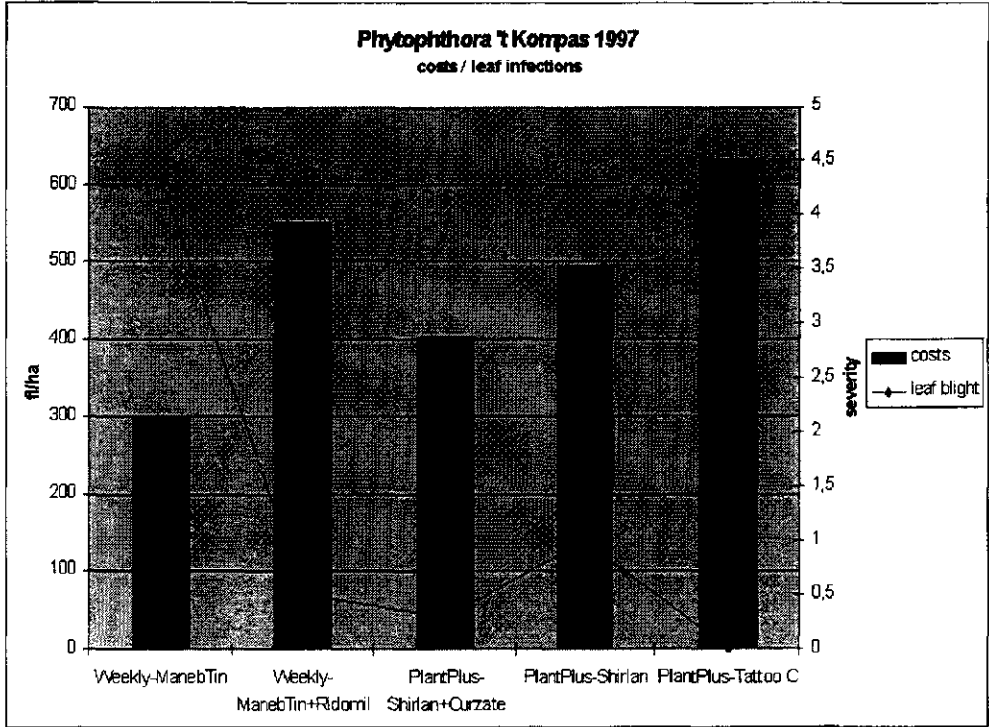**Figure 4.** **Results of fieldtrial at Research Centre 't Kompas in 1997.**
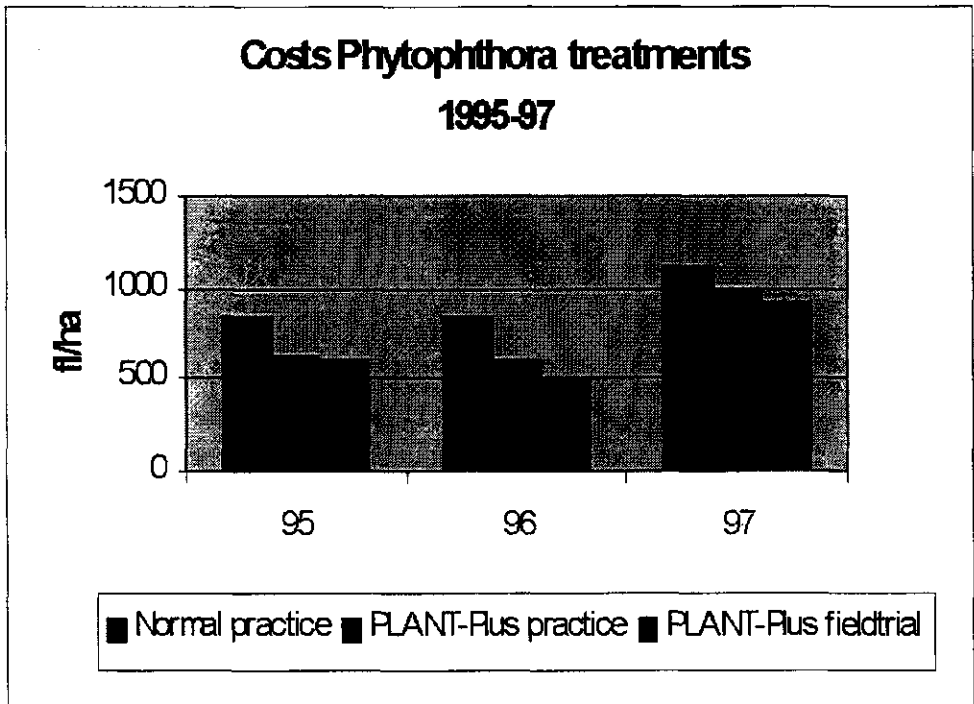

Figure 5. **Costs of Phytophthora treatments in starch potatoes in 1994-'97.**

Here the difference between the years can be seen. Where 1995 en 96 were rather easy years, 1997 was a very difficult season. This results in a higher necessary input of chemicals to prevent infections. In every year with PLANT-Plus savings were possible. The savings in 95 and 96 were higher than in 97.

Future

In 1997 demo projects were started in Austria and Great Britain. In 1998 PLANT-Plus will have an online Internet connection to access data from all over the world. This means PLANT-Plus can easily be used where there is weather data available.

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Use of Smith periods and risk monitors in potato blight forecasting in Northern Ireland

L. R. COOKE[1,2] & G. LITTLE[1]

[1]Applied Plant Science Division, Department of Agriculture for Northern Ireland,
[2]Department of Applied Plant Science, The Queen's University of Belfast
Newforge Lane, Belfast, Northern Ireland, BT9 5PX, UK.

Abstract

During 1993-97, an automatic weather station located on the outskirts of Belfast was used to determine the occurrence of Smith Periods in Northern Ireland. In each year, the first Smith Period preceded the first report of late blight. In 1994-97, Smith Periods were an effective predictor of initial blight outbreaks. However, in 1993, the interval between the first Smith Period and the first blight outbreak was so short that infection must have preceded the Smith Period. The incidence of Smith periods was not clearly related to blight reports within seasons or to incidence on seed crops at the end of the season. In 1997, four Blight Risk Monitors (Farm Electronics) located at sites in Cos. Down and Londonderry recorded a pattern of Infection Periods similar to that from the automatic weather station in Belfast.

Keywords:_Phytophthora infestans_, potato late blight, Smith Period, forecasting

Introduction

In Northern Ireland, in most years weather conditions during the June-September period favour moderately severe or severe outbreaks of potato blight. The Department of Agriculture for Northern Ireland (DANI) is responsible for issuing Potato Blight Warnings to growers. The objectives of the blight forecasting system are:

 - to indicate to growers when to start spray programmes
 - to inform growers when to modify spray interval

Potato Blight Warnings are given via *'Blightline'*, a 24 h recorded telephone information

service on potato blight operated by APSD staff between June and August each year, via local radio and through press releases issued to the local farming press.

Smith Periods have been used for many years for blight forecasting in Northern Ireland. A Smith Period is defined as two consecutive 24 hour periods in which the minimum temperature does not fall below 50°F (10°C) and there are at least 11 hours of 90% or greater relative humidity (R.H.) on each day (Smith, 1956). The 24 hour periods start at 9 a.m. G.M.T., 10 a.m. British Summer Time (B.S.T.).

Before 1993, temperature and humidity data were provided by the Meteorological Service from the main Northern Ireland Meteorological Station at Belfast International Airport, Aldergrove. However, the increasing cost of data dictated a switch to the use of an automatic met. station based at Newforge Lane, Belfast. In 1997, Blight Risk Monitors, purchased from Farm Electronics, were sited at four different locations in Northern Ireland. In this paper, we describe the incidence of Smith Periods in Northern Ireland in the last five years and compare this with the occurrence of blight outbreaks as reported by the DANI Potato Inspectors and Advisers. We also report results with the four Blight Risk Monitors in 1997.

Materials & Methods

Inputs - Meteorological Data
Meteorological data (temperature and humidity) are provided by an ELE automatic met. station sited at Newforge Lane, Belfast adjacent to an official Met. Station (Stevenson Screen). Readings are taken every 10 min. and converted to hourly records, which are off-loaded daily between June and September shortly after 10 am B.S.T. The data are processed on a P.C. using ELE Dialog software and used to calculate Smith Periods. Some empiricism is used when deciding whether to issue a Blight Warning if conditions fall just outside strict Smith criteria in terms of either minimum temperature or hours of 90% R.H. The readings are compared with those from the official Met. Station as a quality control (this manual Station cannot provide the necessary hourly humidity records).

Inputs - Risk Monitors
In 1997, four Blight Risk Monitors were obtained from Farm Electronics at a cost of *c.* £350

each (Anon., 1996). These monitors are simple, free-standing devices which incorporate a temperature and humidity sensor. Once a start time is set, they count up the number of hours each day when the temperature is 10°C or more and the R.H. is 90% or more. If the number of such 'Risk Hours' is 11 or greater, the monitor indicates a risk of blight infection. Thus, if recording is started at 10 am, two consecutive risk days are equivalent to a Smith Period (except the monitors will indicate infection if more than 11 risk hours have been recorded regardless of whether the temperature has fallen below 10°C outside the Risk Hours). The monitors can display data for the last five days, but must be read manually and cannot be networked.

The Risk Monitors were initially set up adjacent to the ELE Met. Station and run for *c.* 2 weeks to check their performance. They were then given to DANI Agricultural Development Advisers and located at Downpatrick and Moira, Co. Down and Coleraine and Magherafelt, Co. Londonderry (Figure 1). The Advisers recorded the output each day as far as possible.

Inputs - details of blight outbreaks from DANI inspectors and advisers
DANI Potato Inspectors and Advisers report all early outbreaks of blight in Northern Ireland to Applied Plant Science Division (APSD) and these are used in Potato Blight Warnings. Potato Inspectors are also requested to provide samples of potato blight from crops in their areas (for use in the annual survey of phenylamide resistance in *Phytophthora infestans*) and the distribution of these provides an indication of the occurrence of infection.

Figure 1. Locations of automatic weather station and Blight Risk Monitors.

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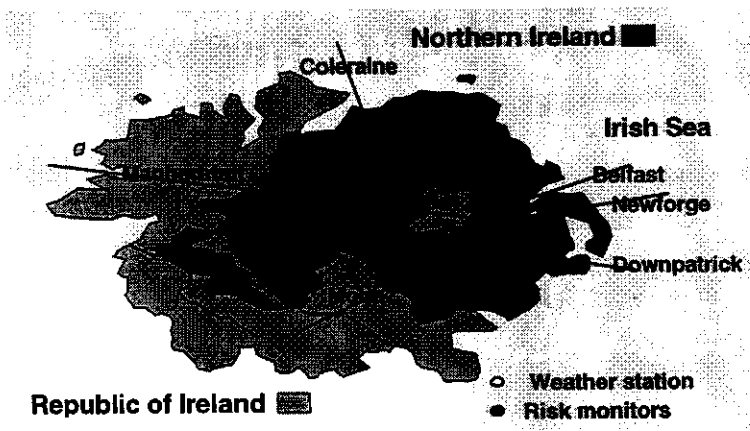
Results

Occurrence of Smith Periods in Northern Ireland, 1993-1997

Figure 2 shows the occurrence of days satisfying (or nearly satisfying) Smith criteria between 15 May and 15 September for each of the years 1993-1997. Full Smith Periods were not recorded before 27 May in any year. In Northern Ireland, night temperatures usually fall well below 10°C up to the beginning of June and the minimum temperature requirement prevents the earlier occurrence of Smith Periods. However, in 1997 there was a near Smith Period over the three days 17-20 May when the number of hours with over 90% R.H. totalled 69, but the minimum temperature fell to 9°C.

In most years, sporadic Smith Periods were recorded during June, but the bulk of Infection Periods occurred during July and August and continued into September. Statutory haulm destruction dates are set for seed potato crops in Northern Ireland usually before the end of August. After this only foliage of ware crops may be infected by blight and by late September most of these either burnt down or senescent.

Relationship between Smith Periods and initial blight outbreaks, 1993-1997

Initial blight outbreaks are most frequently observed in field crops in Northern Ireland (Figure 2), although the occasional infected potato dump is reported. In each of the years 1993-1997, Smith Periods occurred before blight was seen (if the near Smith Period 17-20 May 1997 is included). In 1994-97, the time which elapsed between the first Smith Period and the first reported blight outbreak varied from 9 to 20 days (Table 1). In 1993 blight was seen in one field (and on a dump in a different location) only one day after the first Smith Period, so this infection must have pre-dated the Smith Period.

Table 1. Occurrence of Smith Periods and initial blight outbreaks, 1993-97.

Year	First Smith Period (A)	First blight report (B)	Time (days) A to B
1993	29-31 May	1 June	1
1994	19-21 June	30 June	9
1995	27-31 May	20 June	20
1996	9-11 June	28 June	17
1997	17-20 May	30 May	10

It is harder to relate Smith Periods to blight incidence within seasons as indicated by blight reports and samples received (Figure 2). This may be partly because sampling later in the season is not necessarily a reliable indicator of blight incidence. The Potato Inspectors also provide estimates of the number of crops with >5% blight at haulm destruction, but this does not appear to be related to Smith Periods (Table 2).

Table 2.   Number of Smith Periods and foliage blight incidence, 1993-97.

Year	No. of "Smith days"	No. of Infection Periods	No. of days in Infection Periods	Seed crops (%) with >5% blight
1993	19	5	12	13
1994	35	7	25	8
1995	46	10	37	0
1996	58	10	53	3
1997	69	13	66	n/a

Occurrence of Infection Days recorded by Risk Monitors at four sites in Northern Ireland compared with Infection periods recorded at Newforge, Belfast

In the initial assessment of the four Risk Monitors at Newforge, Belfast, when they were located adjacent to the ELE Met. Station, it was concluded that they tended to over-record Risk Hours slightly, but that the difference was not great enough to impair their usefulness. Figures 3a and 3b show the outputs of the Risk Monitors located in Co. Down and Co. Londonderry. The most striking feature was the similarity of occurrence of Infection Periods across Northern Ireland. All Monitors recorded prolonged Infection Periods in early June, sporadic Infection Periods in mid-June, followed by more Infection Periods in late June and very prolonged Infection Periods in July; there was surprisingly little evidence of regional variation. The reports of blight outbreaks have been assigned to either Co. Down or Co. Londonderry (those in Antrim and Tyrone being ignored for this purpose), but as with the Risk Monitor outputs, these do not show regional differences in their temporal distribution. Unfortunately, as the Risk Monitors were not set up in their final locations until the beginning of June, it was not possible to assess their value as predictors of initial outbreaks.

Discussion

The current blight forecasting system in Northern Ireland has the objectives of indicating a start date for fungicide spray programmes (growers are advised to apply the first spray when

a Blight Warning is issued or when plants touch within drills, whichever is earlier) and of modifying the spray interval. Applying fungicide sprays in direct response to Blight Warnings (other than at the start of the season) has not so far been attempted due to the difficulty of accurately timing sprays in Ireland's unsettled summer weather. Given these limited objectives, Smith Periods have performed reasonably well as a predictor of the first field outbreaks of blight and providing a start date for spray programmes. Within seasons, comparison of the occurrence of Smith Periods with reports of blight outbreaks suggests that Smith Periods tend to over-estimate blight risk, particularly in a season such as 1995 when there was high humidity, but relatively little rain. This is perhaps not surprising as Smith Periods are not intended as a forecasting system for use within seasons, although often used that way.

The Blight Risk Monitors provide an inexpensive adjunct to the Smith Period system and allow Advisory Officers to quote a local indication of risk to their client growers. It is encouraging that, at least in 1997, they indicated that there is reasonable uniformity of conditions favouring blight across the potato-growing regions of Northern Ireland. The same situation was noted in 1993, when met. data from Aldergrove (some 19 miles from Belfast on the Antrim plateau) and from Newforge, Belfast were compared. However, a more sophisticated forecasting system might show a greater degree of regional variation and provide a better correlation with blight incidence within seasons.
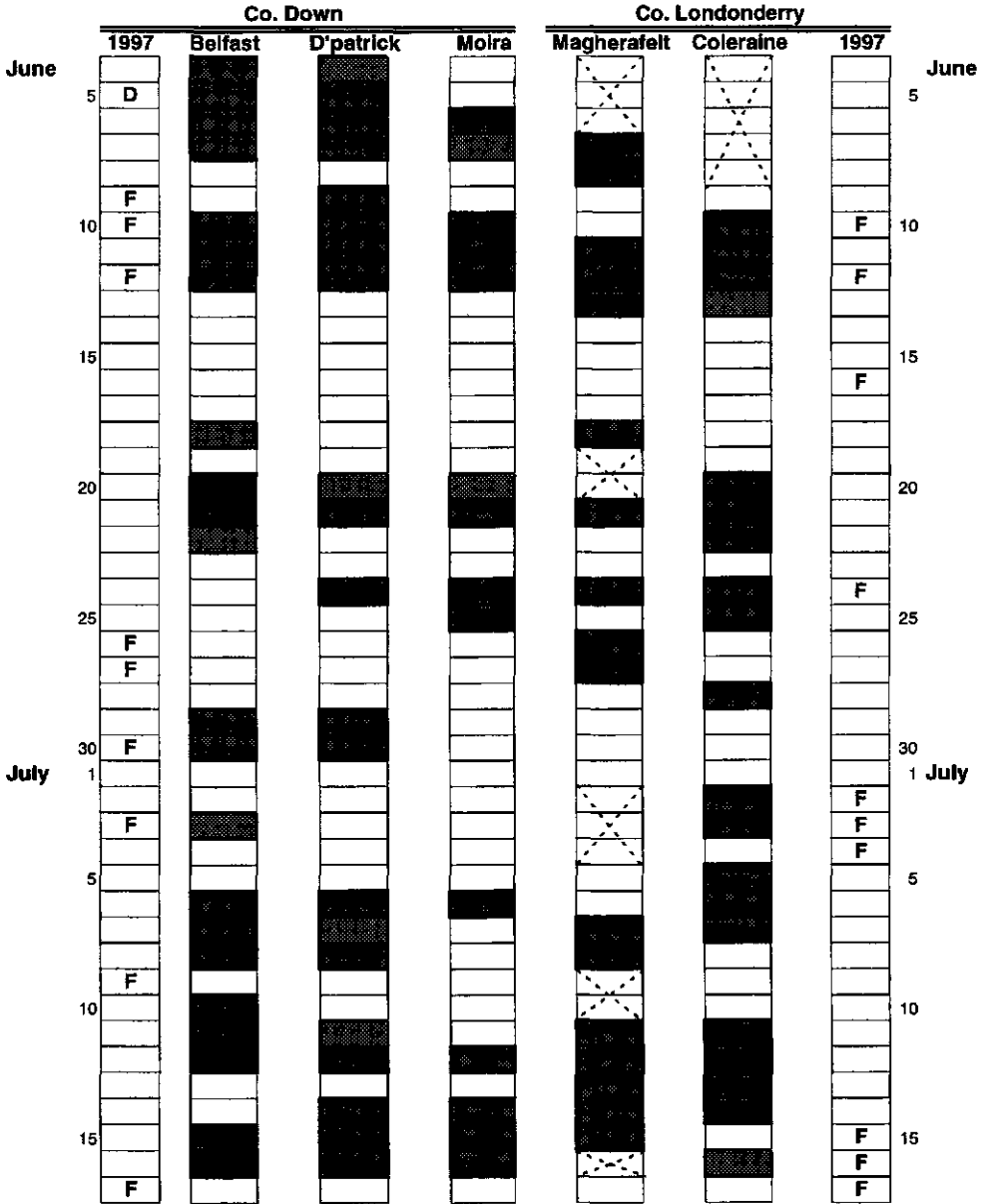
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Figure 2. Occurrence of Smith Periods and blight outbreaks, N.Ireland, 1993-97.
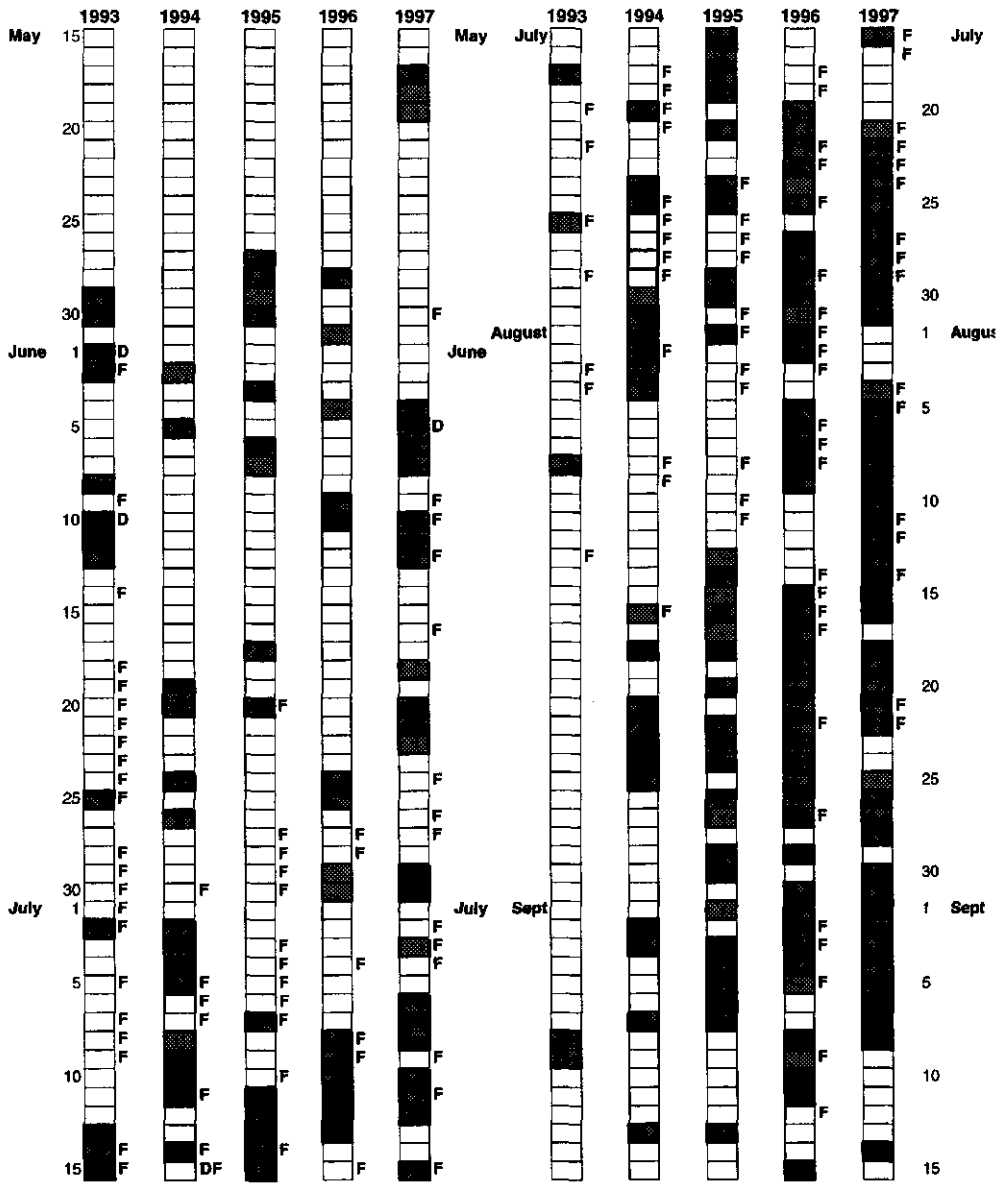
■ = 24 hours with min. temperature 10°C or more and at least 11 h of 90+% R.H.

▨ = 24 hours nearly satisfying Smith criteria

D = blight outbreak on dump   **F** = initial blight outbreak and blight samples from field cro

* in most years sampling is completed early August; details of outbreaks are not available after tl

Figure 3a. Occurance of Blight Infection days at five sites in N. Ireland, 1997.

Data at Belfast were recorded using an ELE automatic weather station

At 4 other sites, Blight Risk Monitors (Farm Electronics), were used to record "risk hours"

11 or more risk hours indicate infection ■ ; 10 risk hours indicate a near-miss ▓

Missing data are shown by dotted crossed lines   D = dump outbreak

F = initial blight outbreaks and blight samples received from field crops

Figure 3a. Occurance of Blight Infection days at five sites in N. Ireland, 1997.
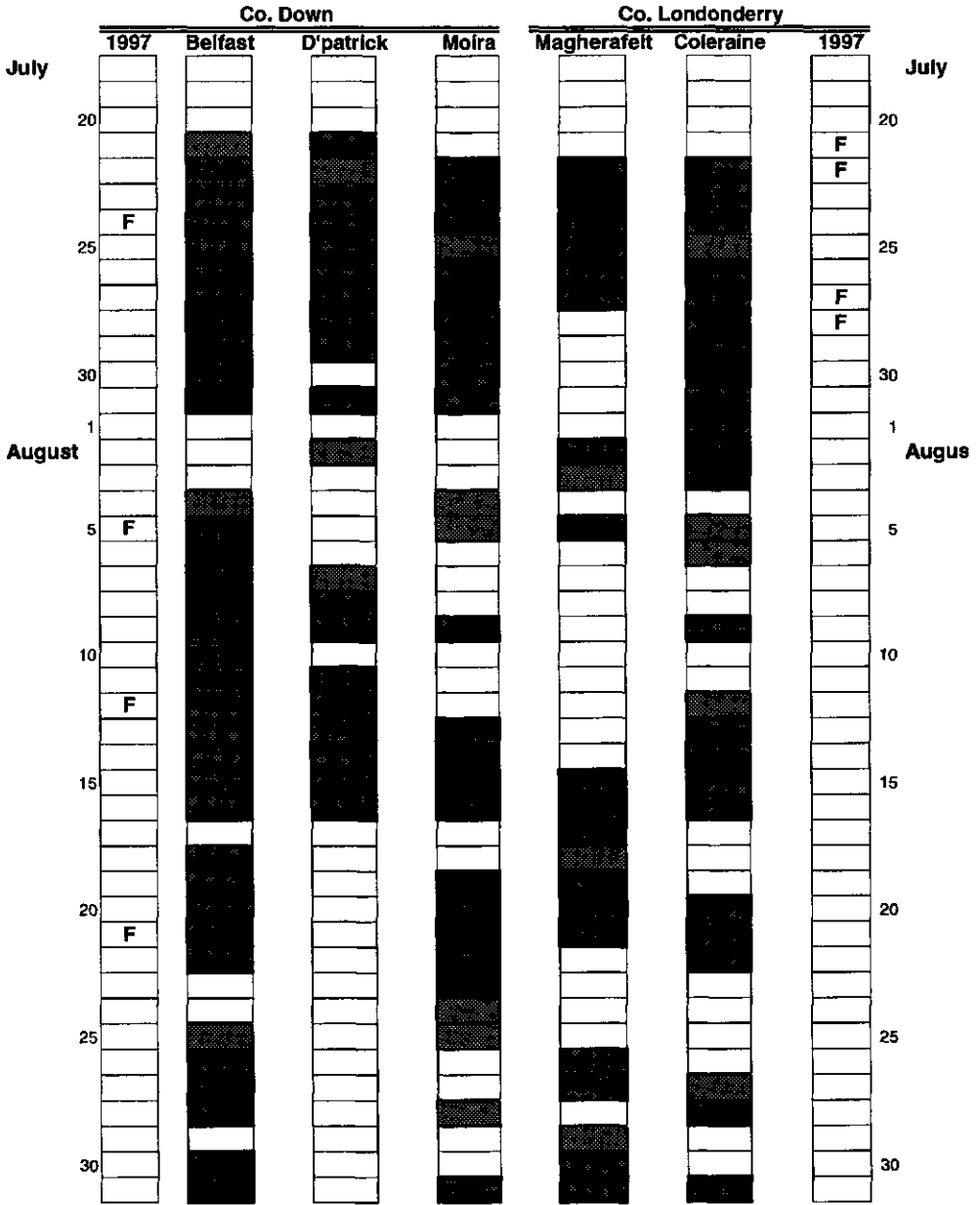

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At 4 other sites, Blight Risk Monitors (Farm Electronics), were used to record "risk hours"
11 or more risk hours indicate infection ▮ ;   10 risk hours indicate a near-miss ▨
Missing data are shown by dotted crossed lines   **D** = dump outbreak
F = initial blight outbreaks and blight samples received from field crops

Second Workshop of an European Network for Development of[3]
an Integrated Control Strategy of potato late blight
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Late blight warning service in Flanders:

experiences in 1997

M. GOEMINNE [*], P. VANHAVERBEKE [*], G. AMPE [**]

[*] PCA - Karreweg 6, B-9770 Kruishoutem, Belgium.
[**] PCA - Ieperseweg 87, B-8800 Rumbeke-Beitem, Belgium.

Abstract

The PCA - Centre for Applied Potato Research - in Flanders (Belgium) provides advice throughout the growing season on optimal time of application and type of fungicide to be used. The warning service makes use of the disease forecasting model of Guntz-Divoux, developed in France and modified in Libramont and Ath (Belgium). To record the necessary meteorological data, the PCA employs a network of 29 automatical weather stations. The theoretical disease model is complemented with information on actual blight pressure, development stage of the crop and the weather forecast. Typical features of the '97 season were the very early attacks of potato blight, and the agressiveness with which the disease spread. The theoretical model performed well enough, and proved to be an effective tool for determination of optimal spraying dates and explaining the development of the epidemic. However, the first attacks − in very early crops covered with plastic sheets − are more difficult to account for with the disease model.

Keywords: *Phytophthora infestans,* late blight warning, Guntz-Divoux, decision support systems.

Introduction

The PCA is an independent organisation that aims to support and improve potato cultivation in Flanders (the northern part of Belgium) through applied research and extension. Established in 1992 as a co-operation between the Provinces of West- and East-Flanders, which together account for approx. 30 000 ha of potatoes, its extension now reaches the whole region

of Flanders where about 37 000 ha of potatoes are grown or 67 % of the total area in Belgium.

The late blight warning service was developed with the support from the Ministry of Agriculture and the European Union, in close co-operation with the "Centre de Recherches Agronomiques" in Libramont and the "Bureau d'Economie Rurale" in Ath, both in the Walloon region. In 1997 the advises were sent either by mail, fax or via Internet to almost 700 farmers, together cultivating about 14 000 hectares of potatoes.

Materials & Methods
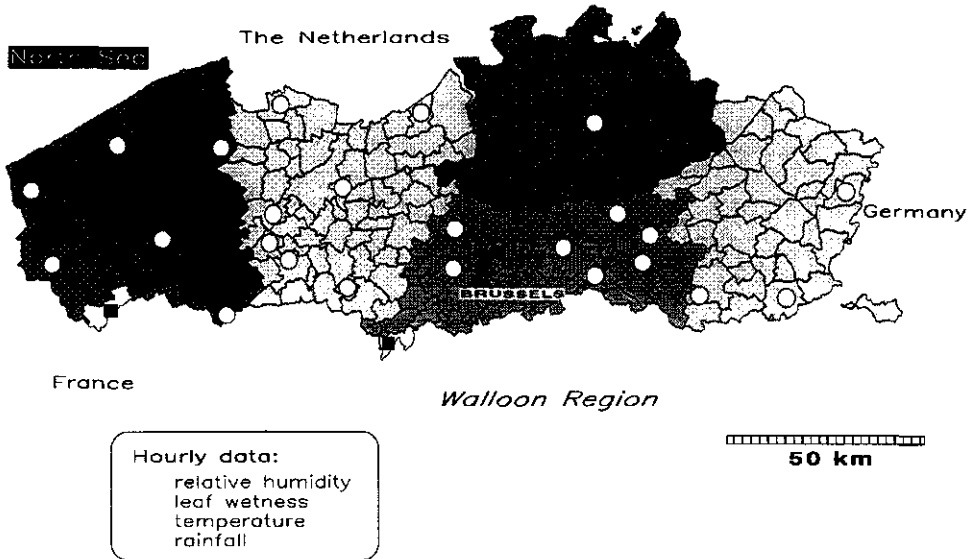
The theoretical disease model

The PCA warning service makes use of the disease-forecasting model of Guntz-Divoux, developed in France and modified in Libramont-Ath (Belgium). This model calculates the theoretical development of the disease based solely on weather data, measured at a standard level of 1.50 m. The basic rules of the disease model are as follows:

- A chance of infection occurs after at least 10 ½ consecutive hours with a relative humidity of more than 90%.
- The incubation or growth of mycelium in the plant's tissue is determined.
- The disease cycles are further grouped into generations, when a strong multiplication of the disease occurs.

Meteorological data

A relatively dense network of 29 automatical weather stations (Mety) records the necessary meteorological data. Registered hourly data include relative humidity, temperature, leaf wetness and precipitation. These records are transmitted every morning via modem to the PCA office in Kruishoutem and subsequently processed according to the rules of the Guntz-Divoux model, to determine daily chance of infection and incubation rate for each location.

PCA WEATHER STATIONS (METY) IN FLANDERS

Hourly data:
  relative humidity
  leaf wetness
  temperature
  rainfall

50 km

Crop data and other inputs

The theoretical disease model is further supplemented with information on growth stage of the crop, cumulative precipitation since previous application, weather forecast, and actual appearance of late blight. Especially the latter information is invaluable to any warning system. Through frequent contacts with its farmer-members, who are encouraged to report blight attacks immediately, the PCA gets a lot of information on potato blight attacks in the field (fields, backyards, refuse piles,...). Early and important blight incidences are confirmed by PCA-staff in the field.

Results and discussion

Early attacks of potato blight
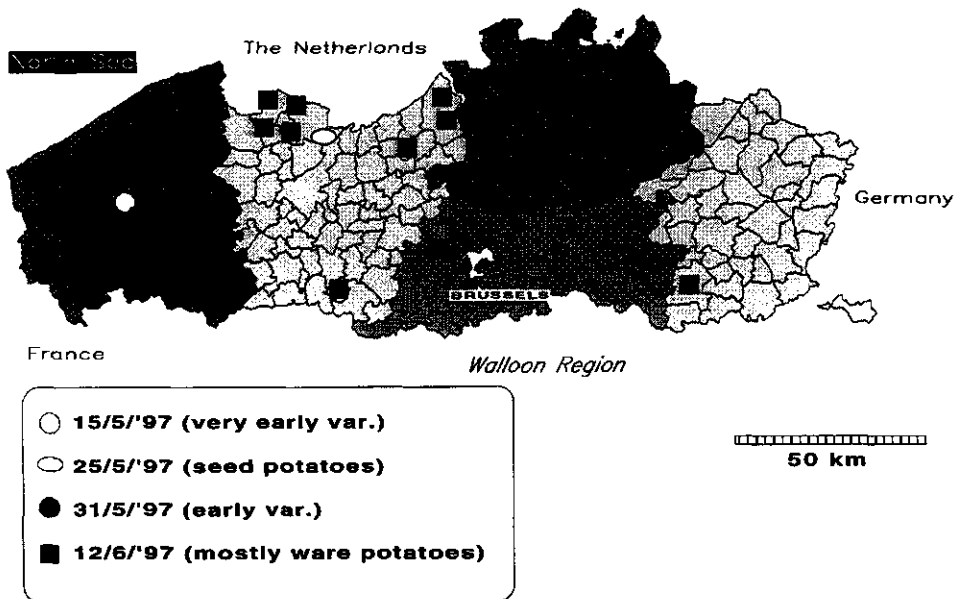
The close spacing – both in time and geographically – of very early crops (grown under cover), early varieties, seed potatoes and maincrop varieties in Flanders makes it complicated to give an advice for first spraying. The first advice is aimed at the very early crops and farmers are urged to spray shortly after removing the cover from the plants, usually around half May or earlier.

As a rule, the first application for maincrop fields should be carried out shortly before the end of incubation of the second disease generation for that field, that is the second generation recorded after emergence of the plants in that field or the neighbourhood (distance <500 m). This implies that the location of the field is important with regard to date of first application: if early varieties are grown in the proximity of the field then the disease could already have developed in this early crop (or refuse pile or backyard garden) before emergence of the maincrop.

The first incidence of potato blight was observed on 15 May – early compared to previous years – in a very early crop that had been covered until the first week of May. By the end of the month the disease had spread considerably in this region, and first attacks were observed in other regions.

BLIGHT REPORTINGS IN FLANDERS : situation on 12/06/1997

- ○ 15/5/'97 (very early var.)
- ⬭ 25/5/'97 (seed potatoes)
- ● 31/5/'97 (early var.)
- ■ 12/6/'97 (mostly ware potatoes)

50 km

In the theoretical disease model, these first reportings and subsequent spread of the disease correspond well with the end of incubation of the second and third disease generation of the season. However, the previous months of March and especially April had been much drier than normal. During the first four weeks of April no infection chances for the fungus were recorded, and a delay in the onset of the disease was expected. Moreover, the winter had been very cold with a soil frozen to a depth of 40 cm, and no blight attacks had been reported or observed in the crops during the previous season.
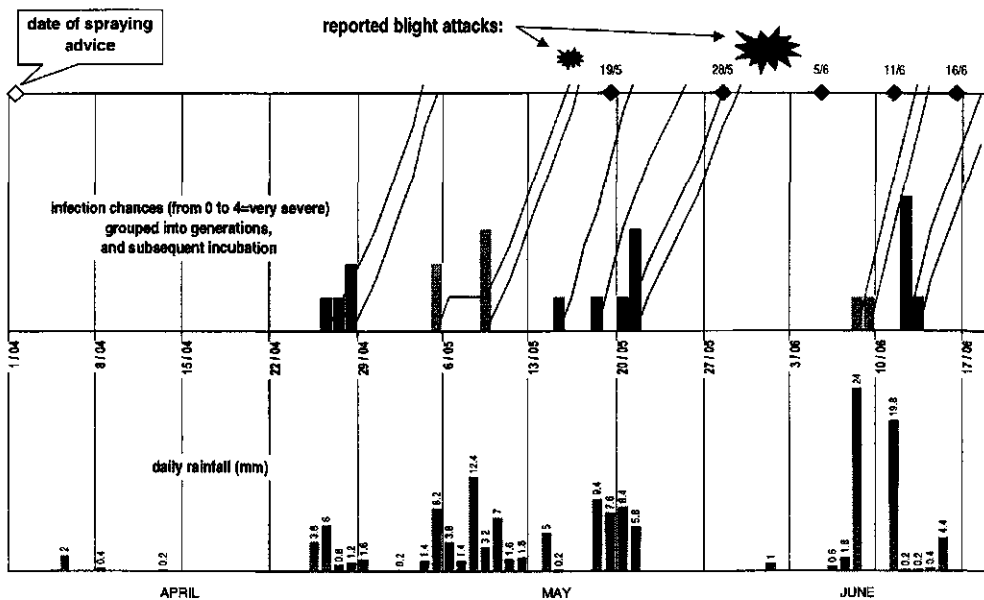
Spread of the disease

The weather during the months of June and July was very conductive to the spread of potato blight. Severe attacks in the maincrop variety Bintje were reported from 20 - 22 June, in crops where the first application was delayed until around 15 June (farmers who skipped the first two advice sprayings, mostly because of late emergence of the plants).

In most fields the blight situation remained under control, with farmers resorting to organotin fungicides and short intervals between applications. Spraying technique was very important, as every shortcoming was immediately punished by the fungus: infected plants could generally be found along field edges, in corners, or where e.g. a blocked nozzle left a row of plants unprotected.
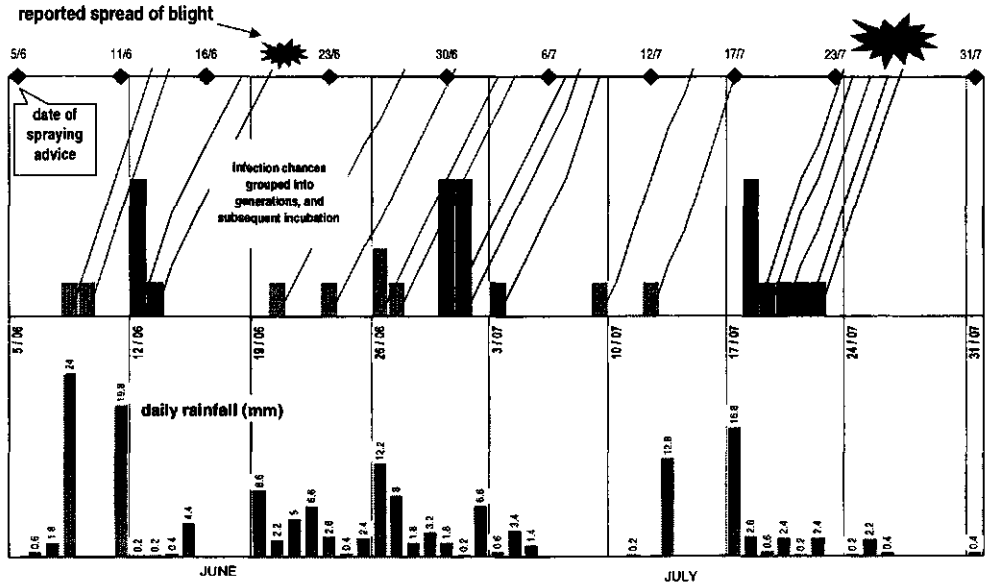
On 24 to 27 July the disease had spread considerably in a number of fields that had been sprayed according to the advice on 17 July, but with protectant fungicides (incl. fluazinam) instead of a 'translaminar' fungicide; the unrelenting rainfall in the following week had diminished the level of protection due to washing off. Translaminar fungicides proved very effective, more because of their rainfastness (of the component taken up by the leaves) than of their retroactive effect after infection.

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First large scale application of IPI model for
potato late blight prediction in the Po Valley

R. BUGIANI , P. GOVONI , L. COBELLI

Servizio Fitosanitario - Regione Emilia-Romagna

Via Corticella 133, I-40129 Bologna - Italy

Abstract

An Advisory Service for the first occurrence of Late blight on potato in the Po Valley was set up. The Service made use of the I.P.I. "negative prognosis" forecasting model elaborating daily met-data provided by a different set of weather stations and a network of sporetraps placed within unsprayed potato plots and monitoring the inoculum in the potato growing areas. In 1997 climatic condition were not conducive for the disease. Aerobiological monitoring showed a low spore concentration. Only 2 blight occurrence were detected and IPI warnings always anticipated the first symptoms of the disease in the field. Advisory Service, compared with a traditional calendar strategy with 5-7 days spray interval, allowed farmers to save from 2 to 6 sprays depending on different potato growing areas and cultivars with an average spray saving of 50%.

Keywords: Advisory service, Potato, Late blight, Forecasting

Introduction

Late blight caused by *Phytophthora infestans* is the disease most feared by potato growers in Emilia Romagna region and in the north of Italy in general. They usually apply many chemicals both preventive and curative with the aim to avoid any risk of epidemics even though climatic conditions in the Po Valley are not always favourable for blight development specially during dry season when the disease rarely occurs in the field. This situation leads to apply very often useless sprays.

The use of a forecasting model within a regional warning service was thought to be the best way in order to better rationalize the chemical sprays against the disease reducing at the same time the blight risk for the crops. Last year the first step was to compare several blight forecasting models most widely used in Europe and United States (Guntz-Divouz, I.P.I., Blite-Cast, Neg-Fry, Smith, Winstel criteria) and in the case to adapt them to the italian environment. Results of validation over three years shown that I.P.I. and Smith were the best always anticipating the occurrence of the disease in the field. Others such as Guntz - Divouz and Winstel's criteria proved to be quite reliable in predicting the disease most of the time (Bugiani et al., 1996). However the choice was to use the I.P.I. model (Bugiani et al., 1993) firstly because it was set up in Italy and therefore does not need to any adaptation and secondly because of its relative semplicity in that it uses daily met-data.

The second step was the practical large scale application of the IPI forecasting model on the regional territory and the organization of a blight warning service for the potato farmers like that already working in Emilia Romagna region for tomato growers.

The following are the results of this first year application of the Potato Blight Warning Service.

The organization of the warning system

The Potato Blight Warning Service for the prediction of the late blight first occurrence made use primarily of the information provided by the I.P.I. forecasting model. Met-data obtained by local weather stations, synoptic weather stations, and sometimes also by mechanic weather stations, are processed so as to give farmers warnings about the risk of blight epidemics and the need to spray.

Besides, in order to have information about the inoculum of the pathogen in the environment a network of volumetric sporetraps was set up within the potato growing areas of the region and working all over the crop growing season.

Furthermore, the first symptoms of late blight were continuosly monitored within a series of potato plots measuring 100 m^2 and left unsprayed by the farmers. The aim was to have both a check of the reliability of the model and aerobiological monitoring and made aware farmer of the usefulness of the system in saving sprays.
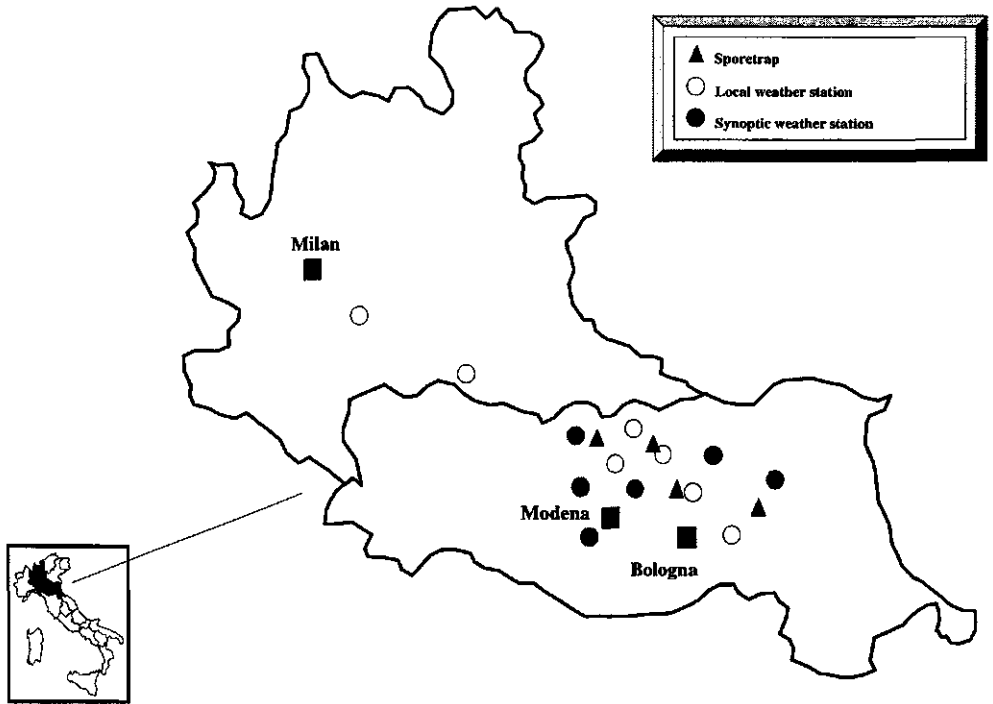
Figure 1. Distribution of synoptic and local weather stations and spore traps used by potato late blight Advisory Service in Po Valley in 1997.

Meteorological Data

Along with the network of weather stations of The Regional Agrometeorological Service, many automatic climatic stations are present on the territory. Most of them belong to farmer's associations, while few belong to the University and Agriculture Institute. Meteorological data used to elaborate blight warnings are gathered from all these different sorces in order to obtain weather information the most representative of the potato growing areas of the region (Table 1).

Met-data provided by synoptic weather stations belonging to the Regional Agrometeorological Service were collected via modem while others excepted Settala station in Milan Province, through portable PC.

Table 1. Weather stations used to elaborate IPI warnings.

Locality	Province	Owners	Automatic weather station	Weather sensors
Settala	Milan	Farmer's association	Local *	T, RH, R
Martignana	Milan	Farmer's association	Local	T, RH, R, Lw
Castelfranco	Modena	Regional Agromet Service	Synoptic	T, RH, R, Lw
Finale	Modena	Regional Agromet Service	Synoptic	T, RH, R, Lw
Albareto	Modena	Regional Agromet Service	Synoptic	T, RH, R, Lw
S. Pietro Capofiume	Bologna	Regional Agromet Service	Synoptic	T, RH, R
S. Agata Bolognese	Bologna	Regional Agromet Service	Synoptic	T, RH, R
Mezzolara	Bologna	Farmer's association	Local	T, RH, R, Lw
Castel S. Pietro	Bologna	Farmer's association	Local	T, RH, R, Lw
Budrio	Bologna	Farmer's association	Local	T, RH, R, Lw
Crevalcore	Bologna	Farmer's association	Local	T, RH, R, Lw
Funo	Bologna	Farmer's association	Local	T, RH, R, Lw
Marmorta	Bologna	Farmer's association	Local	T, RH, R, Lw
Anzola	Bologna	MAF Institute	Local	T, RH, R, Lw
Altedo	Bologna	University Bologna	Local	T, RH, R, Lw

* mechanic weather station

Aerobiological Network

Aerobiological monitoring could be a key tool within the regional blight warning service because it enhances the information provided by the IPI forecasting model and the network of unsprayed potato plots. In fact the IPI model gives "negative prognosis" predictions about the potential risk of blight occurence on the basis of climatic data, but it does not take into account inoculum potential in the different potato growing areas. Monitoring airborne concentrations of sporangia can be used to evaluate inoculum potential and particularly when IPI threshold is overcome, to predict the risk of infection and the most probable time of blight occurence in the field (Picco, 1992; Bugiani et al, 1995). In 1997 four sporetraps were placed in the most important potato growing areas of Emilia Romagna (Fig. 1).

Sporetraps were placed 1.5 meters high within unsprayed potato plots and checked twice a week for the daily concentration of *Phytophthora* spp. sporangia in the environment.

Results

In 1997, the first practical application of the I.P.I. forecasting model for potato blight occurrence was carried out in some potato growing areas of the Po Valley.

Dry climatic conditions with rare rainfalls and low temperature specially during april and may in Emilia Romagna region, were not conducive for blight epidemics. In fact, in Bologna and Modena Province no disease was detected both on commercial and unsprayed plots and IPI cumulative index did not reached high value even after risk threshold overcoming. On the contrary, first symptoms of the disease were detected in two unsprayed plots in Milan Province due to prolonged periods of heavy rainfalls between may and june and in accordance with I.P.I. blight prediction (Fig 2).

Figure. 2. I.P.I. output of some weather stations in Po Valley in 1997. ↓ - first late blight occurrence in unsprayed plots in Milan Province.
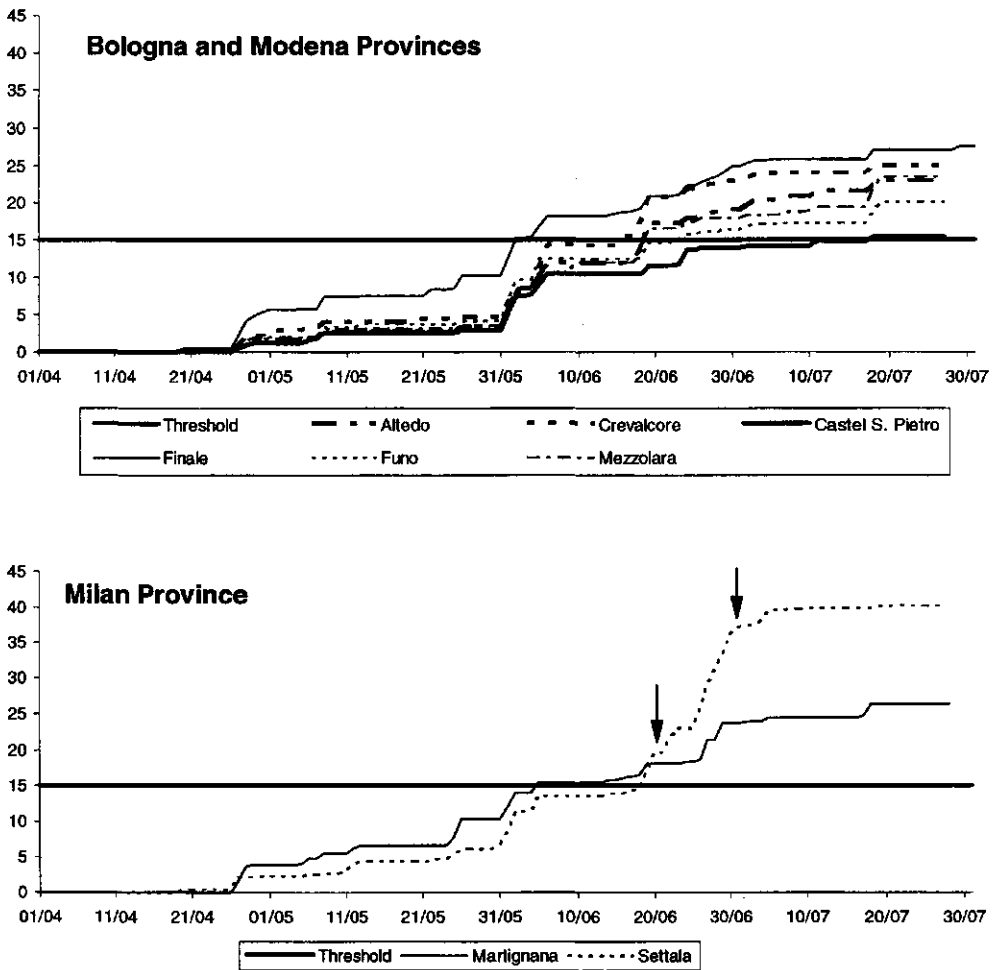
The aerobiological monitoring carried out in 1997 within the potato growing areas confirmed that climatic conditions were not favourable for the disease development. In fact spore concentration was very low and discontinuos throughout the whole potato growing season (Fig 3). On the other hand, previous aerobiological sampling carried out in 1995 and 1996 in the same area showed that spore concentration was higher and more constant during climatic conditions conducive for the disease. One to two peaks of spore concentration always anticipated the first symptoms of disease in the field (Fig. 4).

In the whole potato growing areas, I.P.I. risk threshold was averagely overcome on june, 20, few cases only in the first decade of june (Milan and Modena Province) and one case in the last decade of july (C.S.Pietro station in Bologna Province).

The advices of the first chemical application against *Ph.infestans* were diffused to the farmers in accordance with the model risk threshold overcoming by means of fax, bulletin and technical briefing.

Late blight traditional control was carried out following a calendar strategy starting averagely on may,10 with a 5-7 day spray interval. Therefore the application of the IPI forecasting model proved to be useful tool to rationalize the chemical treatments and save 3-5 sprays in most of the potato growing areas of the region, 1-3 in Modena Province and all the spray in those plots belonging to C.S.Pietro station. On the whole the practical use of the model allowed farmers to save averagely 50% of the chemical applications carried out traditionally against the disease (Table 2).
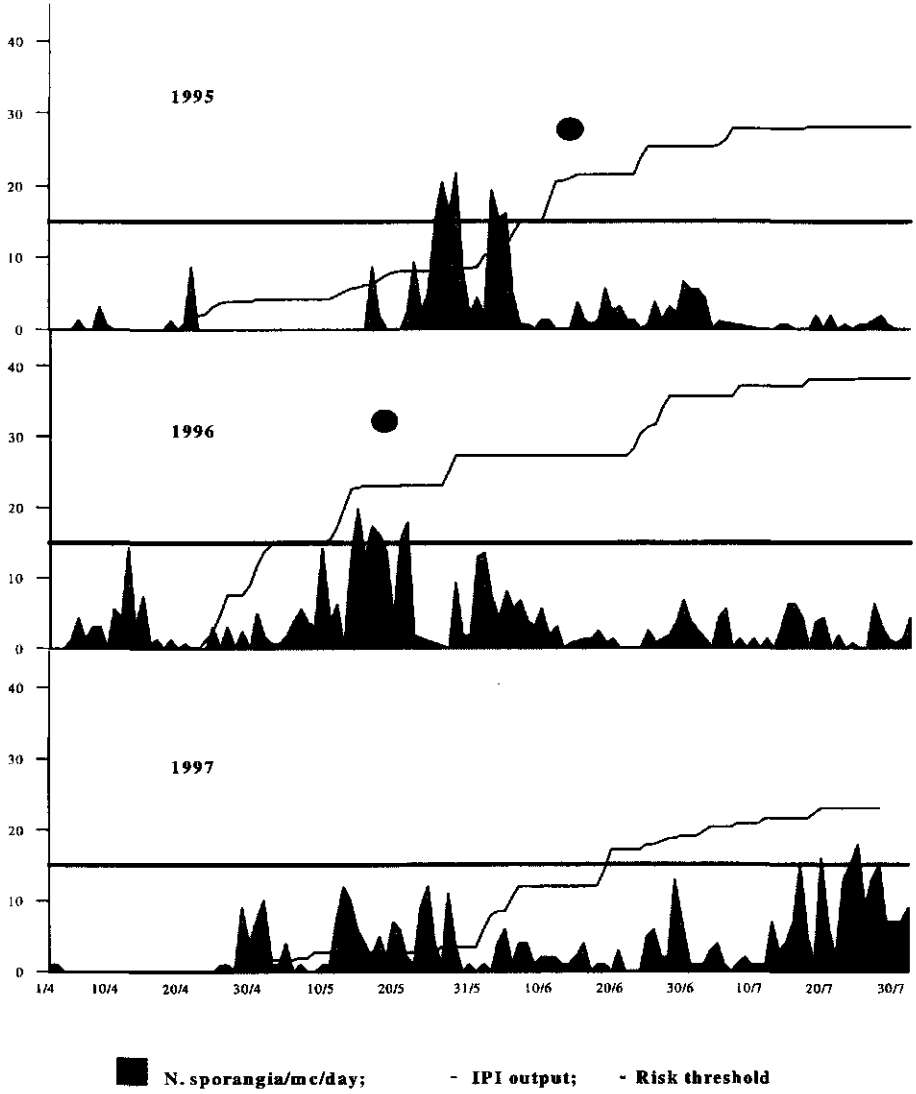
Figure. 4. Aerobiological monitoring of *Phytophthora* sporangia and I.P.I. output over 3 years in Altedo station. ●: disease occurrence in unsprayed plots.

Table 2. Comparison of traditional blight control strategy and IPI strategy in terms of n° of sprays.

Locality	Province	Date of IPI blight warning	IPI strategy (n° of sprays)	Traditional strategy (n° of sprays) *	Spray saving (%)
Settala	Milan	June, 19	3	6-8	50-62
Martignana	Milan	June, 5	5	6-8	17-37
Castelfranco	Modena	June, 6	5	6-8	17-37
Finale	Modena	June, 2	5	6-8	17-37
Albareto	Modena	June, 5	5	6-8	17-37
S. Pietro Capofiume	Bologna	June, 18	3	6-8	50-62
S. Agata Bolognese	Bologna	June, 6	5	6-8	17-37
Mezzolara	Bologna	June, 19	3	6-8	50-62
Castel S. Pietro	Bologna	July, 18	0	6-8	100
Budrio	Bologna	June, 24	2	6-8	67-75
Crevalcore	Bologna	June, 16	3	6-8	50-62
Funo	Bologna	June, 24	2	6-8	67-75
Marmorta	Bologna	June, 19	3	6-8	50-62
Anzola	Bologna	June, 16	3	6-8	50-62
Altedo	Bologna	June, 19	3	6-8	50-62

* Differences are due to cultivars and harvest time
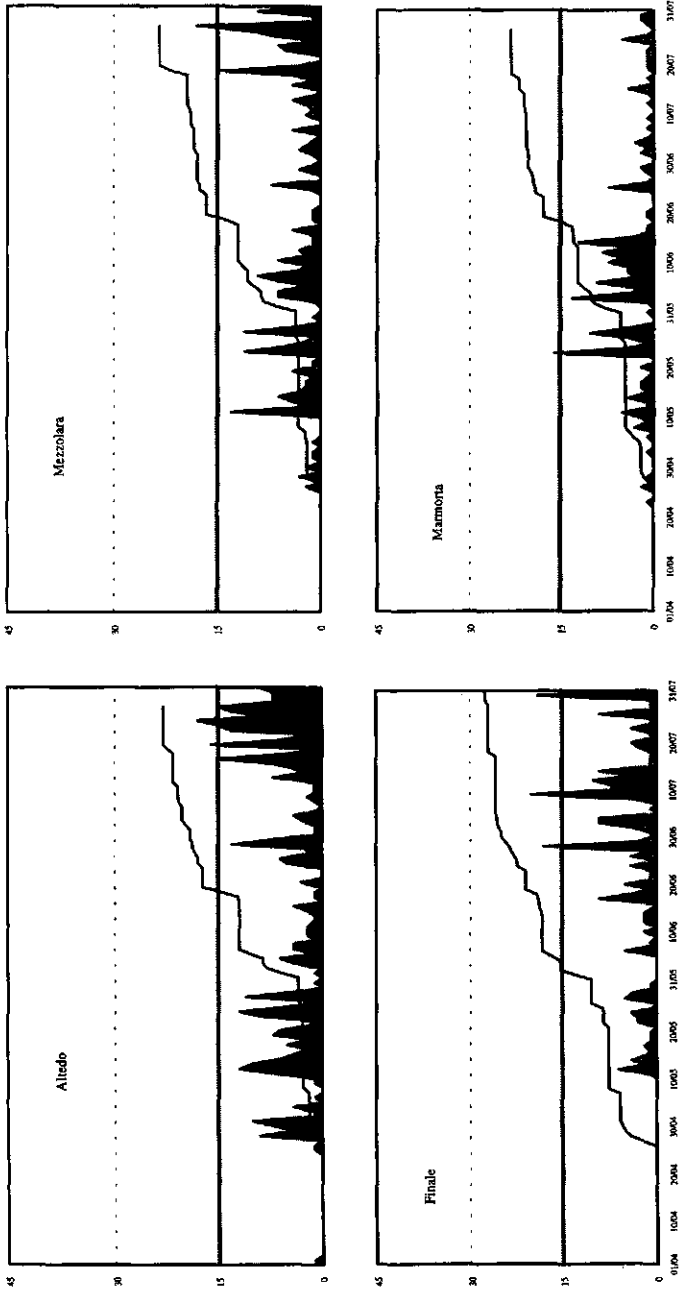
Future Outlook

The warning service will be improved adding to the I.P.I. negative prognosis forecasting model a decision system able to provide farmers with information about the sprays needed to control the disease once the IPI risk threshold is overcome. Some of these decision systems, already used in other warning services are being studied. This further improvement will allow us to complete the potato blight warning system.

Furthermore, in 1998 the information about the risk of blight occurrence provided by IPI model will be included in GIAS 2000, the new computer-based system of the Emilia-Romagna Region based on geographic information system (GIS) technology. GIAS 2000, along with potato and tomato blight warnings will include data from different sources (crop phenology, soil type, pest/disease monitoring from control farms, meteorological data from Regional Agrometeorological Service). The IPI model with GIS technology will help farmers and field technicians to have improved real-time prediction about the risk of blight occurrence on potato crops.

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Figure. 3. Daily mean concentration of *Phytophthora* sporangia ( ), I.P.I. output (-) and Risk Threshold (-) in 4 stations of Emilia Romagna region in 1997.

Weather stations used to elaborate IPI warnings

Locality	Province	Owners	Automatic weather station	Weather sensors
Settala	Milan	Farmer's association	Local *	T, RH, R
Martignana	Milan	Farmer's association	Local	T, RH, R, Lw
Castelfranco	Modena	Regional Agromet Service	Synoptic	T, RH, R, Lw
Finale	Modena	Regional Agromet Service	Synoptic	T, RH, R, Lw
Albareto	Modena	Regional Agromet Service	Synoptic	T, RH, R, Lw
S. Pietro Capofiume	Bologna	Regional Agromet Service	Synoptic	T, RH, R
S. Agata Bolognese	Bologna	Regional Agromet Service	Synoptic	T, RH, R
Mezzolara	Bologna	Farmer's association	Local	T, RH, R, Lw
Castel S. Pietro	Bologna	Farmer's association	Local	T, RH, R, Lw
Budrio	Bologna	Farmer's association	Local	T, RH, R, Lw
Crevalcore	Bologna	Farmer's association	Local	T, RH, R, Lw
Funo	Bologna	Farmer's association	Local	T, RH, R, Lw
Marmorta	Bologna	Farmer's association	Local	T, RH, R, Lw
Anzola	Bologna	MAF Institute	Local	T, RH, R, Lw
Altedo	Bologna	University Bologna	Local	T, RH, R, Lw

* mechanic weather station

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Comparison of traditional blight control strategy and IPI strategy in terms of n° of sprays.

Locality	Province	Date of IPI blight warning	IPI strategy (n° of sprays)	Traditional strategy (n° of sprays) *	Spray saving (%)
Settala	Milan	June, 19	3	6-8	50-62
Martignana	Milan	June, 5	5	6-8	17-37
Castelfranco	Modena	June, 6	5	6-8	17-37
Finale	Modena	June, 2	5	6-8	17-37
Albareto	Modena	June, 5	5	6-8	17-37
S. Pietro Capofiume	Bologna	June, 18	3	6-8	50-62
S. Agata Bolognese	Bologna	June, 6	5	6-8	17-37
Mezzolara	Bologna	June, 19	3	6-8	50-62
Castel S. Pietro	Bologna	July, 18	0	6-8	100
Budrio	Bologna	June, 24	2	6-8	67-75
Crevalcore	Bologna	June, 16	3	6-8	50-62
Funo	Bologna	June, 24	2	6-8	67-75
Marmorta	Bologna	June, 19	3	6-8	50-62
Anzola	Bologna	June, 16	3	6-8	50-62
Altedo	Bologna	June, 19	3	6-8	50-62

* Differences are due to cultivars and harvest time

Second Workshop of an European Network for Development of[1]
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Application at the moment of the day with the highest efficacy
with the weather-based DSS GEWIS

E. BOUMA

Applied Research for Arable Farming and Field Production of Vegetables

P.O.-Box 430, NL-8200 AK Lelystad, The Netherlands

Introduction

The weather circumstances before, during and after application of agro-chemicals are very important for the efficacy. Knowledge of the behaviour of pesticides to weather circumstances can be a tool to achieve a better efficacy and even to reduce the dose in well-defined applications. Formulation type and the dynamic buildup of the wax-layer at the upperside of the leaf are important for sticking or the speed and way of uptake of the active ingredient by the leaves. The thickness of these wax-layers is influenced by meteorological parameters.

Keywords: formulation, GEWIS, decision support system, weather related applications, wax-layer

Formulations

Pesticide formulations can be divided in two groups: apolar (water-repellent) and polar (fat-repellent) (Table 1). The apolar group of the products diffuses easily in or through the waxlayer because they are able to solve the fatty and waxy matter quite well. Apolar substances are rainfast very quick and are less dependent on weather conditions. The diffusion and sticking qualities of polar products are much more difficult.

Therefore also the efficacy of late blight fungicides depends on weather circumstances

before, during and after application. They have to be applied on (almost) dry leaves. Most of the protectant fungicides need dry, sunny weather after application. They can dry quickly on the leaves under those circumstances.

Table 1. Main formulation types of late blight fungicides.

Apolar	Polar
EC	WP
OFL	SC

Application at the moment of the day with the highest efficacy

It is difficult for farmers to combine all the processes for the highest efficacy, therefore a Decision Support System called GEWIS was developed. The knowledge of the relations between crop protection agents and meteorological circumstances are combined in GE-WIS. The system uses the meteorological data from an in-crop farm weather station and calculates the moments with the highest efficacy (Figure 1).

Figure 1. The efficacy of fluazinam.
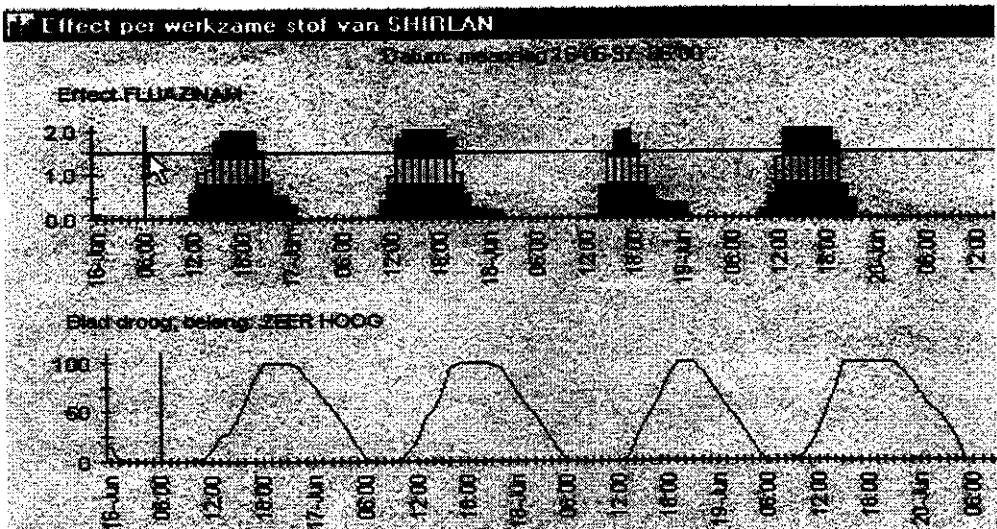
The system calculates the physical behaviour of the agrochemicals in the different stages of the process for example leaf wetness, drying of the fungicide on the leaves and sticking behaviour of the fungicide to the leaves.

With the help of this dss the farmer can choose the best moment of the day to apply. With this system he can anticipate run-off of fungicides by rain or too wet leaves for application by dew.

The system will be tested in 1997, improved and tested again in1998.

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an Integrated Control Strategy of potato late blight
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Epidemic development of Phytophthora on ware potatoes production in Northern France

S. DUVAUCHELLE[1], L. DUBOIS[2]

[1]SRPV Nord Pas de Calais, BP 47, F-62750 LOOS EN GOHELLE, France

[2]FREDEC Nord Pas de Calais, BP 74, F-62750 LOOS EN GOHELLE,France

1995, a year of early risks

In 1995, the epidemiological risks calculated by the models GUNTZ-DIVOUX and MIL-SOL indicated some very early contaminations. From April onward, contaminations were recorded in Nord-Pas de Calais, in Picardy and in Champagne. The threshold for starting up the first treatment (third generation) was reached in early May. Early in June, some attacks of late blight were observed on plots which were not treated.

The observations enabled us to count a large number of piles of potato waste. This waste stemmed partly from the sorting activity. The problems on vitreous potatoes encountered in 1994 accentuated this problem of waste at the beginning of the season. These residues of crops constituted the primary focus of late blight. In Nord-Pas de Calais, some symptoms of late blight appeared from April on the vegetation which was present on the piles of waste.

Weather conditions (heat and drought) during the summer have slowed down the epidemic development. Late in August, in Champagne, the weather conditions were in favour of the contaminations on tubers, on varieties for starch production.
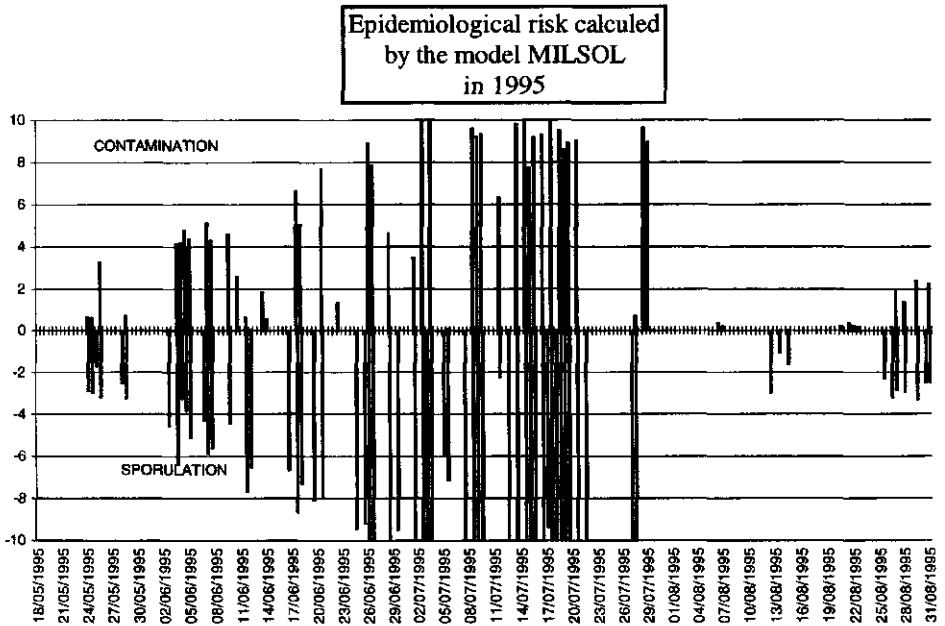
1996, a later outset of the epidemic

The 1996's epidemic was characterised by a start that was occurred much less earlier than the previous years. The epidemic threshold given by the third generation of the model GUNTZ-DIVOUX took place around June 10th. As regards the North-Western regions of France, the frosts in early May stopped the disease development. Some contaminations
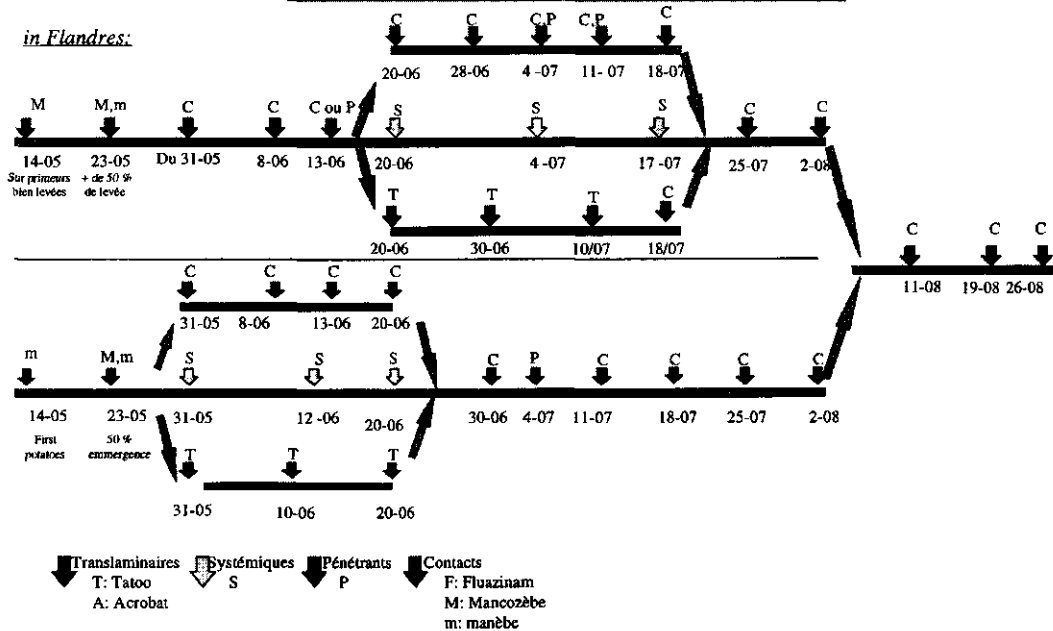
could be suppressed at the model level. Some efforts have also been made by the profession so as to reduce the number of waste piles. The disease pressure remained moderate in June. A slight acceleration was noticed at the beginning of July. The weather conditions from July 15th to August 15th limited the epidemic development. From August 15th, the rainy conditions were in favour of contaminations.

1997, a critical year

The start of the epidemic is relatively slow, till June 10th some symptoms on waste piles were observed. Besides, from June 10th, an important acceleration of the disease was noticed at the model level. On the field, significant rainfalls have leached contact products. The conditions of application were very difficult. Moreover, the vegetation was sprouting a lot. Some plots were found without protection or badly protected in late June. This resulted in a great spreading of the late blight over the field. At the model level, the risk was very high, the contaminations and the appearances of necroses followed one another. The high temperatures in August slowed down the epidemic development. Nevertheless, the risk was never nil. The mists, fogs, and storms maintained a certain pressure.

Epidemiological risk calculed by the model MILSOL in 1995

in Flandres:

C	C	C.P	C.P	C
20-06	28-06	4 -07	11- 07	18-07

M	M,m	C	C	C ou P	S	S	S	C	C

| 14-05 | 23-05 | Du 31-05 | 8-06 | 13-06 | 20-06 | 4 -07 | 17 -07 | 25-07 | 2-08 |
| Sur primeurs bien levées | + de 50 % de levée | | | | | | | | |

T	T	T	C
20-06	30-06	10/07	18/07

C	C	C
11-08	19-08	26-08

C	C	C	C
31-05	8-06	13-06	20-06

m	M,m	S	S	S	C	P	C	C	C	C

| 14-05 | 23-05 | 31-05 | 12 -06 | 20-06 | 30-06 | 4-07 | 11-07 | 18-07 | 25-07 | 2-08 |
| First potatoes | 50 % emmergence | | | | | | | | | |

T	T	T
31-05	10-06	20-06

Translaminaires Systémiques Pénétrants Contacts
T: Tatoo   S   P   F: Fluazinam
A: Acrobat   M: Mancozèbe
   m: manèbe

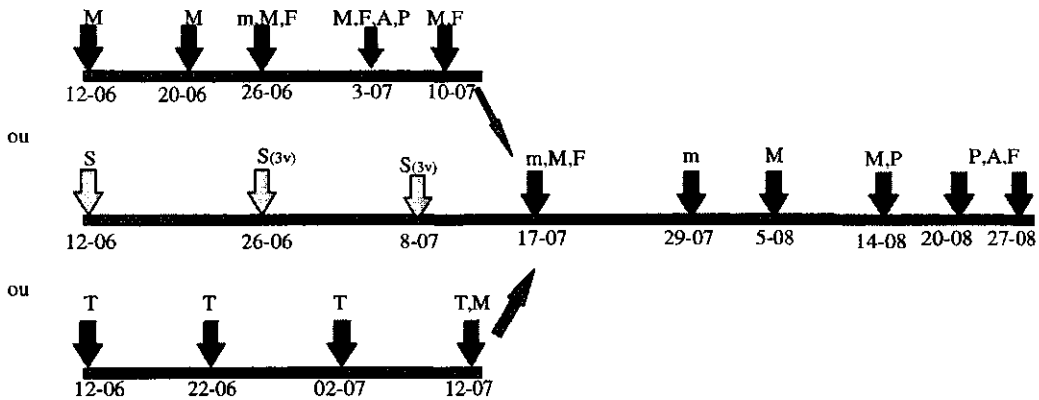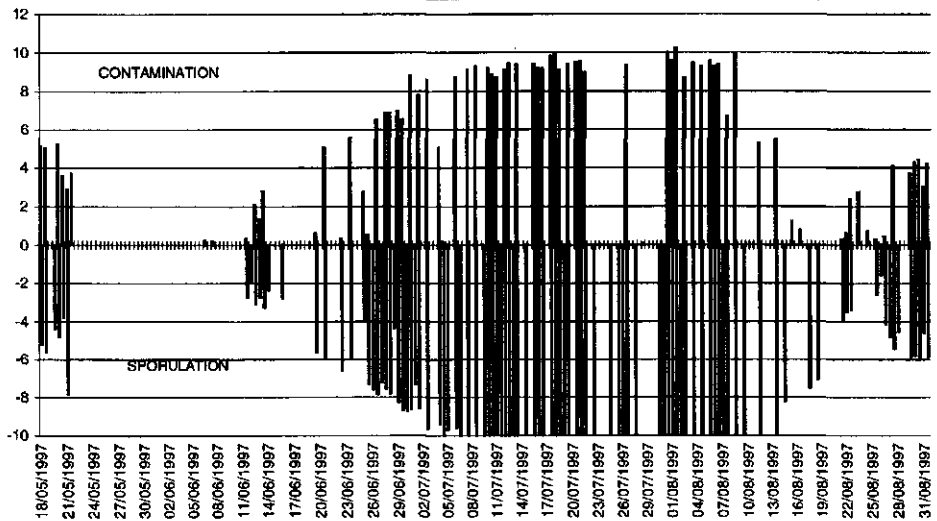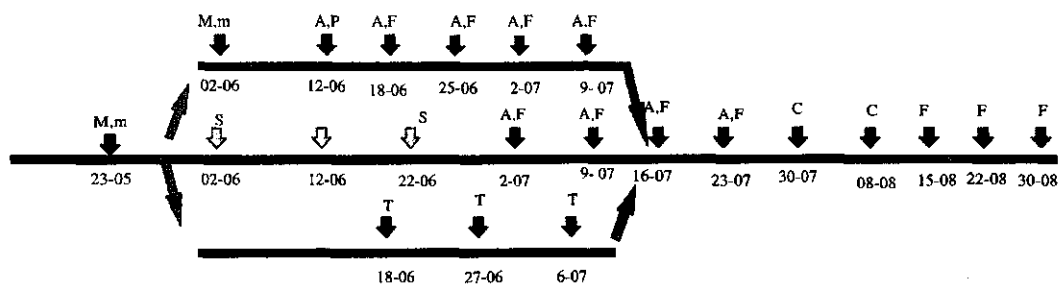**Epidemiological risk calculed
by the model MILSOL
in 1996**

Plant Protection Service of Nord Pas-de-calais Treatment recommendations in 1996

ou

ou

Epidemiological risk calculed by the model MILSOL in 1997

M.m   A.P   A.F   A.F   A.F   A.F

02-06   12-06   18-06   25-06   2-07   9-07

M.m

23-05   02-06   12-06   22-06   2-07   9-07   16-07   23-07   30-07   08-08   15-08   22-08   30-08

S   S   A.F   A.F   A.F   A.F   C   C   F   F   F

T   T   T

18-06   27-06   6-07

Evolution of recommendations from epidemic to epidemic

In the light of information collected by the epidemiological models, the first treatments were started up from the third generation (GUNTZ-DIVOUX) and/or some symptoms were present on piles of waste whatever the stage of crops (sometimes in course of emergence). The risks of contamination of young stems were very important, that's why early treatments were required. Concerning a year with low risks (1996), the first treatment was to be done at the epidemic threshold. During the summer, under hot weather conditions, the recommendations had to be adjusted and systematic treatments banished. The warning stations recommended to lengthen the intervals between two treatments (Nord - Pas de Calais - Picardy) (1995) or to cancel one or two treatments (Champagne) during a period of nil risk (1995). This reduction in the number of treatments wasn't harmful to the sanitary state of the plots.

For the beginning of 1997, a reasoning with an interval of 7 days is possible. However, from mid-June, the slightest digression could bring about an attack of late blight.

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Populations studies of *Phytophthora infestans*
in Finland and Norway

A. HERMANSEN[1], A. HANNUKKALA[2] AND R. HAFSKJOLD[3]

[1]The Norwegian Crop Research Institute, Plant Protection Centre,

Dept. of Plant Pathology, Fellesbygget, N-1432 Ås, Norway

[2] Agricultural Research Centre, Institute of Plant Protection, FIN-31600 Jokioinen, Fin-

land

[3]Agricultural University of Norway, Dept. of Horticulture and Crop Sciences,

P.O. Box 5022, N-1432 Ås, Norway

Abstract

Phytophthora infestans was isolated from potato leaves and tubers collected from different parts of Finland (FIN) and Norway (N) in 1993-1996. Isolates were assessed for mating type, resistance to metalaxyl and virulence phenotype. Both mating types were present in most regions in FIN and N. The A1/A2 ratio was in a range for oospore formation. Metalaxyl resistance is currently present at different levels in the two countries. In FIN the proportion of resistant strains have decreased to a low level. In N more than half the number of isolates were resistant to metalaxyl in 1996. All known virulence genes were present in both countries (R9 not tested). A molecular marker (RG57) will be used to study genetical variations within and between subpopulations. Further studies of the fungal population and the role of oospores will include all the Nordic countries.

Key words: *Phytophthora infestans*, mating type, metalaxyl resistance, virulence genes

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Influence of rain on the activity of fungicides

against potato late blight

S. K. MATHIASSEN[1], H. SCHULTZ[2] & P. KUDSK[1]

Danish Institute of Agricultural Sciences
Department of Weed Control and Pesticide Ecology[1]
Department of Plant Pathology and Pest Management[2]
Flakkebjerg, DK-4200 Slagelse,Denmark

Abstract

The influence of rain on the biological activity of different fungicides against late blight
was examined in pot trials on two different cultivars of potato plants grown outdoors.
The biological activity of Shirlan was either increased or unaffected by rain. With
Dithane and Vondac the results were inconsistent as the activity was either increased, de-
creased or unaffected by rain. The varying results with the dithiocarbamates were not re-
lated to cultivar or rain volume. With Daconil the results varied between cultivars. The
activity was significantly reduced by rain on *Bintje* while no detrimental effect of rain
was found on *Kaptah*. In contrast, the activity of Tattoo was significantly reduced by rain
on *Kaptah* while it was unaffected or significantly increased on *Bintje*. In most cases 5
mm of rain significantly reduced the activity of Acrobat while no influence of 27 mm of
rain was seen.

Key words: Potato late blight, fungicides, activity, rainfastness

Introduction

In Denmark dithiocarbamates are the most widely used fungicides to control of potato
late blight. At the moment only two other fungicides - Tattoo and Daconil - are registered
for the control of late blight but Shirlan and Acrobat are expected to be registered soon.

Informations is available concerning the rainfastness of several of the above-mentioned fungicides, however as different methods have been used in the experiments it is difficult to compare the results. The objective of this experiment was to examine the influence of rain on the biological activity of the fungicides under similar conditions.

Material and methods

The experiment was carried out on two different cultivars (*Bintje* and *Kaptah*) in order to test if rainfastness varied on cultivars with different leaf surface characteristics. Potato plants were established by planting pregerminated sections of tubers in 2 l pots in a soil/ sand/ peat mixture (2:1:1 w/w) containing all necessary macro and micro nutrients. The pots were placed on outdoor tables and subirrigated automatically. Plants were thinned when they were 25 cm high to ensure all leaves to be full exposed to the fungicide application.

Fungicides were applied using a laboratory pot sprayer equipped with two Hardi 4110-14 flat fan nozzles. A pressure of 2.5 bars and a velocity of 5.1 km/hour was used and the sprayer delivered a spray volume of 152 l/ha. *Bintje* was sprayed on 15 July and *Kaptah* on 31 July.

The following commercial formulations were used: Dithane DG (750 g/kg mancozeb), Vondac M DG (750 g/kg maneb), Shirlan (500 g/l fluazinam), Daconil 500 F (500 g/l chlorothalonil), Tattoo (248 g/l propamocarb+301 g/l maneb) and Acrobat MZ (75 g/l dimethomorph+667 g/l mancozeb). As the objective of the experiments was to examine the rainfastness of the fungicides it is desirable not to achieve a 100% effect of the applied dose without rain because differences in rainfastness then can be concealed. Consequently, the fungicides were applied in 1/4 and 1/20 of the normal dose. Normal doses of Dithane DG, Vondac M DG and Acrobat MZ were 2 kg/ha, Shirlan 0.4 l/ha, Daconil 500F 2.5 kg/ha and Tatoo 4 l/ha.

Rain treatments were carried out in a rain simulator 24 hours after application. Rain volumes of 5 and 27 mm were applied at an intensity of 27 mm per hour . The low volume was meant to simulate a rain shower while the high volume simulated irrigation. Each treatment was replicated 5 times.

As soon as the plants were dry following the rain treatments 2 leaflets were detached from each plant. The leaflets were placed on a net in plastic boxes. Wet filter paper was placed in the bottom to maintain 100% relative humidity. Ten drops of a sporangial suspension containing 10^5 spores/ml of *Phytophthora infestans* were placed on each leaflet. The boxes were kept in a room at a temperature of 18° C and supplied with artificial light 24 hours a day. Four to five days after inoculation the number of drops infecting the leaflets was counted and the percent leaf area infected by *P. infestans* was assessed. Percent area infected was assessed again 2-3 day later.

Results and discussion

The results are shown in Table 1. Each value represents the mean of 10 replicates (untreated 20 replicates). The number of lessions indicates how many of the 10 applied sporangia drops that caused an infection on the leaflet. The number of lessions was only counted at the first assessment date because later on the mycelium had spread out making it impossible to determine which drops had caused infection and which had not.

The susceptibility of the cultivars to *P. infestans* varies. *Bintje* is considered to be medium to very susceptible while *Kaptah* is medium susceptible. At the first assessment on *Bintje* all drops placed on untreated leflets had caused infections and the percentage of leaf area covered by the lessions on control was close to 100% suggesting that the assessment should have been made some days earlier. Therefore the assessment of the number of lessions was uncertain on *Bintje* as it was difficult to distinguish which droplets caused infection and which did not while the assessment of percent infected area was precise and a clear dose-response were present with all fungicides. On *Kaptah* the infection rate was more appropriate at the first assessment (60% on untreated) increasing to 100% during the following 3 days. Dose-response was not present with Dithane and Shirlan. On both cultivars only few significant results were present at the last assessment. The rain treatments were compared within each cultivar, fungicide and dose using Duncans Multiple Comparison Test. In Tab. 1 and 2 values with the same letter were not significantly different, however only the rain treatments within fungicide and dose can be compered. The differences in number of lessions and percent infected area had to be rather high to produce significant effects. This was due to a high variation between replicates and reflects the complexity when several factors - plant, fungus, fungicide and rain - interact.

Tabel 1. Rainfastness of different late blight fungicides on *Bintje* assessed by biological activity. Letters refers to Duncans Multiple Comparison test within each fungicide and dose. Means with the same letter were not significantly different. [1] assessment date 21 June. [2] assessment date 23 June.

Fungicide	Dose (g or ml pr ha)	Rain	Number of lesions[1]	% infected leaf area[1]	% infected leaf area[2]
Untreated			10.0	96.5	95.5
Dithane DG	100	None	5.9 B	74.5 B	100.0 A
		5 mm	8.5 A	90.0 A	100.0 A
		27 mm	4.6 B	10.0 C	100.0 A
	500	None	2.7 A	22.0 A	84.0 A
		5 mm	2.4 A	34.5 A	79.0 A
		27 mm	3.9 A	51.0 A	95.0 A
Vondac M DG	100	None	1.1 C	46.0 AB	96.5 A
		5 mm	6.6 A	65.0 A	95.0 A
		27 mm	3.1 B	24.0 B	91.5 A
	500	None	1.9 B	16.5 B	90.0 A
		5 mm	4.5 AB	56.0 A	89.5 A
		27 mm	5.6 A	65.0 A	100.0 A
Shirlan	20	None	9.1 A	92.5 A	100.0 A
		5 mm	7.0 A	67.5 B	100.0 A
		27 mm	7.7 A	65.5 B	99.0 A
	100	None	4.2 A	33.5 A	90.0 A
		5 mm	4.0 A	35.5 A	100.0 A
		27 mm	4.0 A	48.0 A	98.0 A
Daconil 500F	125	None	7.0 B	65.5 B	100.0 A
		5 mm	9.6 A	95.0 A	100.0 A
		27 mm	9.6 A	96.0 A	100.0 A
	625	None	2.4 C	33.0 A	86.0 B
		5 mm	4.7 B	51.0 A	100.0 A
		27 mm	6.6 A	57.5 A	100.0 A
Tattoo	200	None	8.8 A	87.5 A	100.0 A
		5 mm	10.0 A	97.5 A	100.0 A
		27 mm	4.1 B	46.0 B	100.0 A
	1000	None	1.8 A	21.0 A	84.0 A
		5 mm	1.9 A	17.5 A	67.0 A
		27 mm	1.8 A	14.5 A	71.0 A
Acrobat MZ	100	None	3.4 B	37.5 B	95.0 A
		5 mm	6.9 A	72.5 A	100.0 A
		27 mm	6.6 A	46.5 B	99.0 A
	500	None	0.5 B	2.5 B	45.0 B
		5 mm	1.6 A	33.0 A	99.0 A
		27 mm	1.3 AB	18.0 AB	73.0 AB

Tabel 2. Rainfastness of different late blight fungicides on *Kaptah* assessed by biological activity. Letters refers to Duncans Multiple Comparison test within each fungicide and dose. Means with the same letter were not significantly different[3] assessment date 4 August[4] assessment date 7 August.

.Fungicide	Dose (g or ml per ha)	Rain	Number of lessions[3]	% infected leaf area[3]	% infected leaf area[4]
Untreated			7.8	55.3	98.5
Dithane DG	100	None	1.1 B	5.6 AB	69.0 A
		5 mm	1.1 B	4.0 B	94.0 A
		27 mm	4.3 A	15.5 A	89.5 A
	500	None	1.9 A	19.0 AB	100.0 A
		5 mm	2.6 B	32.5 A	100.0 A
		27 mm	1.8 A	7.2 B	94.4 A
Vondac M DG	100	None	2.6 A	36.5A	100.0 A
		5 mm	0.5 B	4.5 B	86.0 B
		27 mm	4.5 A	21.5 AB	98.0 AB
	500	None	1.4 A	15.0 A	89.0 A
		5 mm	0.0 B	0.0 A	57.0 A
		27 mm	1.0 AB	2.0 A	61.5 A
Shirlan	20	None	1.6 A	22.5 A	100.0 A
		5 mm	1.5 A	2.1 A	59.0 B
		27 mm	0.7 A	2.5 A	46.5 B
	100	None	2.1 A	24.5 A	80.0 A
		5 mm	1.0 B	4.5 AB	68.5 A
		27 mm	0.3 B	1.0 B	56.0 A
Daconil 500F	125	None	4.9 A	33.5 A	100.0 A
		5 mm	4.6 A	39.5 A	100.0 A
		27 mm	4.6 A	23.0 A	100.0 A
	625	None	1.1 A	2.6 A	86.0 A
		5 mm	1.6 A	13.0 A	76.0 A
		27 mm	2.9 A	11.5 A	66.5 A
Tattoo	200	None	3.4 B	7.5 B	95.0 A
		5 mm	6.9 A	27.5 A	100.0 A
		27 mm	7.7 A	39.5 A	100.0 A
	1000	None	0.6 B	3.5 A	100.0 A
		5 mm	1.5 AB	17.1 A	96.0 AB
		27 mm	2.3 A	9.0 A	78.0 B
Acrobat MZ	100	None	0.0 B	0.0 B	74.5 B
		5 mm	2.1 A	10.7 A	86.0 AB
		27 mm	3.6 A	10.1 A	100.0 A
	500	None	0.4 A	1.6 A	98.0 A
		5 mm	0.1 A	0.5 A	86.0 A
		27 mm	0.4 A	1.7 A	96.7 A

It is important to realise that the experiment was not designed to compare the efficacy between fungicides as doses were much lower than the recommended doses but only to examine the influence of rain on each specific fungicide.

Dithane DG

The first assessment on *Bintje* revealed that 5 mm of rain significantly reduced the activity of 100 g/ha Dithane. In contrast, the activity was significantly increased after 27 mm of rain. However, when the dose was increased from 100 to 500 g/ha the activity of the no rain treatment as well as 5 mm rain was increased whereas the activity was reduced after 27 mm of rain indicating that the high efficacy of this treatment in the lower dose was unreliable. No significant differences between treatments were observed at the high dose and at the last assessment.

On *Kaptah* 27 mm of rain significantly increased the number of infections at the low dose and tended to increase the leaf area covered with *P. infestans* at the first assessment. At 500 g/ha significant differences were found between 5 and 27 mm of rain but none of the rain treatments differed significantly from the 'no rain' treatment. No significant differences were observed at the last assessment date.

Vondac

On *Bintje* the percentage infected leaf area was unaffected of rain at the low dose, however both rain volumes significantly reduced the activity of 500 g/ha at the first assessment. No differences were found at the second assessment.

On *Kaptah* 5 mm of rain significantly increased the activity of 100 g/ha of Vondac at all assessments while 27 mm did not affect the efficacy. No significant differences in activity were seen at 500 g/ha.

Shirlan

At the first assessment on *Bintje* a significant reduction in percent infected leaf area was observed at the low dose when rain was applied after application. At the higher dose and at the last assessment no significant differences were seen.

On *Kaptah* a similar tendency to an increased biological activity following rain was found on both assessment dates. A significant reduction in the percent infected leaf area was present at the high dose at the first assessment and at the low dose at the last assessment.

Although the results were not significant in all cases a general trend was found that rain stimulated the activity of Shirlan.

Daconil

On *Bintje* the activity of 125 g/ha Daconil was significantly reduced at the first assessment date irrespectively of rain volumes. At the high dose the activity was unaffected of rain treatments at the first assessment but at the last assessment the percent infected area was significantly increased when rain had been applied.

On *Kaptah,* no detrimental effects of rain were found at any dose or any assessment consequently, the rainfastness of Daconil varied between cultivars.

Tattoo

On *Bintje* 27 mm of rain significantly increased the activity of 200 g/ha Tattoo at the first assessment while no differences were found between the no rain treatment and 5 mm of rain. At 1000 g/ha no differences were observed between rain treatments.

On *Kaptah* the activity of 200 g/ha was reduced by rain whether assessed as number of lessions or percent infected leaf area. At 1000 g/ha 27 mm rain reduced the activity when assessed as number of lessions but increased the activity at the last assessment of percent infected leaf area. The influence of rain on the activity of Tattoo varied between cultivars.

Acrobat

On Bintje the activity of Acrobat was significantly reduced at both doses when 5 mm of rain was applied. At 100 g/ha the differences between no rain and 5 mm rain were only significant at the first assessment whereas at 500 g/ha the results were significant at both assessments. No significant differences between the no rain treatment and 27 mm of rain

were found.

On *Kaptah* both rain volumes significantly reduced the fungicidal activity at the low dose while no differences between treatments were observed at 500 g/ha.

The results of Dithane and Vondac were rather inconsistent as rain either significantly reduced the activity, significantly increased the activity or did not interfere with activity. In previous studies the influence of rain on dithiocarbamate fungicides on potato leaves was examined using chemical analyses. Rainfastness of the dithiocarbamates was found to depend on particle size, formulation and adjuvants (Kudsk et al, 1991). In general the dithiocarbamates are not assumed to be very rainfast and a more clear response to rain than observed in the present experiment was expected.

The stimulating effect of rain on the biological activity of Shirlan has been confirmed in several experiments (Schepers, 1996, Mathiassen et al, 1996). In this experiment Shirlan was the only fungicide not adversely affected by rain irrespectively of rain volume and cultivar. A possible cause for this stimulating effect can be redistribution resulting in a better distribution of fungicide on the leaf. In the present experiment we intended to optimise spray distribution by using small nozzles.

Redistribution by rain from the central part to the edges of the leaf can, however, result in a very uneven distribution of fungicide on the leaf surface (Kudsk et al., 1991). The biological efficacy are then dependent on whether the sporangia drops are placed on leaf areas with high or low fungicide concentrations. This may explain the unexpected better effect of some fungicides containing maneb and mancozeb following 27 mm rain compared to 5 mm rain.

No significant differences in rainfastness between the two cultivars was found. The influence of rain on the activity of Tattoo and Daconil differed between cultivars but the differences were not consistent.

Conclusion

Due to a high variation only few conclusions can be drawn from the experiment.

Under the conditions prevailing in the present experiment Shirlan was the only fungicide

which was not adversely affected by rain. The results with Dithane and Vondac were inconsistent, as the activity in some cases was significantly increased by rain, in other cases the activity was significantly reduced or unaffected by rain. With Daconil, Tattoo and Acrobat the results varied between cultivars and rain volumes.

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Rainfastness of mancozeb and Curzate M

on potato leaves

A. EVENHUIS[1,3], H.T.A.M. SCHEPERS[1], C.B. BUS[1], W.L.M. STEGEMAN[2]

1) Research Station for Arable Farming and Field Production of Vegetables, PO Box 430, NL-8200 AK Lelystad, The Netherlands.
2) DuPont de Nemours (Nederland) BV, PO Box 145, NL-3300 AC Dordrecht, The Netherlands.
3) Research Station for Arable Farming and Field Production of Vegetables, location Horst-Meterik, PO Box 6077, NL-5960 AB Horst, The Netherlands.

Abstract

Knowledge on rainfastness of fungicides is important in order to optimise preventative spraying to control potato late blight. The rainfastness of mancozeb and Curzate M (cymoxanil + mancozeb) on potted potato plants was investigated using a rain simulator. Rain simulation was carried out after spraying potato plants with the fungicides. Intervals between spraying and rain simulation varied from one to four hours. Effectivity of the fungicides after rainfall was studied by inoculation of detached potato leaves with *Phytophthora infestans* in a bioassay. Mancozeb and Curzate M were both washed from the leaves resulting in loss of effectivity.

Introduction

Potato late blight caused by *Phytophthora infestans* De Bary can cause considerable damage in potato growing. Potatoes are sprayed regularly with fungicides to control late blight. There is a growing concern regarding the use of pesticides. Reductions can be

obtained with longer intervals between spraying or by using lower fungicide dosages. In order to optimise preventative spraying with fungicides and minimise or avoid risks involved, more knowledge on rainfastness of the fungicides is necessary.

No study on rainfastness of Curzate M had been undertaken, yet. Studies on rainfastness of mancozeb have been carried out by Shephard (1981), Kudsk *et al.* (1991) and Lindner *et al.* (1994). All found loss of activity of mancozeb after rain simulation on plants raised in greenhouses. We carried out experiments to elucidate the rainfastness of mancozeb and Curzate M (cymoxanil + mancozeb) on plants grown outdoor. The effect of rainfall on fungicidal activity was studied in a bioassay, resembling the pinna method used by Creuzburg-Eggert *et al.* (1972).

Materials and methods

Potato plants. Potato plants (cultivar Bintje) were raised in pots in the greenhouse. The pots were filled with 10 l clay soil. Tubers were placed at a depth of 10 cm. The pots were placed in the field, three weeks after emergence of the potato plants. The rim of the pot was at soil level. The plants were allowed to grow under field conditions until the experiments were performed.

Spraying. Potato plants were sprayed in a spraying cabin developed at the Research Station for Arable Farming and Field Production of Vegetables at Lelystad, in co-operation with TFDL-DLO. The fungicides were sprayed using TJet 110.03 nozzles. The nozzles moved at a speed of 3.6 km/h, and approx. 30 cm over the top of the potato plants. Each time the equivalent of 250 l/ha was sprayed onto the plants. The pressure was set at 3 bars. Volume, and droplet size were the same in each experiment.

Fungicide dosages used in the rainfastness experiments were 2 kg/ha Dithane WP (80% mancozeb) and 2 kg/ha Curzate M (4.5% cymoxanil; 65% mancozeb). Fungicides were used as formulated products. Dosages used in the experiments were lower than label dosages, which were 4 kg/ha Dithane WP and 2,5 kg/ha Curzate M.

Inoculum preparation, inoculation and incubation. Fysio 1.4 of *P. infestans* was used in all experiments. The fungus was maintained on slices of potato tubers (cv Bintje) under

moist conditions at 16°C in the dark. An inoculum suspension of zoosporangia was made by rinsing a one week old culture of *P. infestans* on potato slices with demineralized water. The inoculum density was counted using a haemocytometer and adjusted to 10.000 zoosporangia per ml. Potato leaves (preferably the 3rd leaf > 5 cm from the top) were detached from the plant just before inoculation. The detached leaves were stuck in wetted oasis and placed in a plastic container. Inoculation was carried out by placing a 50 µl droplet of a zoosporangia suspension on five leaflets of a potato leaf. To maintain a high relative humidity during incubation the containers were covered in plastic bags. The containers were placed in the dark and the temperature was set at 16°C. Inoculum quality was tested by inoculation of an unsprayed leaf, in each container. Another unsprayed leaf was treated with water to detect any infection from natural inoculum sources of *P. infestans*.

Disease observations. Disease assessments were made one week after inoculation. Lesion formation and the percentage of the leaflet covered by the lesion were assessed on each of five leaflets closest to the top of a potato leaf. Disease incidence was estimated as the percentage of leaflets infected by potato late blight. Disease severity was estimated as the percentage of leaflets surface colonised by *P. infestans*. The lesions were checked for sporulation of *P. infestans* by eye or with the aid of a stereo microscope (40x). Sporulation intensity was not quantified.

Rainfastness. Three plants were treated with water, mancozeb and Curzate M, respectively. From each fungicide object three plants were subjected to simulated rainfall. The plants were placed on a rotating table (5 rpm). Rainfall was simulated by using a self built rain simulator. The nozzle used was a FullJet FL-5VS hanging 3 meter above the potato plants. The water pressure was set upon 2 bars. Rain intensity was adjusted to 10 mm in 16 minutes. Rain simulations were carried out 1 hour, 1.5 hours and 4 hours after spraying the fungicides. However, since the fungicides could not be sprayed simultaneously, the actual interval between spraying and rain simulation inevitably differed from the intended time interval, to a maximum of 14 minutes.

In the 1.5 hours treatment it was prevented that the droplets from the spraying dried before rain simulation. This was achieved by placing the plants in a closed container in which a high relative humidity was maintained. Between spraying and rain simulation

this container was kept in a climate chamber at 5°C. Placing the potato plants in this climate chamber was the only possibility to prevent spraying droplets from evaporating before rain simulation. The rainfastness experiment was carried out four times.

Detached leaves. Picking the leaves from the potato plants might have an effect on the efficacy on the uptake of the locally systemic cymoxanil present in Curzate M, and influence the efficacy. Therefore one experiment was conducted in which the leaves were inoculated, but remained on the plant during incubation. Potato plants were sprayed with mancozeb and Curzate M as described above. One plant of each fungicide treatment was subjected to rain simulation one hour after spraying. One plant remained dry. Four leaves per plant were inoculated. The leaves were covered in little plastic bags, which were moistened on the inside, to maintain a high relative humidity, to allow penetration of *P. infestans*. The potato plants were incubated for one day at 16°C in the dark. After 24 hours the plastic bags were removed and the plants were taken into the light and placed at 20°C. Disease assessments were made five and seven days after inoculation.

Statistics. Data were analyzed using Genstat 5 release 3.1. The percentage protection of the fungicides was calculated from the observed disease incidence ($\%C_{obs} = 100$ - disease incidence). Analyses of variance (ANOVA) were applied to percentage protection data and disease severity data. Least significant differences (LSD) at the $P = 0.05$ level were calculated from the standard error of difference generated in the analysis.

Results

Inoculation of *P. infestans* on untreated potato leaves almost always resulted in lesions covering the leaves completely. This showed that the *P. infestans* culture remained pathogenic during the experiments, and that the conditions were favourable for infection. The correlation between the percentage protection the fungicides offered against potato late blight and the disease severity was high ($r^2 = 0.84$). From the late blight lesions found in the experiments 96% sporulated. Therefore the percentage protection was justly based upon the disease incidence of the potato leaflets.

Rainfastness. Altough in experiment 4a the percentage protection was 100% for all objects, results were not significantly different from result in experiment 4, which was car-

ried out at the same time. The effect of rain simulation on the efficacy of fungicides against *P. infestans* is shown in table 1. When no rain was applied Mancozeb and Curzate M showed 88% and 95% protection, respectively. Due to rain simulation (10 mm in 16 minutes) mancozeb lost 21% of its effectivity (i.e. 100 - {100 * [(73 + 65 + 70)/3] / 88 }). The loss of activity of Curzate M was 15%. The difference, though not significant, is caused by the 1.5 hour treatment, in which the spray droplets were not allowed to dry between spraying and rain simulation. Apparently mancozeb is easily washed from the leaves when the drops from the fungicide spraying are not yet dried at the moment of rain simulation, whereas Curzate M hardly lost effectivity in this treatment. In experiment 1 the percentage protection of Curzate M was significantly (P < 0.05) higher than that of mancozeb. In the other three experiments no significant differences were found between fungicides applied. However, when the poor control of Curzate M in the 4 hour treatment in experiment 2 was not included in the analysis, a tendency was found that Curzate M provides better protection against *P. infestans* than Mancozeb.

Table 1. The percentage protection of fungicides against *P. infestans*, after rain treatments to investigate rainfastness of fungicides in a bioassay (four experiments). In experiment 4a, the leaves were not detached from the plants during incubation.

Fungicide treatment[a]	Interval between spraying and rain simulation [h]	Percentage protection (100-disease incidence) Experiments						Mean[b] disease severity [%]
		1	2	3	4	4a	Mean[b]	
Mancozeb	1	30	100	100	60	100	73	19
	1.5	20	90	50	100	-[d]	65	28
	4	60	100	20	100	-	70	18
	n[c]	70	100	80	100	100	88	7
Curzate M	1	40	80	100	90	100	78	12
	1.5	100	100	70	90	-	90	8
	4	70	20	100	100	-	73	12
	n	100	100	90	90	100	95	3
LSD (0.05)		70	31	66	50	21	30	22

a: When no fungicide was applied all the inoculated leaflets developed late blight lesions.

b: Mean calculated from experiments 1,2,3 and 4.

c: No rain simulation.

d: No data available.

Discussion

Detached leaves. Leaves were detached from the plant approximately five hours after spraying. The phloem and xylem transport is interrupted, which might affect the action of the fungicides against *P. infestans* in the bioassay. Especially the uptake of the locally systemic fungicide cymoxanil might be affected. The efficacy of mancozeb, which remains on the surface of the leaf is probably not influenced. Table 1 shows that the results obtained with potato leaves left on the plant (experiment 4a) were largely comparable to the results from the detached leaves in the bioassay (experiment 4). This is an indication that detached leaves can be used to test the efficacy of products that contain a mixture of preventative and locally systemic active ingredients against potato late blight.

Inoculum. The inoculum pressure applied in the bioassay was high and the circumstances were favourable for *P. infestans* development. In the field, inoculum pressure is probably lower, and weather conditions are not constantly favourable for late blight development in potato. Therefore, the fungicides show lower protection levels in the bioassay, than might be expected in the field. Nevertheless, the bioassay gives an insight in the relative effectiveness of the different combinations and treatments to control late blight under severe conditions in the field. Neuhaus *et al.* (1974) found the same ranking order of fungicides tested for their efficacy to control late blight of potatoes in field experiments as in laboratory experiments, but protection levels in the field were higher.

Rainfastness of mancozeb and Curzate M. Although rain simulation is not the same as rainfall in the field it is commonly and satisfactorily used to test rainfastness. In our experiments mancozeb lost 21% activity, and Curzate M 15% due to 10 mm simulated rainfall (table 1). In experiments of Shephard (1981) mancozeb lost 50% activity after unknown amount of rainfall. Lindner *et al.* (1994) found 43% loss of mancozeb activity on tomato after 10 mm rain simulation. The difference in loss of activity between our observations and the data from literature might be explained by the fact that we used plants grown outdoors, where others used plants grown in greenhouses. It is expected that the cuticle of plants grown outside is thicker than that of greenhouse plants (Baker & Hunt, 1981). It is plausible that this has some effect on the rainfastness of the fungicides. A bioassay gives information on the loss of efficacy of the fungicide but does not provide information on the amount of deposit of the fungicides on the plant. Kudsk *et al.* (1991),

retained 45% of the mancozeb applied on potato plants after 9 mm rain. They indicated that mancozeb should be resprayed after heavy rain.

The rainfastness of Mancozeb and Curzate M was not increased when the interval between spraying and rain simulation increased from one to four hours. Maybe by increasing the interval to one day or longer, rainfastness of the fungicides might increase. Research on spraying chlorothalonil showed that rainfastness increased with time (0, 1, and 7 days) since application (Bruhn & Fry, 1982). The same pattern was found for fluazinam and fentin-acetate (Schepers, 1996; Schepers, 1997). This aspect needs more research when mancozeb and Curzate M are concerned.

Dithane WP (1.6 kg/ha mancozeb) and Curzate M (1.3 kg/ha mancozeb + 0.09 kg/ha cymoxanil) did not show significant differences in percentage protection (table 1). When the difference from the intended time interval between spraying and rain simulation was introduced as a covariable in the variance analyses still no significant differences were found. However, a tendency was found that Curzate M gave better control than mancozeb when the leaves did not dry between spraying and rain simulation (Table 1, treatment 1.5 h). Crop protection levels lower than 90% were found 8 times using mancozeb and 5 times using Curzate M out of a total of 16 observations (Table 1). Disease severity in the mancozeb treatment tended to be twice as high than in the Curzate M treatments. This indicates that the reliability of Curzate M is higher than that of mancozeb. Since the amount of mancozeb in Curzate M was lower than in Dithane WP, cymoxanil is the most likely ingredient of Curzate M responsible for a better reliability. The amount of active ingredient per hectare in the mancozeb and the Curzate M treatment used in these experiments were lower than used in agricultural practice. Moreover the inoculum pressure applied in the bioassay was very high. Taking both aspects into account higher control levels will probably be obtained in the field. Further research is needed on the rainfastness of mancozeb and Curzate M under field conditions and other rainfall regimes.

Conclusions. In absence of simulated rain, the disease control in the Curzate M treatment was higher than in the Mancozeb treatment. Both Mancozeb and Curzate M lost some effectivity due to rain simulation. After exposure to 10 mm of simulated rain, there was a tendency for a higher control with Curzate M compared to Mancozeb alone. There is an

indication that the slower drying of the fungicide solution on the potato leaves positively influences the rainfastness of Curzate M relative to that of Mancozeb.

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Comparison of fungigation, ground and aerial

application of foliar fungicides for late blight

N. C. GUDMESTAD*, G. A. SECOR* & D. A. PRESTON**

*Department of Plant Pathology, North Dakota State University, Fargo, ND,
USA **Department of Horticulture, University of Minnesota, Grand Forks, MN,
USA

Summary

Fungicide usage on the potato crop has increased dramatically in the United States since the introduction of new immigrant genotypes of *Phytophthora infestans*. Studies were initiated to investigate the level of chlorothalonil residues throughout the plant canopy when the fungicide was applied by air, ground or fungigation methods. Ground application of fungicide generally provided the highest chlorothalonil residues throughout the potato canopy and was influenced by water volume. Differences in chlorothalonil residues were not affected by type of aircraft used or by water volume. Application of fungicide through the irrigation system generally provided the lowest chlorothalonil residues throughout the plant canopy. Fungicide residues delivered by a 'drop boom' suspended from the irrigation system were comparable to or higher than residues observed by any other method.

Keywords: fungicides, chlorothalonil, application method, *Phytophthora infestans,* late
blight

Introduction

A number of factors affect the efficiency of fungicides used for the management of late blight in a potato crop. Some of these factors include, the timing of the initial fungicide application; the interval between subsequent fungicide applications; the rate of the fungi-

cide to be applied and; the extent of fungicide coverage throughout the plant canopy. Since most effective fungicides used today are protectant, they must be in contact with foliar surfaces of the plant prior to the infection process. Subsequent fungicide applications must be made to ensure that new foliage is adequately protected and to replace fungicide residues that have been lost due to "weathering."

Fungicide coverage must be thorough in order to maintain an adequate level of protection. Fungicide residues must not only cover individual leaflets and leaves, but must also be present in high enough concentration throughout the canopy to be effective. Microclimates favourable for the development and infection of *Phytophthora infestans* are most likely to occur in lower plant canopies where deposition of fungicides is most difficult.

Renewed emphasis has been placed on achieving adequate fungicide protection since the increase in late blight due to the introduction of immigrant late blight genotypes into North America during the 1980s. Costs associated with the production of potato have also risen dramatically in the U. S. in recent years. A significant portion of this increase in production cost is associated with the concomitant increase in fungicide usage to manage immigrant genotypes of the late blight fungus. As a result, a more detailed understanding of how foliar fungicides can be used more effectively and efficiently is warranted. Additionally, new advances in pesticide application technology have been developed since previous studies were published.

Fungicide applications are made in the U. S. by three primary methods, aircraft, mechanical ground sprayers and fungigation through irrigation systems. Considerable improvements have been made in the design of mechanical sprayers. Considering the increased use of aerial application and chemigation of fungicides, studies were initiated to evaluate fungicide application technology for improved management of foliar diseases of potato.

Materials and Methods

A preliminary study was conducted in 1995 in a commercial potato field, c.v. Russet Burbank, to compare chlorothalonil residues in the upper, middle and lower one-third of

the canopy after the fungicide had been applied via air, ground and fungigation. Fungicide applications began approximately 60 days after planting (DAP). Chlorothalonil was applied as Bravo Zn every seven days at the rate of 1.75 l/ha for the first two applications and 2.5 l/ha thereafter. Aerial applications of fungicide were delivered with a water volume of 46.75 l/ha. Ground applications of fungicide were delivered with a water volume of 168.3 l/ha with 172 kpa pressure.

Fungigation water volume was approximately 15 mm/ha. Each fungicide application method was performed on two replicated fields (six fields total) measuring approximately 55 ha.

Leaves were sampled randomly from the upper, middle and lower one-third of the canopy after the fifth application of fungicide. Five leaves from each portion of the canopy were removed from each of five replications throughout each field. One cm^2 subsamples from each leaf were obtained and placed immediately into vials containing 10 ml toluene. Subsamples from each vial were analysed for chlorothalonil residues using high performance liquid chromatography (HPLC) (Bruhn and Fry, 1982).

The study was repeated in 1996 with modification. Chlorothalonil was applied at the same rate and interval as 1995, however, leaves sampled for residue analysis were obtained after the fifth and ninth applications. Leaf sampling and residue analysis in 1996 was as previously described.

Aerial application of chlorothalonil fungicide in 1996 was performed using two different aircraft each with two water volumes. A single-wing Thrush (approx. 185 km/hr) and a biplane Ag Cat (169 km/hr) aircraft delivered water volumes of 46.75 l/ha and 65.45 l/ha each on separate replicated fields. Ground applications of chlorothalonil were made with 233.75 l/ha at two different pressures, 310.3 and 586.1 kPa, respectively. Fungigation of chlorothalonil was applied at a rate of 7.5 mm/ha.

In 1997, chlorothalonil residues throughout the canopy were studied after fungicide had been applied at three rates, 1.75, 2.0 and 2.5 l/ha on replicated fields on a 5 day schedule for the entire season. Based on previous results obtained by our group, fungigation application studies were discontinued in lieu of investigating an experimental 'drop boom' suspended from the center pivot irrigation system. Leaf sampling and chlorothalonil resi-

due analysis were performed as previously described.

Results

Studies performed by our group have attempted to compare fungicide coverage as affected by method of application, water volume, and pressure of delivery. Chlorothalonil residues throughout the canopy were generally higher with ground applied fungicide compared to aerial or chemigation applied fungicide (Figure 1 & 2). Chlorothalonil residues were generally higher throughout the canopy after nine applications of fungicide compared to the level of chlorothalonil after five applications (Figure 2).

No significant differences were observed in fungicide residues among the methods of aerial application (Thrush vs. Ag Cat) or water volume. Water volume was a more important variable with ground application than with aerial application of fungicide. The higher water volume used in 1996 (Figure 2) generally increased chlorothalonil residues in the lower canopy compared to 1995 (Figure 1). Increased pressure of fungicide delivery did not appear to have any effect on fungicide residue levels in the canopy.
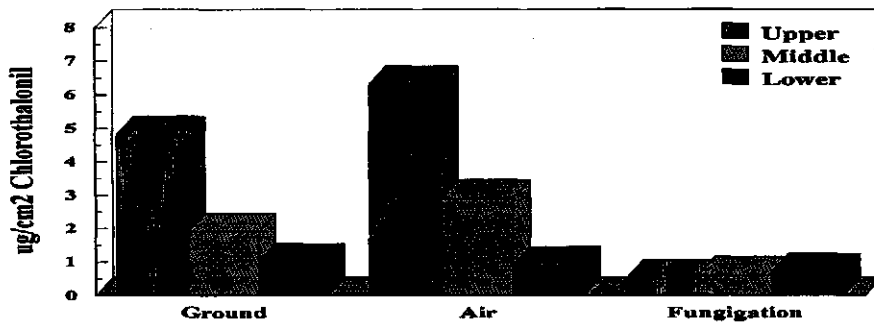

Figure 1. Residue levels (ug/cm^2) of chlorothalonil in the upper, middle and lower plant canopy after application by ground, air or fungigation in 1995.

Although fungigation of chlorothalonil results in significantly less residue throughout the plant canopy compared to aerial or ground application, a slight increase in fungicide residue was noted in 1996 (Figure 2) when water volume was less than that used in 1995 (Figure 1). It is clear, however, that using a 'drop boom' suspended from the main irrigation unit, is superior for fungicide delivery than fungigation. Chlorothalonil residues delivered via a drop boom were higher than residues found throughout the canopy when fungicide was applied by air in 1997 (Figure 3).

Discussion

Several studies have been performed that relate to fungicide deposition onto potato and tomato plant canopies (Bruhn and Fry, 1982a, 1982b; Courshee, 1967; Deonier, 1955; Ebeling, 1963; Luken and Ou, 1976; Shoemaker, 1979). Fungicide coverage depends on a number of factors including leaf position in the canopy, canopy density, leaf shape and size, leaf texture and pubescence and growth habit. Generally, fungicide residue levels decline exponentially with increased distance from the top of the plant canopy (Bruhn and Fry, 1982a; Courshee, 1967). This appears to be especially true for crops which that a uniformly dense canopy, such as potato, than with other crops (Courshee, 1967). Results reported here are in agreement with those previously published. However, data obtained in 1997 using an experimental drop boom appear to increase the amount of fungicide reaching the lower plant canopy compared to other methods of fungicide delivery we investigated.

Several other factors also affect fungicide coverage in potato crops. Bruhn and Fry (1982a, 1982b) found application method, potato cultivar, and application dosage affected coverage. They found that fungicide coverage applied by helicopter resulted in fairly uniform coverage of foliage throughout the upper half of the canopy but poor coverage in the lower half. Fungicide applied with a tractor mounted sprayer declined exponentially. Bruhn and Fry (1982a) felt that the differences in fungicide coverage pattern between the two methods was probably the result of differences in droplet size and the relative importance of impaction and sedimentation of droplets to fungicide deposition. Their results agree with those of others (Courshee, 1967; Ebeling, 1963). Although residues in the upper half of the canopy were directly related to fungicide dosage (Bruhn and Fry, 1982a), fungicide residues in the lower canopy were not changed by fungicide dosage rate. We found no difference in fungicide residues anywhere within the plant canopy as a result of dosage rate.

Although cultivar did not significantly affect distribution of fungicide residue levels in the studies of Bruhn and Fry (1982a, 1982b), this may be due to the choice of cultivars used. Katahdin and Monona are both determinate in growth habit and may not reflect potential cultivar differences that may exist if an indeterminate growth habit cultivar had been included such as cv. Russet Burbank used in our studies,
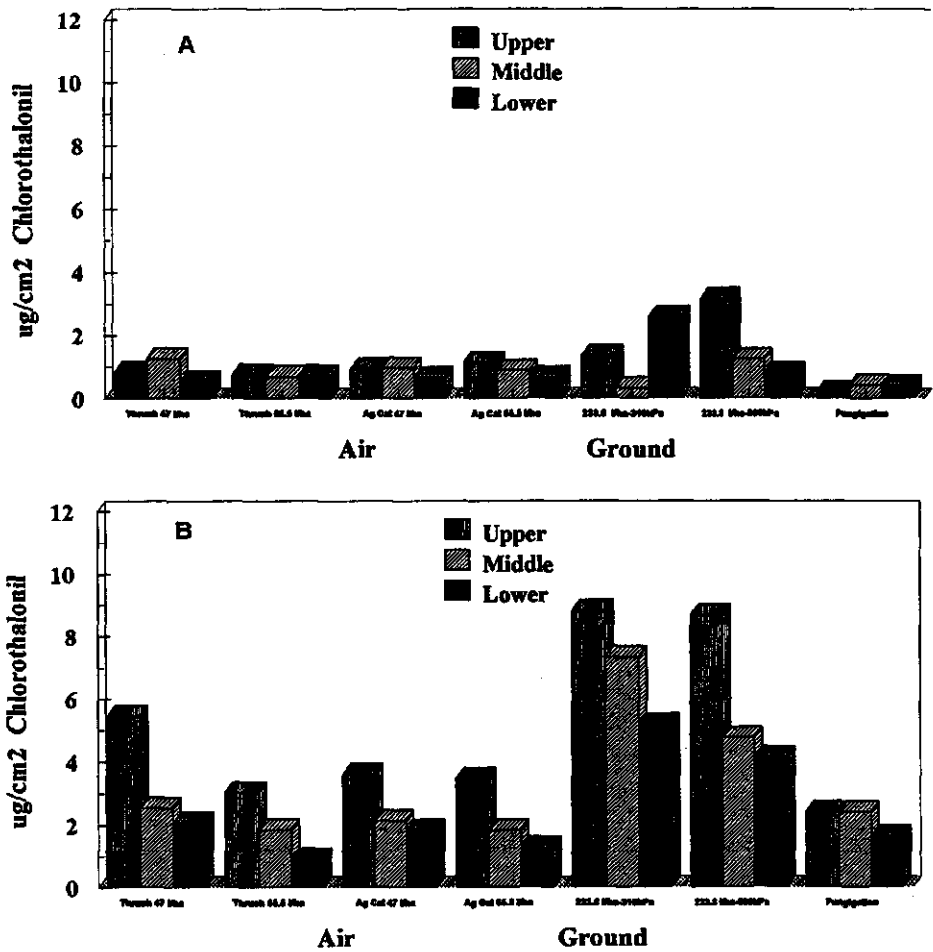
Figure 2. Residue levels (ug/cm²) of chlorothalonil in the upper, middle and lower plant canopy after application by ground, air or fungigation in 1996 using various water volumes (air) or air pressures (ground). (A) Residue levels after five applications of chlorothalonil. (B) Residue levels after nine applications of chlorothalonil.
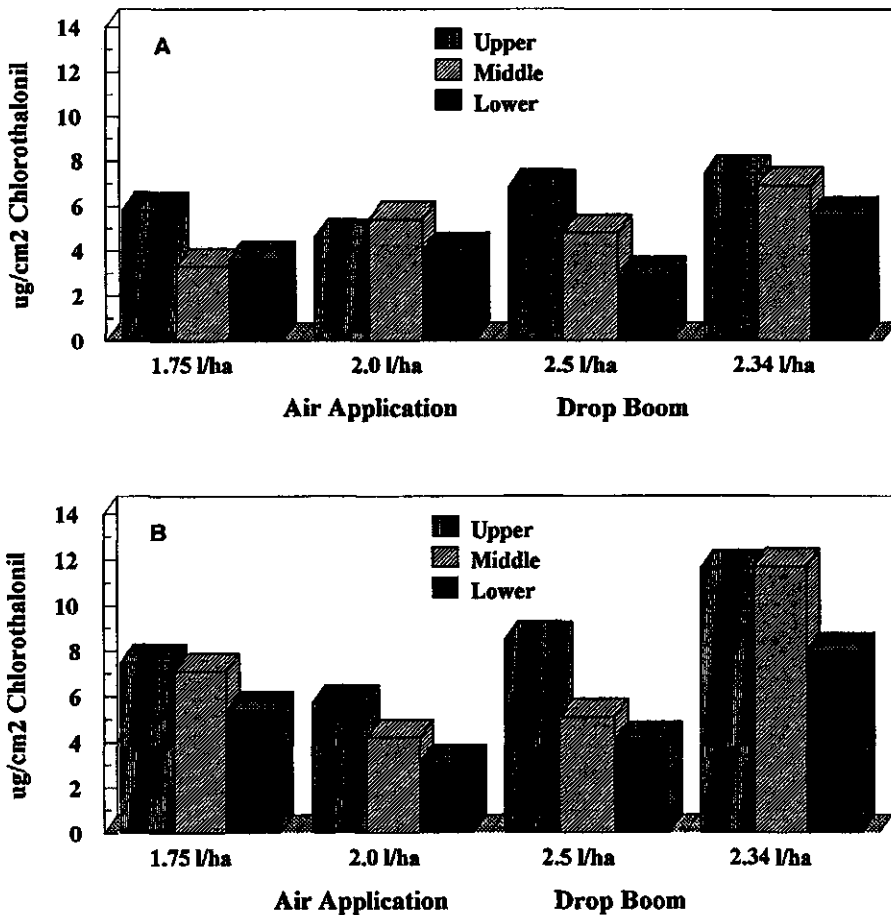
Figure 3. Residue levels (ug/cm2) of chlorothalonil in the upper, middle and lower plant canopy after application by air using three rates of fungicide or by an experimental 'drop boom'. (A) Residue levels after six applications of chlorothalonil. (B) Residue levels after nine applications of chlorothalonil.

Conclusions

A number of factors have been identified that clearly impact the efficiency of fungicide applications to a potato crop. While a number of these factors involve the crop itself (growth habit, leaf position, leaf shape, size, texture, and pubescence), other factors such as method of application, water volume, and amount of hydraulic pressure play an important role in fungicide efficiency regardless of potato cultivar. Recent improvements

with ground application technology may provide a better method of fungicide delivery and management of late blight, but results to date have been inconclusive. Clearly, improvements in the delivery of fungicides via overhead irrigation equipment is needed and results of studies presented here are very encouraging. Drop boom technology for overhead irrigation units have an advantage over traditional fungigation in maintaining fungicide residues on plant surfaces while being environmentally sound.

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Comparison of application methodology using fungicides differing in systemicity

J.S. PASCHE*, G.A. SECOR*, J. WRIGHT**, D.A. BAER*, & N.C. GUDMESTAD*

*Department of Plant Pathology, North Dakota State University, Fargo, ND, USA

**University of Minnesota-Morris, Morris, MN, USA

Summary

A study was performed to determine the effect of fungicide application methodology on the efficacy of three fungicides used for control of *Phytophthora infestans.* Disease severity of leaves from the upper, middle, and lower canopy was used to determine the efficacy of Bravo Zn, Tattoo C, and Acrobat applied by ground or fungigation. Control provided by Tattoo C and Acrobat was generally better than that provided by Bravo Zn, although differences were not always significant. Fungigation was nearly as effective for fungicide application as ground, especially with fungicides with some systemicity.

Key Words: *Phytophthora infestans,* fungigation, fungicides, application methods, late blight

Introduction

Prior to the 1990's *Phytophthora infestans (Pi)* was found across the US predominantly as an A-1 mating type with a US-1 genotype (Goodwin et. al., 1995). Ridomil, which was used to protect potato crops from *Pi* US - 1 /A- 1, contains the active ingredient metalaxyl, and is very effective against US-1. During the past three years, US-8/A-2, which is metalaxyl resistent, has become the dominant genotype across the US. Following the appearance of the A-2 mating type of *Pi,* with resistance to metalaxyl, and increased

aggressiveness, there has been an increased effort to register new fungicides to combat the immigrant genotypes. Systemic compounds including Tattoo C (propamocarb HCL + chlorothalonil), Acrobat (dimethomorph), and Curzate (cymoxanil) have been introduced under Environmental Protection Agency (EPA) section 18 guidelines. These compounds are primarily used in crisis situations where a crop is in danger of being completely over-whelmed by *Pi*. It is generally believed that these compounds are more efficacious against US-8 Pi over existing non-systemic compounds on the market.

The objective of this study was to determine the efficacy of the Tattoo C, Acrobat, and Bravo Zn, as well as the efficacy of ground and fungigation application technology on control of late blight throughout the potato canopy.

Materials and Methods
Russet Burbank seed pieces were planted in 4x7.6 m blocks. Four replications of 8 treatments were arranged in a randomized complete block design. The treatments included both ground and fungigation applications of Tattoo C, Bravo Zn, Acrobat, and an untreated control.

Tattoo C contains a 1: 1 mixture of propamocarb HCL and chlorothalonil. It was applied at a rate of 2.7 liters/hectare for the 1st, 3th, and 5th applications, alternating with Bravo Zn which was applied on the 2th, 4th, and 6th application dates. Propamocarb is a fungicide providing both local and acropetal systemicity. The active ingredient of Bravo Zn is chlorothalonil applied at a rate of 2.7 liters/hectare. Bravo Zn is a protectant, contact fungicide with no systemicity. Acrobat contains dimethomorph and mancozeb as the active ingredients. Acrobat was applied at a rate of 2.25 kg/hectare with dimethomorph providing both local and translaminar systemicity. Each fungicide was delivered with 626.4 liters/hectare for ground applications, and 6.9 mm/hectare for fungigation.

Three to five leaves from all four replications of each treatment were randomly collected twice weekly from the upper one third, middle one third, and lower one third of the foliage. Leaves were placed into humidity chambers (>90% RH), inoculated with a mist of Pi inoculum containing $1.5\text{-}2.0\text{x}10^4$ zoospores/ml, and incubated at 15°C with 16 hours of light. The *Pi* suspension was uniformly sprayed to wetness onto the upperside of the

leaves. The percent infection of each leaf was recorded at 4, 5, 6, and 7 days after inoculation (DAI) (Malcolmson, 1969).

Inoculum of *Pi* used, US-8 genotype, A2 mating type, from our culture collection at North Dakota State University, was grown on Rye B agar for approximately 15 days at 15°C in the dark. Sporangia were collected from the agar using sterile distilled water and placed in the dark at 10°C for 2 hours to allow zoospore production. The suspension was filtered through nylon mesh to remove mycelium, and the zoospores were counted using a hemocytometer. The suspension was diluted to 1.5-2.0×10^4 zoospores/ml, and then used to challenge inoculate leaves collected from the field.

Results

Fungicides with systemic properties (Tattoo C and Acrobat) generally provided late blight control that was superior to Bravo Zn (Fig. 1). These differences, although not always significant, were more apparent when fungicides were applied by a mechanical ground sprayer (Figure 1A).

Disease control was generally superior when Tattoo C, Acrobat and Bravo Zn were applied by ground compared to application by fungigation (Figure 2). However, these differences were rarely significant. Disease control was generally highest in the upper two thirds of the canopy (upper and middle) than in the lower third of the plant canopy (Figure 3).

Discussion

Several factors effect the efficacy of foliar fungicides used in the management of potato late blight. These factors include the timing of the initial fungicide application; the interval between fungicide application; the rate of the fungicide used and; the extent of the fungicide coverage throughout the plant. In the last instance, fungicide coverage is critical, especially when an active ingredient of the fungicide is absorbed by the plant foliage and incapable of being redistributed to the lower parts of the plant canopy during periods of rain or irrigation. While many contact, protectant fungicides are known to redistribute, locally systemic fungicides are unable to do so.

Locally systemic fungicides, such as Tattoo C and Acrobat, must be applied to each part of the plant canopy in order to be fully effective. Our research group has observed the lack of late blight control in the lower plant canopy when fungicides such as Acrobat, Tattoo C

and Curzate are applied by aircraft. Fungicide residues applied by aircraft are generally very low in the lower half of the plant canopy (Bruhn and Fry, 1982; Gudmestad, et al., 1997), which would explain why locally systemic fungicides provide very little control with this method of application. Although fungicide residues resulting from fungigation are also typically very low (Gudmestad, et al., 1997), coverage is complete throughout the plant canopy. We hypothesize that fungicides such as Acrobat and Tattoo C would be amenable to application through the irrigation system (i.e., fungigation). Data reported here support that hypothesis. Therefore, it would appear that fungicides with some systemic properties can be applied by ground or by fungigation, with similar results.

Data from this study has shown control of late blight by Tattoo C and Acrobat by both ground and fungigation application. These compounds are both locally systemic but Tattoo C has been shown to also move acropetally. If biological activity and control of late blight is shown to accompany acropetal movement of Tattoo C into new foliage, increased coverage of potato plants by ground or fungigation should provide control of late blight in new growth. Such studies are warranted to correlate application methodology, coverage, and efficacy.

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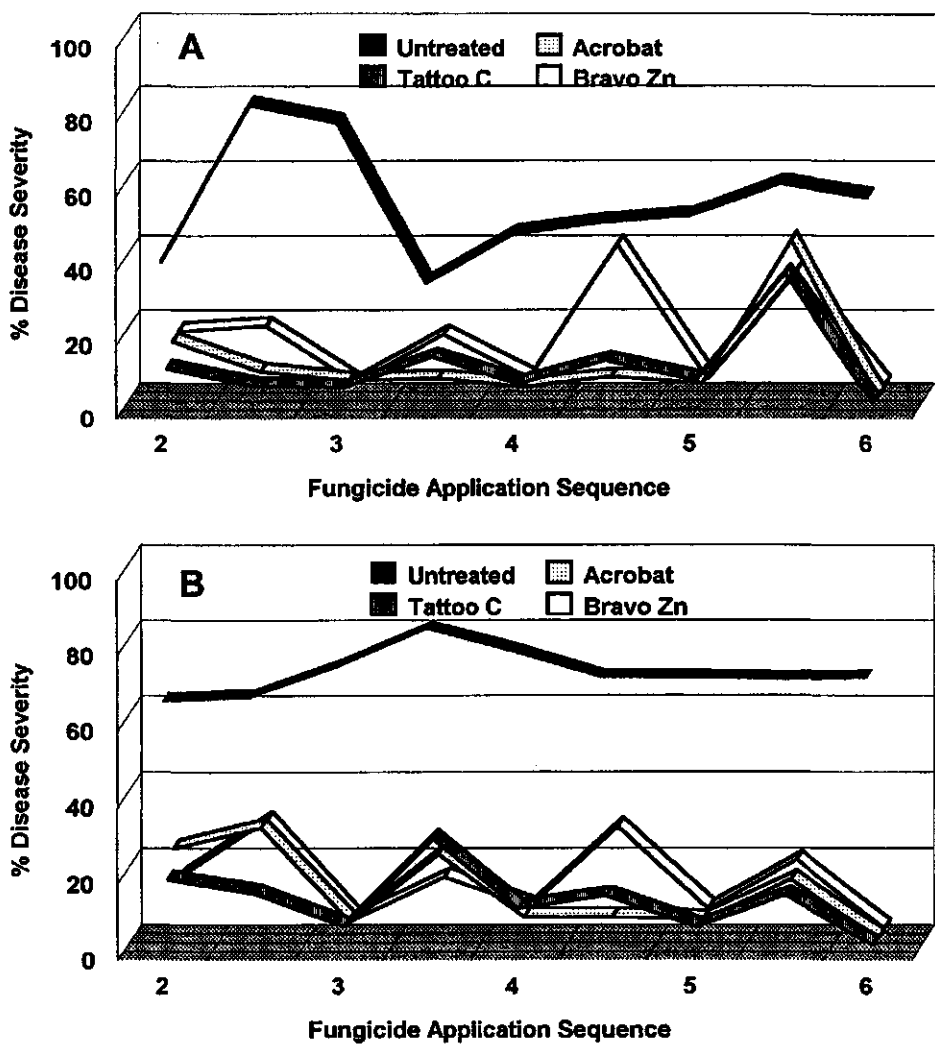
Figure 1. Late blight disease severity in challenge inoculated potato leaves collected from plots treated with fungicide applied by ground (A) or fungigation (B).
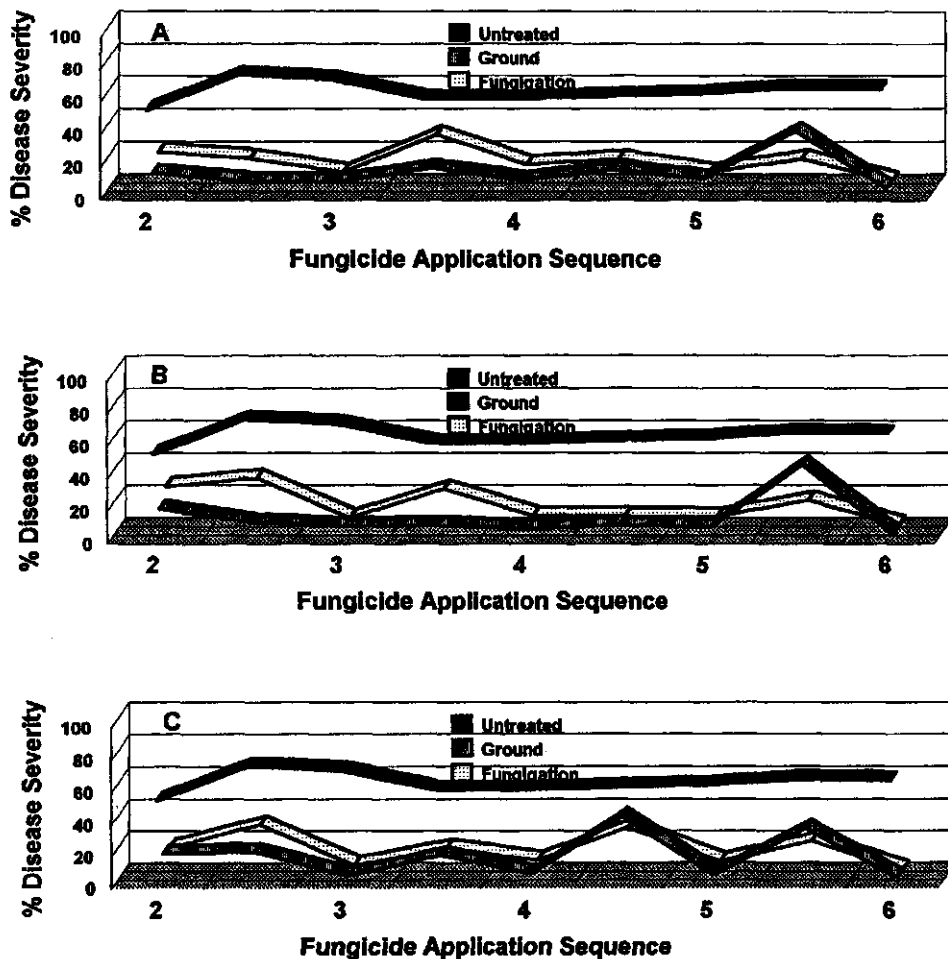
Figure 2. Late blight disease severity in challenge inoculated potato leaves collected from plots treated with Tattoo C (A); Acrobat (B); or Bravo Zn (C); fungicides applied by ground or fungigation.
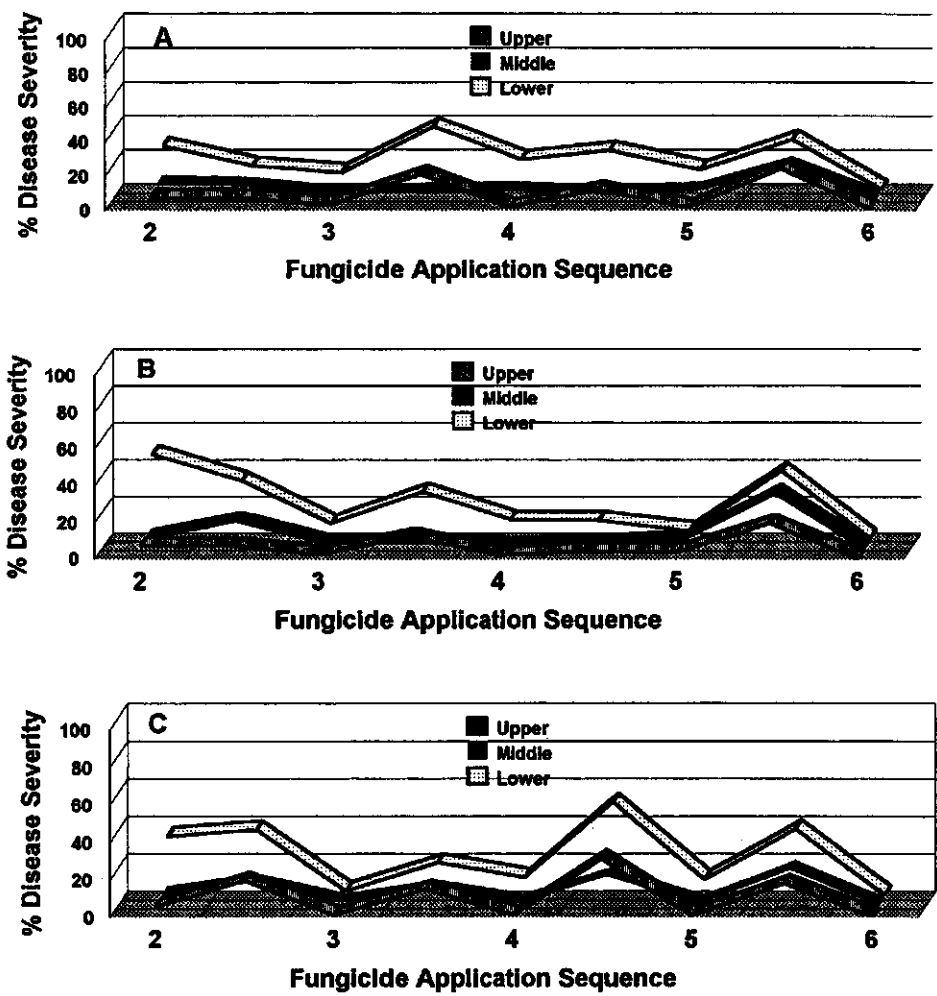
Figure 3. Differences in late blight disease severity in upper, middle, and lower plant canopy leaves collected from plots treated with Tattoo C (A); Acrobat (B); or Bravo Zn (C).