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C.E. Westerdijk and H.T.A.M. Schepers (editors)

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Preface

Integrated control of potato late blight

A Concerted Action entitled “European network for development of an integrated control strategy of potato late blight (EU.NET.ICP)” encouraged participants to a yearly workshop. After four years and four Workshops (Proceedings comprised in four PAV-Special Reports: 1, 3, 5 and 6) the Concerted Action came to an end, but through enthusiastic participants and sponsoring by Agrochemical companies the series of Workshops continued. In September 2000 the fifth workshop was organised in Munich (München, Germany) and partly sponsored by Aventis, BASF, DuPont and Syngenta. The Scottish Agricultural College (SAC) organised the sixth workshop in Edinburgh from 26-30 September 2001, greatly . sponsored by Aventis, Bayer, BASF, Dow, DuPont and Syngenta. The workshop was attended by 68 persons from 16 European countries and the USA. Representatives from all countries presented the late blight epidemic in 2001 and recent research results regarding integrated control and decision support systems of late blight in potatoes. The papers and posters presented at the Workshop and discussions in the subgroups are published in this Proceedings, PPO-Special Report no. 8.

For further information please contact the network secretariat where also additional copies of this Proceedings can be ordered.

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The development and control of *Phytophthora infestans* in Europe in 2001

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Introduction

From 26-30 September 2001 a Workshop was held on control of *Phytophthora infestans*. Representatives from 16 European countries presented the development and control of late blight in their country in 2001. In this paper these presentations are summarised. The weather conditions of 2001, the disease progress and the input of fungicides are presented and condensed in Table 1 and 2.

Weather conditions

In the Po Valley in **Italy** late blight pressure was low throughout the growing season. The very first symptoms of the disease occurred on early cultivars on 14 May, following an infectious event on 6-7 May. Afterwards, other primary infections occurred sporadically on 22 May. Climatic conditions (hot and dry from the last decade of May to half June) were not conducive to late blight which did not develop further. Only 2-3 infectious periods were recorded in the growing season.

In the Basque Country in **Spain** no blight epidemic occurred. In one field some infected plants were found 2 August. The summer was very dry and hot, sometimes temperatures reached 38°C. Most fields were irrigated. Only two periods with a high infection risk were recorded: 10 July and 27 July.

In **Switzerland** the first late blight attack was observed in the western part of the country on 11 May in a polythene covered crop. Due to wet weather conditions especially in June, the late blight epidemic developed faster than in 2000, but not as fast as in 1999. At the end of the season many attacks were registered in the western and central part, but only a few in the eastern part of Switzerland.

In the intensive production areas in the north east of **Austria** (Weinviertel) first blight was observed on 19 June. This is on an average over the last 20 years. Due to rain showers there were three periods of high infection pressure in the Weinviertel: 16-23 June, 20-30 July and 31 August-7 September. Most infections appeared after the first period. No increase of infections was observed after the second period. In the north of Austria (Waldviertel) late blight occurred on 3 July. This is on an average over the last 20 years. Also three periods of high infection pressure have to be mentioned in the Waldviertel: 18-23 June, 20-28 July and 24 August-6 September. Most infections were found from the end of July until mid August after the second period, most problems with late blight arose on late crops. In the region of Petzenkirchen in the western part of lower Austria, late blight appeared two weeks earlier than the last years. These first lesions were found on leaves of Bintje on 22 June. Due to rainfall, two periods with high infection pressure were recorded: 15-20 June and 20-29 July. During the rest of the season infection pressure was low. In 2001 infections on leaves and stems occurred in Bintje and Merkur in Petzenkirchen. In August *Alternaria solani* was causing more problems than *P. infestans*.

The first blight in **Germany** was recorded 2 May in a polythene covered crop in the Rheinland Pfalz region. The epidemic pressure was high in Bavaria and very high in the northern regions.

The disease pressure in the early crops in Brittany (**France**) was high from April onwards. Some heavy attacks were observed in crops covered with plastic. The first treatments had to be applied as soon as the potatoes reached 50% emergence. The fungicides were often washed off by rain forcing the growers to use rainfast products. Ware potatoes and potatoes for the food industry in Northern France were planted from end of April until beginning of June. The weather was very favourable for blight; very high rainfall. Early April, many waste dumps were observed with blighted plants. The disease pressure was very high in late May, when the first fields emerged. The first spray had to be applied as soon as the emergence reached 30%. Some heavy attacks were observed on unprotected fields in late May. Some fields were 40% destroyed. The attacks affected mainly stems and bunches. The dry weather conditions in late June stabilised the disease development, but the pressure remained very high. The epidemic started again when the rains came back in early July together with a strong crop growth. Many blighted plants were observed from 20 July. The rain storms in

July maintained the pressure. New infections were observed from 24 August.

In Flanders (**Belgium**) a wet March was followed by a very wet month of April (highest rainfall since registration started in 1833). This led to a delay in planting, the months of May and June were very dry and unfavourable to late blight. The first blight was observed on a dump on 2 May. In that same week many infected dumps were found. A close survey in 4 potato growing areas revealed an average density of 1 dump for every 2 km² – or 1 dump in a radius of 800 m! After these observations in the first week of May, no more late blight attacks were reported until 12 July. From the beginning of July until the end of the season, weather conditions were in fact very favourable to late blight, leading to widespread attacks in 9 fields out of 10. These attacks could be controlled with frequent sprayings and did not result in serious losses or damage. In Wallonia (**Belgium**) the very wet and rather cool weather in April delayed planting. Cold temperatures also delayed the first symptoms of blight. May and June were very dry which resulted in slow growth of the potatoes due to water deficit. Sources of late blight disappeared during June. From mid-July to half of August very rainy periods were alternated with dry and very hot periods. The first symptoms in commercial fields appeared at mid July and epidemics were general from the first half of August, which was later than in previous years. The end of season (September) was extremely rainy: it prevented optimal timing of sprays and delayed haulm killing and harvest which created critical conditions for the occurrence of tuber blight.

Wet weather in April delayed planting by 3-4 weeks in **The Netherlands**. May and June were relatively dry resulting in a delay of the blight epidemic compared to previous years. Blight was first observed on a dump in Noord-Holland. In early, polythene covered, crops the first blight was observed 17 May. In the beginning of the season blight mainly developed in the starch potato area in the north-east. Volunteers and organic crops were free of blight until second half of July. Until September fungicides could be applied when necessary and blight was controlled effectively. Due to almost continuous rainfall in September, applications had to be delayed creating critical conditions for tuber blight. Nation wide 150 weather stations are used to provide DSS systems with weather data. Almost 30% of the 10,000 potato growers use DSS (PC, fax, Internet).

The very wet weather in Autumn/Winter 2000 seriously delayed potato harvesting in **England & Wales**. At the end of May 2001 in some areas as much as 5% of the previous years' crop had still not been lifted and a significant proportion of these crops were destined for set-aside. There was considerable concern that this scenario would result in increased blight risk as a result of the potentially higher numbers of volunteer potatoes. Although most maincrops had been planted by mid/end April, wet weather in late April/early May caused delays in some areas resulting in a spread of planting dates. A small proportion of crops were planted as late as early June. Many growers started routine spray programmes on second early/maincrops much earlier than normal and before the usual stage when the haulm started meeting along the rows. This is because of the perceived higher blight risk and, in the main, spray programmes were maintained at 7 – 10 day intervals throughout the growing season. Blight was first reported at the end of May in the early, plastic covered crops in the south west of England and also in East Anglia. In June, the weather remained mostly dry and settled and there were further isolated reports of blight on dump sites in the south-west of England, East Anglia and the north-west of England. Towards the end of June there was localised heavy rainfall in north-east Norfolk (East Anglia) which delayed routine spray applications. This resulted in extended intervals and outbreaks in crops were reported. During July there continued to be further reports on crops and volunteers in coastal areas of Wales, the south west of England and East Anglia. Despite localised wet weather in many parts during August and further isolated outbreaks of blight there was no general UK wide blight epidemic as experienced in previous years.

In **Northern Ireland** the first blight in crops was not reported until 2 July due to a cold and wet first half of June. However the first blight infection period was recorded from 25-28 May and the first blight was found on a dump on 4 June. During the first half of June nights were cold whilst the remainder of June was cooler and wetter than normal. However, July was very warm and humid with high night time temperatures resulting in blight outbreaks in most potato growing areas. During August, blight pressure remained high to extreme but growers continued with fungicide sprays at close intervals, which resulted in good control.

In **Scotland** the first high risk period was recorded on 26-27 June. The first reported outbreak was in the South West during the week ending 6 July. In spite of many Smith Periods in some parts of the country, there were few outbreaks of blight. Good control was helped by weather conditions being generally favourable for the maintenance of suitable

fungicide intervals. There were a few outbreaks late in the season but these had very light infection that died out due to dry conditions. In conclusion, blight was not a concern in commercial crops in 2001.

In **Jersey** the first outbreaks of late blight occurred in fields that had been covered with polythene (nearly 66% of fields are covered) from the third week of March. The epidemic began in the third week of April in fields which had not been covered. This is slightly later than in 2000 in both cases but not as early as in 1992 and 1999. Weather conditions favoured the development of blight towards the end of April and into the first week of May at a time when harvesting was beginning. Beaumont periods occurred over 22 days between 1 April and 2 June, while Smith periods occurred in the middle and end of May. By 11 June over 60% of the crop had been harvested, after which a further period of epidemic conditions occurred in mid and late June. The number of outbreaks recorded in 2001 was 382, slightly less than in 1999 and 2000, but half the infection pressure of the epidemic in 1998.

In **Ireland** blight was observed in June on several fields in the southern and eastern regions. Blight developed further in June and was first seen in unsprayed plots at Oak Park, Carlow on 29 July. The accumulated risk value was comparable to 1998, 1999 and 2000 but lower than 1997. Disease control was generally good in fields that were sprayed every 7-10 days.

The first symptoms of late blight were found in **Poland** on 6 June on early cultivar Orlik in voivodship Łódź in central Poland. In the north (Bonin) the first symptoms were found early in the season (15 June), on very early potato susceptible cultivar Gabi. The appearance of the disease was caused by higher air temperatures in May and rainfall in the beginning of June. On the medium resistant cultivar Rywal, blight was noticed later (2 July), after heavy rainfall in June (184,2 mm). After that, epidemic development of the disease was observed during July. Later, the epidemic was slowed down due to less rainfall at the end of July. In the next months the disease again developed quickly (rainfall in August - 143,2 mm, in September - 196,2 mm). The infection pressure was higher compared to earlier years. In untreated plots, late blight destroyed potato plants within 1-2 weeks. Stem blight symptoms were observed also during 2001 season. In south region of Poland (Stare Olesno) late blight appeared rather late (about 1 July). Meteorological conditions in June were not favourable for the disease. Higher rainfall mid July and warmer air temperatures were favourable for the disease development. Later, blight development was again slower because of lower rainfall in August.

Rate of disease development, at control plots in Stare Olesno, was significantly lower than in Bonin. In some regions in the south, many fields were completely destroyed by floods.

In **Latvia** the weather was very favourable for blight due to heavy rainfall, sometimes >100 mm within 2 days. The first blight in organic crops was observed 20 June, followed by further outbreaks in the period 25 June-beginning July.

In **Sweden** blight was first observed around 17 May in early potatoes grown under cover. These very early infections originate from oospores. Nearly all fields with early potatoes in the area were heavily infected 7-10 days later. Heavy infections were observed in the south-west and most potato fields were attacked by mid June. A change to dry weather in the last week of June saved the situation. The disease spread north and reached as far north as Boden (65°50'N, 21°45'E) by mid July.

In **Finland** the first blight was observed 2 July in a plastic covered crop and 4 July in a open field crop. Severe outbreaks in untreated fields were observed between 4-15 July which is one week earlier than in 2000. Fungicide applications started in time and very few outbreaks were recorded.

In **Denmark** crop growth was 7-10 days later than normal. Based on the national forecasting system a general warning for risk of primary attacks was issued on 22 June. In the period 14-24 June, 4 new primary attacks were recorded. In 3 out of 4 fields there was an indication that oospores were involved. In the period 25 June-5 July, 31 new primary attacks were recorded. The infection pressure was low in June and first part of July. Epidemics developed only in late July. 70-80% of the conventional fields became infected at a low level.

In **Norway** blight was in most regions observed later than in 1999 and 2000. However, the first blight was observed in an early plastic covered crop on 6 June, which was earlier than in 2000. Blight was observed in the main crops from half July onwards. The infection pressure was normal, less fields were infected than in 1999 and 2000. Epidemics did not develop in “normally” treated fields, although late in the season some fields were infected at a low level.

Fungicide input

In the PoValley in **Italy**, climatic conditions helped farmers in controlling the disease. Farmers using DSS managed to control the disease with 2-3 sprays, while farmers that did not use DSS applied 6-8 sprays. The active ingredients applied most frequently were:

metalaxyl, cymoxanil and fluazinam.

In the Basque Country in **Spain** the growers on average apply 2-3 sprays with mainly systemic and contact fungicides.

In **Switzerland** the fungicide use of 152 PhytoPRE participants was recorded. On average they used 2.4 sprays with a contact fungicide, 3.5 sprays with a locally systemic fungicide and 0.5 sprays with a systemic fungicide.

In **Austria** early seed potatoes were sprayed 4 times. Late varieties needed 6-7 sprays. In the most common fungicide strategies 2-3 sprays with systemic and translaminar fungicides (metalaxyl, propamocarb, cymoxanil, dimethomorph) were followed by 2-4 sprays with contact fungicides (mancozeb, maneb).

In **Germany** fungicide input varied according to the disease pressure. In regions with a normal disease pressure 3-5 sprays were sufficient to control blight. In regions with a very high pressure 7-16 sprays were applied to control blight.

In **France** the number of treatments ranged from 15 in Artois to 23 in Flanders where mancozeb was frequently washed off by rain. Cymoxanil containing fungicides had to be used regularly. During the active growth period, systemic products, with a spray interval of not more than 10 days, provided a protection of new growth. Rainfast products allowed a reduction in the number of treatments and provided a good protection of the foliage.

In Flanders (**Belgium**) an average of 13 sprays was applied in the susceptible variety Bintje. The average spray-interval was 8.5 days in June, only 5.6 days in July and 6.9 days in August and September. Fentin was added to other fungicides more than 5 times towards the end of the growing season. In July, more than 60% of the sprayings were made with cymoxanil or dimethomorph. Almost no phenylamides were used. In Wallonia (**Belgium**), 11-13 treatments were recommended according to the regions and the cultivar susceptibility. The first warning was sent 9 June in the main potato production area and 20 June in south part of Wallonia. Fungicide input consisted of 3-4 “simple” contacts, 1-2 systemics, 4-5 translaminars and 2-3 organotins. The traditional contact fungicides (dithiocarbamates, chlorothalonil) were frequently washed off by the stormy showers in July and August and permanent rains in September requiring the fast renewal of the treatments.

In **The Netherlands** the registered fungicides are restricted to fluazinam, cymoxanil and dithiocarbamates. On average 10-18 sprays were applied of which 70% with fluazinam and 20% with mancozeb/metiram + cymoxanil.

In **Northern Ireland** the number of fungicide sprays in seed crops ranged from 6-13, which was higher than year 2000. The main fungicides used were systemic (phenylamide, propamocarb) based for the first 2-3 sprays. Some growers commenced with protectants (fluazinam, mancozeb) when the plants were small. Mid season saw increased use of translaminars (cymoxanil, dimethomorph) + fentin. These combinations gave very good results in controlling blight when present at low levels in the crop. Fluazinam and fentin were widely used late season.

In **Jersey** the majority of growers applied between 3-5 sprays once the polythene was removed. From the limited information available it appears that the use of phenylamide-3 way-mixtures has increased to 65% in 2001. Resistance to phenylamides has been steadily decreasing over the last 4 years, from 25% in 1997 to 11% in 2000 and 10% in 2001.

In **Poland** less than 40% of the potato acreage is treated with fungicides. The number of treatments is between 1-8 with an average of 2. The use of systemic fungicides (phenylamides, propamocarb) is 49%, translaminar fungicides (cymoxanil, dimethomorph, famoxate, fenamidone) 25% and contact fungicides (chlorothalonil, mancozeb, fluazinam) 25%.

In **Latvia** 3-6 sprays were applied to control blight. Products which contained (locally) systemic active ingredients (metalaxyl, propamocarb, dimethomorph) were applied in the beginning of the season and were followed by fluazinam, mancozeb and “Champion”.

In **Sweden** a tendency was observed to start spraying earlier whereas also the number of sprays increased. In one area in the south-west, which experienced severe difficulties to control blight during the last couple of years, the recommendation was to start spraying when the plants were 10 cm high. This resulted in the first spray around 10 June, which is about 10-14 days earlier than normal. Despite this strategy, several fields were infected and were heavily attacked even though spraying intervals were reduced down to every third day. Some fields were sprayed 15-20 times. In the south 2-3 sprays more were applied compared to other years. In areas located further north the increase was less. In the south metalaxyl (Epok) was used curatively in infected fields. There were reports of a low efficacy of metalaxyl.

Because of extreme variations in weather conditions in **Finland**, the number of fungicide sprays varied widely. In some regions potatoes suffered from drought whereas in other regions potatoes drowned because of too much rain. Most widely used fungicides were

fluazinam and mancozeb, though many farmers start the spray program with 1-2 sprays with propamocarb or dimethomorph. Metalaxyl is not widely used because of resistance problems. In **Denmark** fungicide use was higher than normal. In seed crops 4-6 sprays were applied, in ware potatoes 7-8 and in starch potatoes 10-12. An increased use of fluazinam and mancozeb was observed. Propamocarb was used in 10% of the sprays and the use of dimethomorph decreased.

In **Norway**, systemic fungicides were often used for the first or the second spray. Metalaxyl was not recommended in areas with high levels of resistance (=most areas). Propamocarb (and dimethomorph) were used extensively. Fluazinam was the most important fungicide later in the season, mancozeb was still used (1-2x).

Tuber blight

In the Po Valley in **Italy** no tuber blight was reported.

Because of heavy rain in September harvesting conditions were difficult in the regions Weinviertel and Waldviertel (**Austria**) and some problems with tuber blight were recorded.

In **France**, tuber blight was already observed in some fields in late August. To minimise the risk for tuber blight it was recommended to spray fluazinam.

September in Flanders (**Belgium**) was the wettest since weather recording started in 1833 (in fact, 2001 was the wettest year ever in Flanders). This weather led to very difficult conditions for crop lifting and a high incidence of tuber rot and tuber blight. This resulted in the unloading of stocks of poor quality during October until the first half of December. In Wallonia (**Belgium**) the incidence of tuber blight was very high in both seed and ware production. The tubers were infected very late in September by daily rains which prevented protection with fungicide sprays.

In parts of **England** (East Anglia and particularly in Norfolk), the foliar epidemic continued to develop slowly in early September and high levels of tuber blight were reported in some crops at lifting. Elsewhere in East Anglia, problems with bacterial soft rots were reported in stored crops but it is not known whether the primary cause was tuber blight infection which may have occurred during the senescence/post desiccation period.

In the south of **Sweden** most fields were infected and together with bad harvest conditions this might give rise to problems with tuber blight.

The end of the season in **Finland** was very rainy and rather warm and although the level of leaf blight was very low, severe (up to 50% of yield) tuber blight was recorded in some situations.

Organic crops

In **France** many organic crops were 100% destroyed by the end of July. In Wallonia (**Belgium**) organic crops were effectively protected with 3-6 copper-based fungicide treatments (in 2000 some farmers sprayed 14-17 times). Use of rather tolerant cultivars prevented the large scale occurrence of tuber blight. Only a few fields were infected.

In **Latvia** the total potato area is 40,000 ha. Approximately 50% of that area is “organic”.

In **Sweden** the majority of the organic crops had severe infections with blight. Due to early infections many farmers risked tuber blight and oospore formation by not desiccating their crops.

Due to heavy infection pressure and weather conducive to blight in **Finland**, potatoes in many home gardens were defoliated by the end of June. In varieties which start tuber formation late in the season, severe yield losses due to tuber blight were recorded. Early varieties yielded reasonably well.

In **Denmark** the epidemic in organic crops developed late July. The expected yield of organic potatoes in 2001 is about 25 tonnes/ha compared to 10-20 tonnes/ha in 1999. In **Norway** organic fields were infected late in the season.

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Table 1. The estimated use¹ of fungicides to control *P. infestans* on potato in 1996-2001

	Average number sprays/season					
	1996	1997	1998	1999	2000	2001
Austria	4-6	5-6	4-6	4-12	4	4-7
Belgium	8-12	14-15	12-14	10	12-20	11-13
Denmark	5.5	5.5	8	7.5	7-8	8-9
Finland	3-4	4-5	3-8	2-6	5-9	4-8
France	9-11	11-14	?	15	16-17	15-23
Germany	5-6	7-9	3-10	4-5	2-14	2-16
Italy	6-8	6-8	4-5	8-10	6-8	4-7
Latvia	?	?	?	?	?	3-6
Netherlands	5-12	7-15	7-15	7-16	15-20	10-18
Norway	2.9	4	5	5-6	6-7	5.5
Poland	1.6	1.7	1.7	2	2	1-8
Spain (Basque Country)	3	5-6	3	4-5	2-6	2-3
Sweden	4-7	4-7	4-12	4-11	?	?
Switzerland	6-7	7-9	5-7	6-10	7	6.3
United Kingdom						
*Northern Ireland	2-10	3-15	4-16	4-14	3-12	6-13
*England/Wales	2-10	4-18	8-15	4-16	?	8-12
*Scotland	5	?	8	?	6.5?	?
*Jersey	4-5	4-5	4-5	4-5	4-5	3-5

¹ estimations can unfortunately not be separated in

“minimum to maximum” and “mean” number of sprays.

Table 2. Weather conditions favourable for the development of late blight and dates of first recorded outbreaks of blight in potato in 2001 in relation to other years

	May June July Aug. Sept.					First outbreak				
						2001	2000	1999	1998	1997
Austria	*	**	**	**	***	19 June	14 July	15 May	25 June	17 July
Belgium										
* Flanders	*	*	***	***	***	2 May ²	30 April ²	29 April ^{1,2}	28 April ¹	15 May ¹
* Wallonia	*	*	***	**	***	15 May	19 May	5 July	12 July	
Denmark	*	*	**	***	***	18 June ⁴	20 June	18 June	16 June	end June
Finland	**	**	**	***	***	2 July ¹	4 July ¹	2 June ¹	20 June	1 July
France	***	***	***	***	***	Early April ²	End April ^{1,2}	Early April ²	20 April ²	23 May ²
Germany	**	**	**	**		2 May ¹	11 May ¹	28 April ¹	5 June	30 May
Italy	*	*	*	*		14 May	11 May	10 May	No blight	No blight
Ireland		**	**	***	***	June	4 July	20 July	1 July	25 July
Latvia						20 June				
Netherlands	*	**	**	***	***	17 May ¹	April ²	26 April ²	1-10 May	2 June
Norway	*	**	***	***	**	6 June ¹	16 June ¹	15 June ¹	20 June ¹	6 August
Poland	**	***	**	***	***	6 June	23 June ²	27 May	1-10 June	End June
Spain (Basq Country)	*	*	**	*		2 August	15 June	21 June	15 June	1-7 June
Sweden	***	***	**	**	**	17 May ^{1,4}	5 June ¹	20 May ¹	15 May ¹	24 May ¹
Switzerland	**	***	**	**		11 May ¹	3 May ¹	8 May ¹	15 May ¹	16 May
United Kingdom										
*Northern Ireland	*	**	***	***		2 July	22 June	16 June	8 June	30 May
*England/Wales	*	*	**	**		End May	10 May ²	mid-May ¹	31 May ¹	29 May
*Jersey	***	***	*	*		20 March ¹	20 March	10 March	31 March	7 March
*Scotland						6 July	22 June ¹	12 May ³	25 June	3 July

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

¹ *polythene covered crop*; ² *waste piles*; ³ *volunteers*; ⁴ *oospores possibly involved*

**Report of the fungicide sub-group:
Discussion of potato late blight fungicide characteristics**

R. A. BAIN

Participants:

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Objective:

The objective of the meeting was to review the ratings given to the various fungicide active ingredients at the Munich workshop (PAV-Special Report No 7, pp 19-22).

The ratings are intended as a guide for use in the development of Decision Support Systems or the improvement of existing ones. A table of ratings is given below. There was one

modification compared with the 2000 table in which the effectiveness of fentin fungicides against tuber blight was ++(+).

Table 1. The effectiveness of the most important fungicide active ingredients used for the control of *P. infestans* in Europe. Opinion of the Fungicides Sub-Group at the Edinburgh workshop, 2001

Active ingredient ¹	Effectiveness					Action mode				
	spray interval	leaf blight	new growing point	stem blight	tuber blight	protectant	curative	eradicator	rainfastness	mobility
propamocarb-HCl	7	++(+)	+(+)	++	++	++(+)	++	++	+++	systemic
fluazinam	7	+++	0	+	++(+)	+++	0	0	++(+)	contact
cymoxanil	7	++(+)	0	+(+)	0	++	++	+	++	translaminar
fentin hydroxide	7	++	0	+	++	++	0	0	++	contact
fentin acetate	7	++	0	+	++	++	0	0	++	contact
mancozeb or maneb	7	++	0	+	0	++	0	0	+(+)	contact
metiram	7	++	0	+	0	++	0	0	+(+)	contact
dimethomorph	7	++(+)	0	+(+)	++	++(+)	+	++	++(+)	translaminar
metalaxyl ²	10	++(+)	++	++	N/A	++(+)	++(+)	++(+)	+++	systemic
oxadixyl ²	10	++(+)	++	++	N/A	++(+)	++(+)	++(+)	+++	systemic
copper	7	+	0	+	+	+(+)	0	0	+	contact
chlorothalonil	7	++	0	(+)	0	++	0	0	++(+)	contact

¹ The scores of individual active ingredients are not additive for mixtures of active ingredients.

² = See text for comments on phenylamide resistance.

Key to ratings : 0 = no effect ; + = reasonable effect ; ++ = good effect ; +++ very good effect. ; N/A = not recommended for control of tuber blight.

Phenylamide resistance. The ratings assume a phenylamide-sensitive population. Strains of *P. infestans* resistant to phenylamide fungicides occur widely within Europe. Phenylamide fungicides are available only in co-formulation with protectant fungicides and the contribution which the phenylamide component makes to overall blight control depends on the proportion of resistant strains within the population. Where resistant strains are present in high frequencies within populations the scores for the various attributes will be reduced.

Table 2. Effectiveness of four new fungicide active ingredients used for the control of *P. infestans* in Europe. Opinion of the Fungicide Sub-Group at the Edinburgh Workshop, 2001

Active ingredient ¹	Effectiveness					Action mode				
	spray interval	leaf blight	new growing point	stem blight	tuber blight	protectant	curative	eradicator	rainfastness	mobility
cyazofamid	7	+++	0	+	? ²	+++	0	0	+++	contact
famoxadone	7	++	0	+(+)	?	++	+++ ³	+ ³	++	contact
fenamidone	7	++(+)	0	?	?	++(+)	0	0	++	translaminar
zoxamide	7	+++	0	?	++	+++	0	0	++(+)	contact

¹ The scores assigned to the four new active ingredients are based on limited data and are therefore subject to revision.

¹ The scores of individual active ingredients are not additive for mixtures of active ingredients.

² ? = not enough data available to assign a rating

³ This mode of action is provided by the active ingredient cymoxanil in the product Tanos (famoxadone+cymoxanil).

Key to ratings : 0 = no effect ; + = reasonable effect ; ++ = good effect ; +++ very good effect. ; N/A = not recommended for control of tuber blight.

Definitions:

New growing point - The ratings for the protection of the new growing point indicate the protection of new foliage due to the systemic movement of the fungicide. It is assumed that new leaves were not present at the time of fungicide application.

Protectant activity - Spores killed before or upon germination/penetration. The fungicide has to be present on/in the leaf/stem surface before spore germination/penetration occurs.

Curative activity - the fungicide is active against *P. infestans* during the immediate post infection period but before symptoms become visible, i.e. during the latent period.

Eradicant activity - *P. infestans* is killed within sporulating lesions thereby preventing further lesion development. This mode of action prevents sporangiophore formation and therefore anti-sporulant activity is included within the definition of eradicant activity.

Stem blight control - effective for the control of stem infection either by direct contact or via systemic activity.

Tuber blight control - activity against tuber infection as a result of fungicide application after infection of the haulm, during mid to late season. There is a direct effect on the tuber infection process. The effect of phenylamide fungicides on tuber blight control was therefore

not considered relevant in the context of the table as these materials should not be applied to potato crops if there is blight on the haulm, according to FRAC guidelines. Only the direct (biological) effect of a particular fungicide on the tuber infection process was considered relevant and NOT the indirect effect as a result of manipulation of the foliar epidemic.

N.B. The information in the Tables is based on the consensus of experience of scientists in countries present during the Workshop. The ratings refer to all products currently available on the market in the EU which contain the above active ingredients whether as a single or in a co-formulated mixture. The ratings given are for the highest dose rate registered for the control of *P.infestans* in Europe. Different dose rates may be approved in different countries.

While every effort has been made to ensure that the information is accurate, no liability can be accepted for any error or omission in the content or for any loss, damage or other accident arising from the use of the fungicides listed herein. Omission of a fungicide does not necessarily mean that it is not approved and available for use within one or more EU countries.

The application intervals indicated in the Tables are not intended as a guide as to how frequently a particular fungicide should be used. Where disease pressure is low, intervals between applications may be extended and, in some countries, fungicide applications are made in response to nationally issued spray warnings and/or Decision Support Systems. It is essential therefore to follow the instructions given on the approved label of a particular blight fungicide appropriate to the country of use before handling, storing or using any blight fungicide or other crop protection product.

Further Updating

An updated table will be published in the proceedings of the next workshop, to be held in 2002.

**Operational use of Internet based decision support for the control of potato
late blight in Estonia, Latvia and Lithuania, 2001 with focus on:**

Late blight monitoring, forecasting, and variety observation trials

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Summary

Internet based information and decision support systems are now in operational use in Estonia, Latvia, and Lithuania. The decision support components for late blight monitoring, forecasting, and evaluation of variety resistance were evaluated in 2001 in a collaborative project between the three Baltic countries and Denmark. In the monitoring system, late blight was found initially in home gardens, a little bit later in conventional fields, and even later at experimental stations. Late blight was found as spots in the fields in 67-85% of the fields assessed. The growth stage at first recording of late blight ranged from BBCH 31-35, but a majority of the early attacks were found at BBCH \geq 51. The late blight forecast was too late in 18% of the observations (66 in total) when NegFry calculations were compared to observations from the monitoring network. Variety resistance was evaluated in three trials in Estonia, one trial in Latvia, and one trial in Lithuania. Local varieties were tested against four test varieties from unitary seed material. Stability of resistance in time and space and a new method for classification of variety resistance for use in control strategies are discussed.

Key words: Late blight, monitoring, forecasting, variety resistance, decision support, Internet

Introduction

Comprehensive information and decision support about potato late blight is now operational on the Internet for Estonia, Latvia and Lithuania.

The local information systems can be found at: <http://www.planteinfo.dk/ee>, <http://www.planteinfo.dk/lv>, and <http://www.planteinfo.dk/lt>. The Internet based information and decision support systems are the results of collaborative projects between the three Baltic countries and Denmark (<http://www.ipm-baltic.dk>; Hansen *et al.*, 2000), covering not only late blight but also cereal diseases, weeds, pests, Internet technology, and agrometeorology. In this article we evaluate the monitoring system, the quality of the late blight forecast, and results from untreated variety observation trials.

Methods

Monitoring

Late blight monitoring was carried out in home gardens, in farmers' fields and at experimental stations in Estonia, Latvia, and Lithuania. Results were entered into a special PC-programme and transferred via the Internet to the Web-blight service running on a server in Denmark (Hansen *et al.*, 2001; Röhrig *et al.*, 2001). Results were presented on maps and in tables in Web-blight (<http://www.web-blight.net>). Via simple links, the same information was available in the three local information systems in their own languages. Results from Norway, Sweden and Finland were included in the results.

Forecasting

A forecast for the risk of primary attacks was available on the Internet, based on the modified negative prognosis as used by PC-NegFry. To evaluate the forecast, NegFry calculations were correlated with data collected via the monitoring network. Monitoring data recorded as "Late blight found all over the field" were excluded before analysis. By doing this, the total amount of observations was reduced from 100 to 66. For each observation of late blight attack, the nearest weather station was identified and used for prediction of the time of primary attack. Sometimes, the distance from the late blight observation and the weather station was more than 20 km. It should also be pointed out that measurements at weather stations not always represented very accurately local weather conditions in small fields or home gardens, often surrounded by trees and shelters.

Evaluation of variety resistance against late blight

Field resistance of local varieties was evaluated under natural conditions at five trial sites:

Estonia:

Saku: Berber, Piret, and Anti.

Jõusa: Piret and Anti

Jõgeva: (17 varieties)

Latvia:

Vecaucē: Asterix, Santé, Folva, Mutagenagria, Redstar, and Vineta

Lithuania:

Voke (27 varieties).

All trials included four replications. No artificial inoculation was carried out. The local varieties were tested against four test varieties: Sava, Oleva, Danva, and Kuras. Seed material of the test varieties was sent from Denmark before the season. Sava was chosen to be the reference variety in all the trials. Sava is a moderate susceptible ware potato, widely used in conventional and organic potato production in Denmark. Kuras is a Dutch variety widely used in EU for starch production. Results from trials with Kuras in Denmark indicated that the resistance in Kuras is determined by a combination of partial and race-specific resistance (Hansen et al., this proceeding). Therefore, Kuras was included in the test material to evaluate the stability of the resistance against the *Phytophthora infestans* populations present in the three Baltic countries. Oleva (moderate susceptible) and Danva (moderate resistant), two Danish starch varieties, were included as test varieties.

Results were transferred to the Internet during the season and shown in tables and graphs based on the Web-blight application. In Web-blight, the following epidemiological parameters were calculated: Delay of first symptoms, disease rating when rating of reference variety $\geq 90\%$, final disease rating, apparent infection rate (AIR) (Vanderplank, 1963), and the relative area under the disease progress curve (RAUDPC) (Fry, 1978). Methods for the calculations of the epidemiological parameters are also described in Web-blight (<http://www.web-blight.net>). The Web-blight application is interactive as the user can select any reference variety from a list of varieties in the trial. Results can be sorted ascending or descending according to each epidemiological parameter (Röhrig et al., 2001).

Results

Monitoring

In the three Baltic countries, a total of 100 different fields or home gardens were inspected in 2001. The number of observations was even higher, because most of the fields were inspected several times during the season (see <http://www.web-blight.net>). NegFry predicted the first attacks of late blight for about the middle of June in all three Baltic countries. Early attacks were found in home gardens on June 15th in Lithuania, on June 20th in Latvia, and on June 20th in Estonia (Figure 1). In general, late blight was found initially in home gardens, a little later in conventional fields, and even later at experimental stations. Late blight was found as spots in the fields in 67-85% of the recorded fields (Table 1). Growth stage at first recording of late blight ranged from BBCH 31-35 (Figure 2). Predominantly, late blight was found in both home gardens and conventional fields at BBCH \geq 51 (Table 2). In the Nordic countries first attacks of late blight were found on June 6th in Sweden in fields covered with plastic, in Denmark on June 18th, in Norway on July 2nd, and in Finland July 4th (Figure 1). In the Nordic countries, growth stage at first recording of late blight ranged from BBCH, 30 to BBCH, 51 (Figure 2). In Poland, in the Lublin region, first attacks of late blight were found on June 29th at growth stage 39.

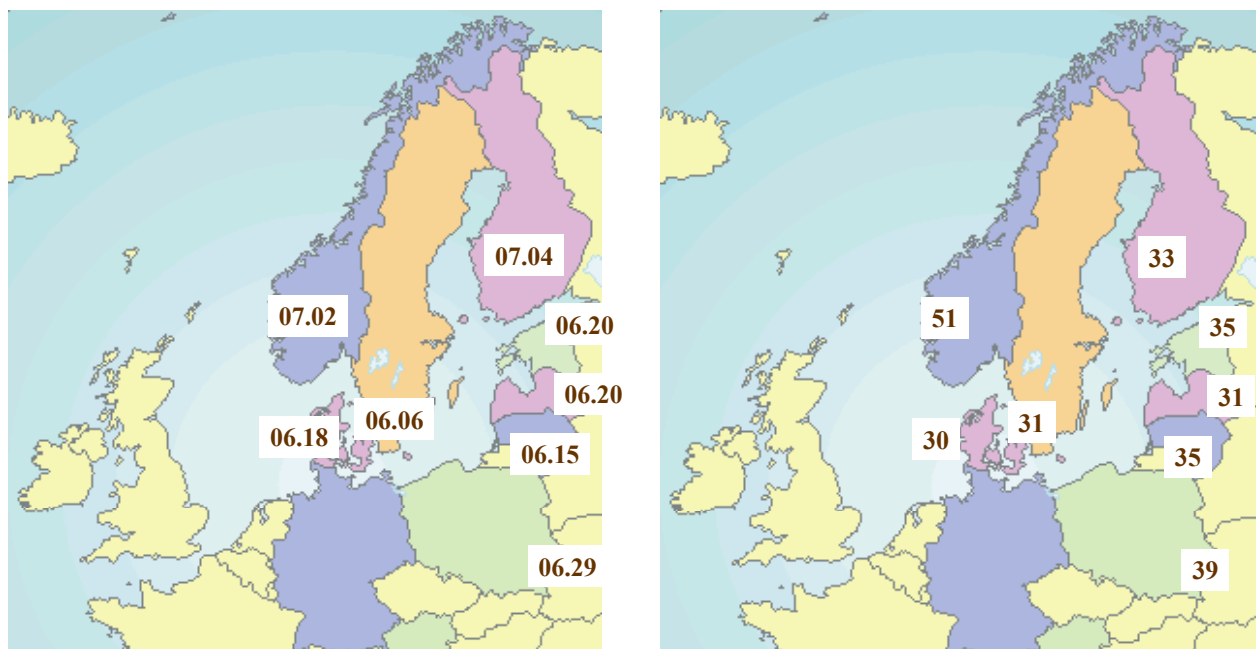


Figure 1. First attacks recorded in the Nordic-Baltic region in 2001 (Date) **Figure 2.** Growth stage at first attack recorded (BBCH).

Table 1. Disease level of first attacks of potato late blight divided into four classes and given as percentage of the total amount of fields assessed.

Country	Percentage of fields recorded as "primary attack" (spots in the field)		Percentage of fields recorded as "late blight found all over the field"		Total Number of fields
	Spots 0.1-5 m ²	Spots 5-25 m ²	Severity 0-1%	Severity >1%	
	Estonia	85%	0%	0%	
Latvia	63%	4%	11%	15%	27
Lithuania	70%	4%	4%	23%	53

Table 2. Growth stage at first recordings of potato late blight. Results include only observations when late blight was found as spots in the field (primary attack).

Country	Number of fields when Primary attacks were recorded at different growth stage (BBCH)			Total number of fields
	Row closing 30-39	Inflouescence 51-59	Flowering 60-69	
	Estonia	4	8	
Latvia	4	11	2	17
Lithuania	1	6	31	38
Total	9 (12.5%)	25 (34.7%)	38 (52.7%)	72 (100%)

Forecasting

During the season in 2001, it became clear that results of the forecast were different when different weather data sources were used. After some sensitivity tests with the NegFry system, it was found that calculations with data from ordinary stations could be fitted to calculations with Hardi metpoles if Rh thresholds in the models were adjusted from 90 to 87% humidity. This was found for data from Latvia (Figure 3) and for a few observations tested from Estonia (not published).

The relationship between the date of primary attack forecasted by NegFry, and first attack observed is shown for Estonia and Latvia in Figures 4 and 5. Combining observations from Estonia, Latvia, and Lithuania, 66 pairs of observations were available. The risk of primary attack was predicted 1-18 days before first symptoms in 48 (73%) cases. The forecast was too

early, 20-30 days before first symptoms in 6 cases (9%) and too late, 0-7 days after first symptoms in 12 cases (18%).

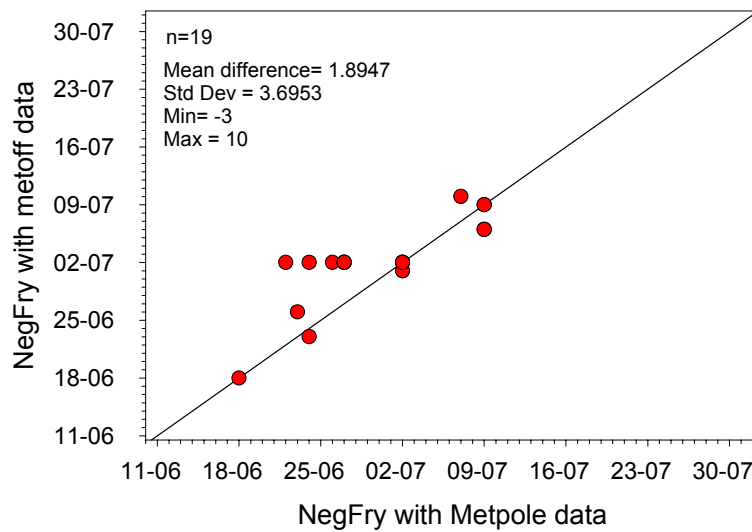


Figure 3. NegFry forecast (date) calculated with metpole data and data from nearby ordinary weather stations. The threshold for relative humidity used in NegFry was lowered for ordinary stations from 90 to 87%, the same threshold as used for Hardi metpoles.

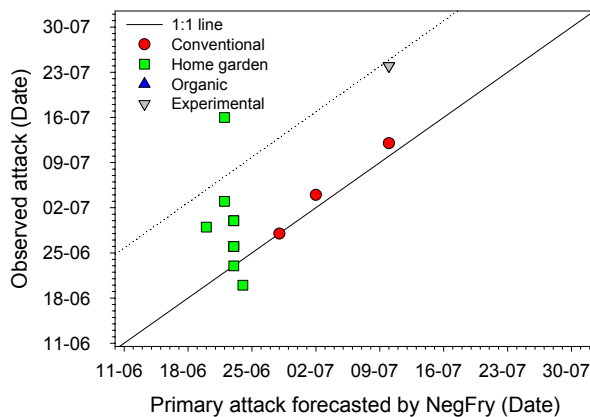


Figure 4. Estonia, 2001. Primary attack forecasted by NegFry versus attack observed. Symbols indicate field type. Dotted line is 14 days after first attack predicted.

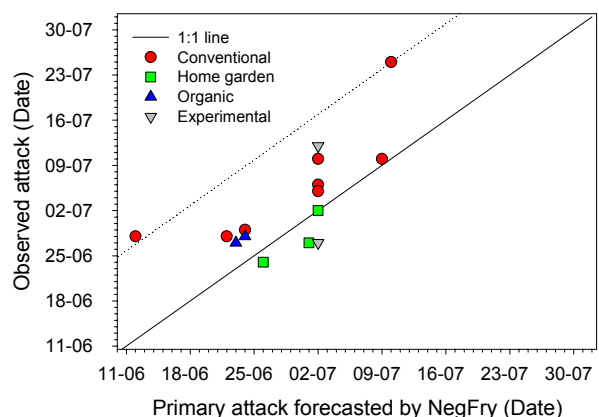


Figure 5. Latvia, 2001. Primary attack forecasted by NegFry versus attack observed. Symbols indicate field type. Dotted line is 14 days after first attack predicted.

In Estonia, NegFry forecasted the risk of primary attacks earlier for home gardens than for conventional fields. This was due to relatively earlier crop emergence of potatoes in the home gardens. Attacks were predicted for all the home gardens during the period June 20th - 23rd,

but attacks were found from June 20th to July 15th (Figure 4). A difference between the home gardens in crop rotation, seed quality and local climate may explain these differences. At Jõgeva Plant Breeding Institute (Estonia), primary attacks were predicted relatively late, July 9th. Late blight was found even 14 days later on July 23rd. Probably, primary inoculum was not present at the trial site, and the attack was caused by secondary spread of airborne inoculum from infected fields in the area.

In Latvia, first attacks were found in home gardens on June 20th and about one week later in conventional fields. The forecast was too late for the home gardens and for Jelgeva experimental station, but correct for conventional fields.

Evaluation of variety resistance

The first symptoms of blight were found at Jõgeva on July 20th, at Saku on July 24th, at Jõusa on July 19th, at Vecauce on July 6th and at Voke on July 13th. Results calculated by the Web-

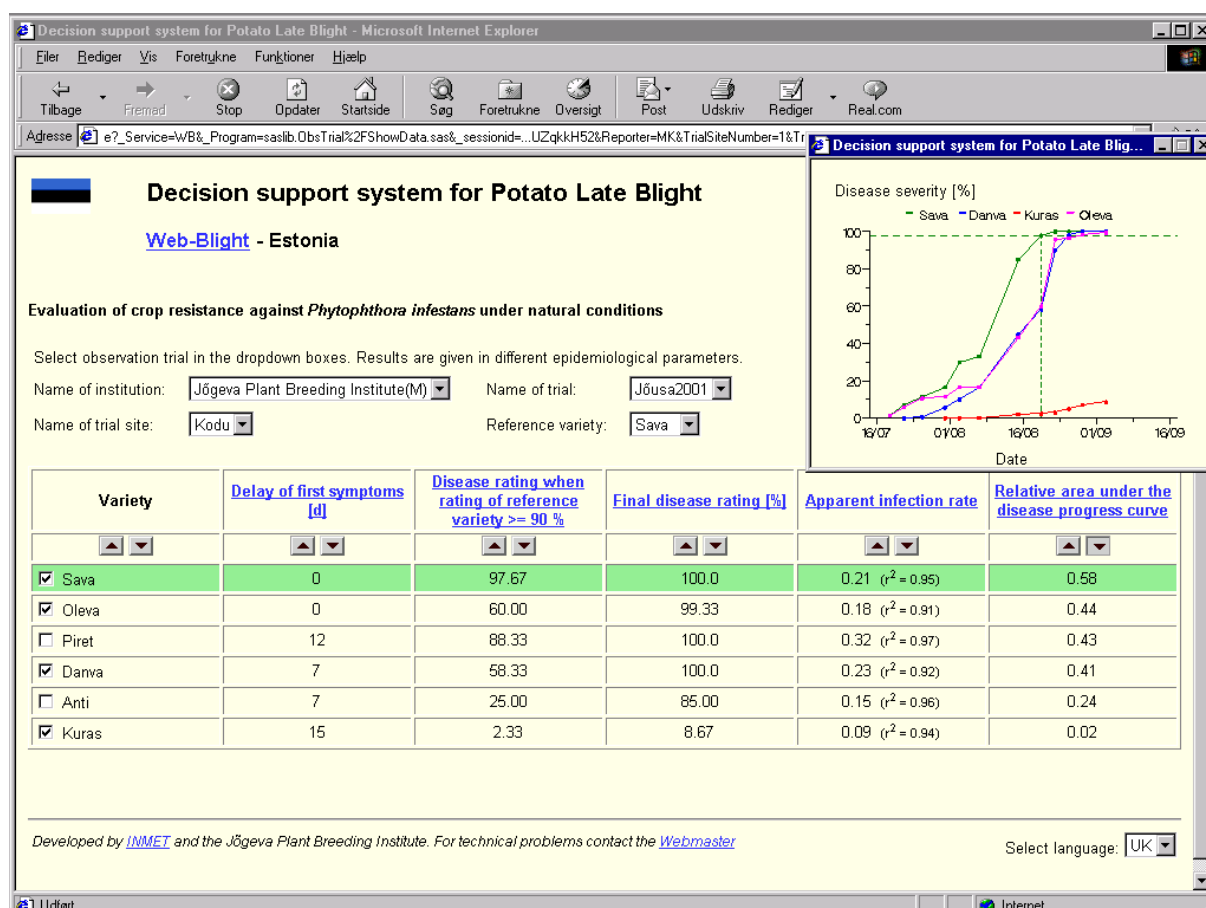


Figure 6. Screen capture of results from the variety observation trial at Jõusa, carried out by the Jõgeva Plant Breeding Institute, Estonia, 2001. Results are available in the local Estonian Information system (<http://www.planteinfo.dk/ee>) and in Web-blight (<http://www.web-blight.net>).

blight application are given for Jõusa, Estonia in Figure 6. Results for all trials, and ranked according to the relative area under the disease progress curve, are given in Table 3. To compare results between different trial sites, the delay of first symptoms and the apparent infection rate (AIR) were transformed into relative values compared to Sava. The delays of first symptoms were calculated relative to Sava, not in days, but in biological time as accumulated risk values according to the NegFry system. The relative apparent infection rates were calculated as AIR variety/AIR Sava (Figure 7).

Table 3. Variety resistance against late blight as per the "Relative area under the disease progress curve" (RAUDPC) in five trials in the Baltic countries. Only 22 of 31 varieties in the Lithuanian trial are given.

Jõgeva, Estonia		Jõusa, Estonia		Saku, Estonia		Vecauce, Latvia		Voke, Lithuania	
Variety	RAUDPC	Variety	RAUDPC	Variety	RAUDPC	Variety	RAUDPC	Variety	RAUDPC
Berber	0.59	Sava	0.58	Berber	0.76	Mutagena	0.72	Zukovskji	0.51
Folva	0.41	Oleva	0.44	Sava	0.60	Asterix	0.71	Venta	0.49
Vivaldi	0.40	Piret	0.43	Piret	0.51	Folva	0.70	Izora	0.49
Van Gogh	0.39	Danva	0.41	Oleva	0.40	Redstar	0.69	Bintje	0.49
Sava	0.33	Anti	0.24	Danva	0.38	Vineta	0.68	Vilija	0.45
Piret	0.32	Kuras	0.02	Anti	0.36	Sava	0.63	Liepa	0.45
Ants	0.31			Kuras	0.09	Santé	0.62	Fresco	0.41
Danva	0.29					Oleva	0.54	Voke	0.37
Oleva	0.23					Danva	0.47	Sava	0.32
Ando	0.08					Kuras	0.06	Santé	0.31
Anti	0.06							Nida	0.28
Sarme	0.03							Plante	0.27
Kuras	0.02							Mirta	0.27
								Oleva	0.26
								Danva	0.22
								Hermes	0.20
								Asterix	0.19
								Raja	0.16
								Saturna	0.14
								Vilnia	0.11
								Aistes	0.03
								Kuras	0.03

According to the international 1-9 scale for late blight resistance, Sava is scored as 4-5. In Estonia, the varieties Berber, Folva, Vivaldi, and Van Gogh obtained a higher RAUDPC than Sava. Low RAUDPCs were obtained for Ando, Anti, Sarme, and Kuras. At Jõusa, the variety Piret had a lower RAUDPC than Sava (0.43 compared to 0.58). Late blight was found 12 days later in Piret than in Sava, but at the same time, the AIR for Piret was about 50% higher than the AIR for Sava. This indicates that major (R) genes are present in Piret.

In Latvia, the varieties Mutagenagrija, Asterix, Folva, Redstar, and Vineta obtained a higher RAUDPC than Sava. The Dutch variety, Santé, was earlier considered a moderate resistant variety, but in this trial Santé had the same RAUDPC as Sava. For Kuras, the AUDPC of 0.06 was the lowest of all varieties tested.

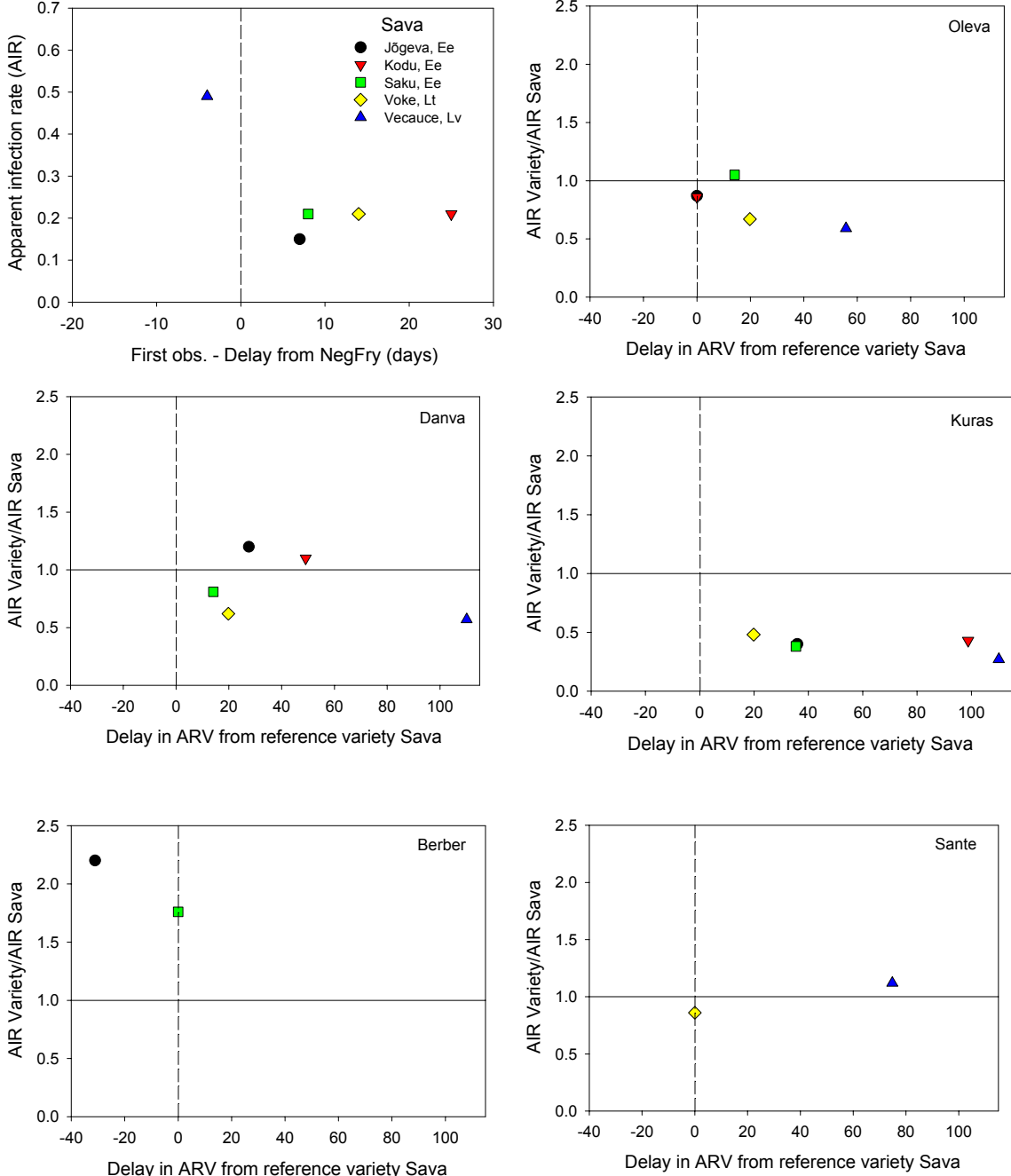


Figure 7. Sava: Delay of first symptoms (days) from the date when NegFry recommended first spray versus the apparent infection rate (AIR). For Oleva, Danva, Kuras, Berber, and Santé: Delay of first symptoms (ARV) from the date when late blight was found in Sava versus the relative AIR.

In Lithuania, the varieties Zukovskij Rannij, Venta, Izora, Bintje, Vilija, Liepa, Fresco, Impale, and Voke all obtained a higher RAUDPC than Sava. Similar to the results in Latvia, RAUDPC for Santé was close to RAUDPC for Sava, and Kuras obtained the lowest RAUDPC of all varieties tested. The Danish starch variety, Danva, is considered a moderate resistant variety (7-8), but in this test, RAUDPCs obtained for Danva were always very close to the RAUDPCs obtained for Oleva (4-5).

First attacks in the reference variety, Sava, were found 4 days before to 24 days after the date predicted by NegFry. The apparent infection rates (AIR) for Sava were in the same range (0.15-0.21) at all trial sites, except at Vecauce (0.49) (Figure 7). In two similar trials in Denmark, 2001 AIR for Sava was 0.28 at Tylstrup and 0.24 at Flakkebjerg (<http://www.web-blight.net>). In Oleva, first attacks were found 0-58 accumulated risk values (ARVs) after Sava. In four out of five observations AIR for Oleva was lower than for Sava. In Danva, first attacks were found 10-110 ARVs after Sava. In three out of five observations AIR for Danva was lower than for Sava. In Kuras, first attacks were found 20-110 ARVs after Sava. The relative AIR for Kuras ranged from 0.27 to 0.43 (Figure 7).

Berber is widely used in Estonia for consumption. In this variety first attacks were found earlier or at the same time as for Sava. The AIR was much higher for Berber than for Sava. First attacks in Santé were found 0 to 75 ARVs (7 days) after Sava. The AIR for Santé was at the same level as for Sava. In NegFry validation trials in Latvia, 1999-2001, Santé was treated as a B3 variety (moderately resistant). Based on the results from the untreated observation trials in Latvia and in Lithuania, 2001, the classification of Santé should be reconsidered because the results for Santé were close to those for Sava (B2).

According to general guidelines for evaluation of variety resistance, AUDPC or RAUDPC values were converted into a 1-9 scale for resistance (Dowley et al., 1999). The international 1-9 scale for resistance has some limitations for use in DSS strategies. A relatively low RAUDPC can be obtained when first attack in the variety is early, but then disease progresses very slowly all through the season (low AIR). This can be found in varieties with a high level of partial resistance. The same RAUDPC can be obtained in other varieties when the first attack is very late, but then with a high AIR. This can be found in varieties with race-specific resistance. Therefore, a new approach for scoring of resistance is proposed based on results for delay of first symptoms and relative AIR compared to standard varieties (Figure 8).

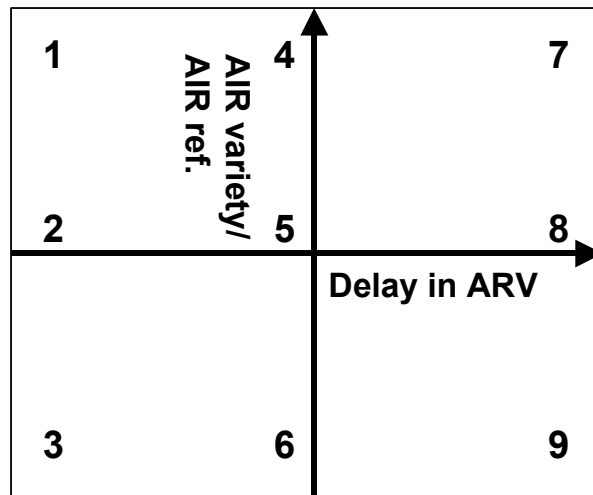


Figure 8. Suggestion for a new classification of resistance (1-9), based on delay in accumulate risk value (ARV), and the relative Apparent Infection Rate (AIR) compared to a reference variety.

The advantage of this approach is that the resistance figures (1-9) now can be converted into basic guidelines regarding control strategies. Additionally, the scale can be used as parameters in DSSs. For varieties in classes 1-3, first spray must be accomplished according to a forecasting system and before late blight is found in the region. For varieties in class 3, intervals can be extended or dosage can be reduced. For varieties in classes 4-6, first spray can be delayed until late blight is found in the region in classes 1-3 varieties. For varieties in classes 7-9, first spray can be delayed until late blight is found in the region in classes 4-6 varieties. For varieties in class 9, fungicide input can be reduced by a delay of first spray **and** by reduced dosages or extended intervals between applications. Varieties in classes 7-9 are the typical classes for race-specific varieties with major R-genes. This kind of resistance can be broken very quickly by adaptation of *P. infestans*, and a continuously monitoring should be carried out for these varieties. For decision on an exact control strategy, information about tuber resistance, growing purposes, infection pressure during the season etc. should be included and handled by the DSS.

Discussion and conclusions

DSS components for late blight monitoring, forecasting, and evaluation of variety resistance were evaluated in Estonia, Latvia, and Lithuania in 2001. Results on monitoring show that it was possible to find late blight as primary attacks (Table 1). Similar results were obtained in 2000, including the Nordic countries and Lithuania (Hansen et al., 2001). In most cases, first

recordings of late blight were found after growth stage 51 and never before start of row closing (Table 2). To find the early attacks it was helpful to use the NegFry forecast indicating when monitoring should be intensified.

Uses of the NegFry forecast assume that the primary inoculum source is infected tubers. The distribution of A1 and A2 mating types and the importance of oospores for the late blight epidemiology in the Baltic countries is not well known. Despite this fact, it is expected that oospores play a role for the establishment of early attacks, especially in home gardens with narrow crop rotation. Early attacks in home gardens (often with early planting and own (bad) seed material) may result in an early, secondary spread to nearby conventional fields not yet infected from local infected tubers. This is a threat to the use of the forecast. After the test of the NegFry forecast during 1999-2001, it has become clear that the quality of the forecast is not good enough. Monitoring will play an important role for the recommendation of first applications until the existing forecast or a new method has been updated, taking into account more components of the (new) late blight epidemiology.

To exploit the monitoring information in control strategies, it is vital that the monitoring information reaches the users as soon as possible after an attack has been recorded. Using the Web-blight application, the monitoring information was uploaded to the Internet as soon as recorded by country reporters. Disease does not stop at borders, and the overview of early late blight recordings in neighbouring countries was used to indicate a possible risk of secondary spread of airborne inoculum from one region to another.

A new approach for describing variety resistance was introduced in this paper. We argue that the one figure from the international 1-9 scale is not good enough for use in a DSS. Therefore, it is suggested that a new classification should be based on more epidemiological parameters as described in Web-blight. In this paper we have used the “delay of first symptoms” and the “relative apparent infection rate”. These parameters are independent of local weather conditions and pathogen population structures, which we are unable to predict. In the Web-blight network for evaluation of variety resistance, the general approach is that important local varieties and test varieties are exposed to natural populations of *Phytophthora infestans*. Varieties should be evaluated in time (years) and space (several countries) to monitor the stability of resistance. Using the collaborative, Internet based Web-blight application new countries can easily join this network. Because all countries are forced to use the same methods, the results obtained can be compared and conclusions will thus be

relatively robust. If the resistance of important new varieties is broken in one or a few countries, this will be a warning that the same can happen in other countries because of the possible fast evolution of *Phytophthora* populations.

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**Sensitivity of European isolates of *Phytophthora infestans* to zoxamide
(RH-7281)**

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Summary

Zoxamide (RH-7281) is a new non-systemic fungicide recently registered in Europe for the control of potato late blight. To determine the range of sensitivities to this fungicide within European populations of *Phytophthora infestans*, a protocol using potato leaf discs sprayed with a series of zoxamide concentrations was developed. This was used to test 33 laboratory isolates of *P. infestans* never exposed to zoxamide and 136 field isolates obtained from European zoxamide field trials in nine countries between 1997 and 2000. Isolates varied in sensitivity with minimum inhibitory concentration (MIC) values from 0.5 to >20 mg/litre; some laboratory isolates were among the least sensitive tested, so this range probably reflects natural variation in the pathogen population. Isolates from zoxamide-treated plots were no less sensitive than those from non-zoxamide-treated plots and there was no association between phenylamide resistance and zoxamide sensitivity. Selected isolates exhibiting a range of *in vivo* sensitivities were tested *in vitro* using poisoned agar plates; all proved very sensitive with EC₅₀ values from 12-88 µg zoxamide/litre. A scanning electron microscopy study of the effect of zoxamide on the development of *P. infestans* showed that it acts after germination, inhibiting further development of hyphae and preventing production of sporangiophores and sporangia.

Key words: potato late blight, zoxamide, RH-7281, fungicide resistance

Introduction

Zoxamide (RH-7281, Zoxium™) is a novel benzamide fungicide developed by Rohm & Haas (now Dow Agrosiences LLC), recently registered in Europe as 'Electis', a co-formulation with mancozeb, for the control of potato late blight. It is specifically active against Oomycete plant pathogens (Egan *et al.*, 1998) and acts by binding covalently to fungal β -tubulin (Young and Slawecki, 2001), inhibiting nuclear division. Zoxamide is rapidly rainfast and zoxamide + mancozeb formulations have shown good protectant activity against late blight in field trials (Bradshaw and Schepers, 2000).

Under EU Directive 93/71/EC, for the purposes of registration of a new pesticide, "Laboratory data and where it exists, field information relating to the occurrence and development of resistance or cross resistance in populations of harmful organisms to the active substance(s), or to related active substances, must be provided". In support of this, the sensitivity of European isolates of *P. infestans* to zoxamide was investigated, using 33 laboratory isolates from sites never exposed to this fungicide and 136 isolates obtained from field trials in nine countries over a four year period, some from zoxamide-treated plots. Because zoxamide is effectively non-systemic, a test relying on the uptake by leaf discs of the fungicide from solution (as used for phenylamides) was not appropriate. Therefore a protocol was developed which used potato leaf discs sprayed with a series of concentrations of zoxamide, inoculated with *P. infestans* and assessed for sporulating growth after 7 days. This was used to test all isolates; in addition selected isolates were tested *in vitro* using a poisoned agar plate method.

The effect of zoxamide on the development of *P. infestans* on inoculated leaves was investigated by scanning electron microscopy to determine when inhibition of fungal growth occurred. Infection was initiated by both directly germinating sporangia and by zoospores.

Materials and methods

Potato plants

Healthy glasshouse-grown potted potato plants (blight-susceptible cultivars lacking R-genes) from high grade seed tubers were used to provide leaf material for inoculation. Leaflets were harvested from plants immediately before use.

Sources of isolates of Phytophthora infestans used in the study

Nineteen isolates of *P. infestans* obtained from potato foliage in five European countries during 1996-97 were supplied from a culture collection. In addition, 14 isolates from the Northern Ireland *P. infestans* collection were selected; all were derived from infected potato foliage except for one, which was from a tuber. These isolates (referred to as 'laboratory isolates') were all from locations where zoxamide had never been used.

Samples of infected potato foliage, potato tubers, or, in one case, tomato fruit and foliage were supplied by Dow AgroSciences from European zoxamide field trial sites, 1997-2000. On receipt, these were incubated under high humidity to induce sporulation. Sporangial/zoospore suspensions were used to inoculate detached healthy leaflets from glasshouse-grown potato plants and maintained on these with weekly transfers (Cooke, 1986). They were subsequently transferred into axenic culture (Cooke *et al.*, 2000) on rye extract agar or pea extract agar.

Determination of mating type and phenylamide resistance

Mating type was determined by pairing isolates with tester isolates of known mating type on agar plates and monitoring oospore formation (Cooke *et al.*, 2000). Sporangial suspensions, prepared from isolates growing on detached leaflets, were tested for phenylamide resistance using the floating leaf disc technique (Cooke, 1986) on 100 and 2 mg metalaxyl/litre.

Zoxamide sensitivity – in vivo test

Stock solutions, prepared from technical grade zoxamide (92%) dissolved in acetone, were diluted with water (1:99) immediately before spray application to give 20, 10, 5, 1, 0.5 and 0 mg zoxamide/litre. A 40 mg zoxamide/litre concentration was used in a few tests where isolates grew on discs treated with 20 mg/l. The abaxial (lower) surfaces of discs (24 mm diameter), cut from potato leaflets, were sprayed with the zoxamide solutions, allowed to dry, then placed on damp filter paper in Petri dishes. Each isolate was tested using five replicate discs for each of five concentrations of zoxamide and the control (1% aqueous acetone). Discs were inoculated with the appropriate sporangial suspension (20 μ l, *c.* 5×10^4 sporangia/ml) and incubated at 15°C with illumination. After 7 days, discs were assessed for sporulating growth of *P. infestans*. Results were expressed as the minimum inhibitory concentration (MIC), defined as the concentration which inhibited growth on at least four of

the five replicate discs. Where possible, isolates were tested at least twice to confirm results. A common isolate (RH1b from the 1997 field samples) was included as a standard.

Zoxamide sensitivity – in vitro test

Results of the *in vivo* test were sometimes inconsistent or gave uniformly high MIC values, including for the standard isolate. An *in vitro* poisoned plate protocol (based on one supplied by Dr David Young, Dow AgroSciences) was therefore used to test selected isolates. Aliquots of solutions of technical grade zoxamide in acetone were added to carrot agar (Erselius and Shaw, 1982) to give final concentrations in agar of 0, 0.98, 3.9, 15.6 and 62.5 µg zoxamide/litre and 0.05% acetone. The agar was poured into 9 cm Petri plates, which were inoculated centrally with the appropriate test isolates (three replicate plates/concentration including the control). The plates were incubated at 15°C and the diameters of the mycelial growth zones measured after 14 days. EC₅₀ values were derived from log-probability plots.

Preparation of fungicide-treated leaf material for scanning electron microscopy

Suspensions containing 270 mg zoxamide/litre (equivalent to 150 g a.i./ha high volume) in sterile distilled water were prepared from ‘RH-7281 2F’ (240 g/litre) and used to spray the adaxial (upper) surfaces of potato leaflets. The leaflets were allowed to dry, then placed adaxial side up in humid boxes. Sporangial suspensions were prepared from cultures of isolate RH1b (from a 1997 French field trial). For direct germination studies, sporangial suspensions were used immediately. For indirect germination, the sporangial suspensions were chilled (4°C, 2 h) to stimulate zoospore release. Each leaflet was inoculated with 20 µl of suspension and incubated (12 h light, 12 h dark) at 15°C for indirect germination and at 20°C for direct germination. After 24, 48, 72 and 96 hours, small pieces of leaflet (*c.* 25 mm²) were excised from the vicinity of the inoculum drops, fixed to a copper stub, rapidly frozen in liquid nitrogen, slushed in an argon atmosphere and sputter-coated with gold. The samples were transferred under vacuum to a JEOL JCM-35CF SEM equipped with a cryo-stage for microscopic examination.

Results

Isolates of Phytophthora infestans

In addition to the 33 laboratory isolates, 140 viable isolates were obtained from the 1997-2000 field trial samples, of which 136 from nine countries were tested for zoxamide sensitivity (Table 1). The field isolates were all derived from infected potato foliage, except for one from a potato tuber and two from a tomato sample from Italy (one foliage and one fruit).

Table 1. Number of isolates from each country tested for sensitivity to zoxamide.

Country of origin	Number of isolates (number from zoxamide-treated plots)				
	Lab. isolates*	1997	1998	1999	2000
Belgium	1	1 (0)	0 (0)	1 (0)	0 (0)
France	5	10 (0)	5 (1)	12 (6)	2 (1)
Germany	4	3 (0)	1 (0)	0 (0)	0 (0)
Italy	0	0 (0)	4 (4)	4 (1)	0 (0)
Netherlands	4	6 (0)	2 (0)	7 (2)	3 (2)
Poland	0	1 (0)	5 (1)	0 (0)	0 (0)
Portugal	0	0 (0)	1 (0)	0 (0)	3 (1)
Spain	0	0 (0)	1 (0)	0 (0)	2 (1)
UK (G. B.)	5	4 (0)	36 (13)	15 (6)	7 (1)
UK (N. Ireland)	14	0 (0)	0 (0)	0 (0)	0 (0)
Total	33	25 (0)	55 (19)	39 (15)	17 (6)

* isolates collected from regions before any field application of zoxamide occurred, 1993-1998

Zoxamide sensitivity in vivo

The 169 isolates tested using the *in vivo* technique varied in their sensitivity to zoxamide with mean MIC values from 0.5 to >20 mg/litre (Figure 1). There was little evidence of any association between country of origin and zoxamide sensitivity (Figure 2). Isolates derived from samples received and tested late in the season tended to give higher MIC values. This was not due to an inherently lower sensitivity to zoxamide, since the standard isolate also gave higher MIC values in these tests. The response appeared to be affected by the condition of the leaf material, which, although derived from healthy, glasshouse-grown plants, varies due to environmental and seasonal factors, particularly if tests are performed outside the normal growing season.

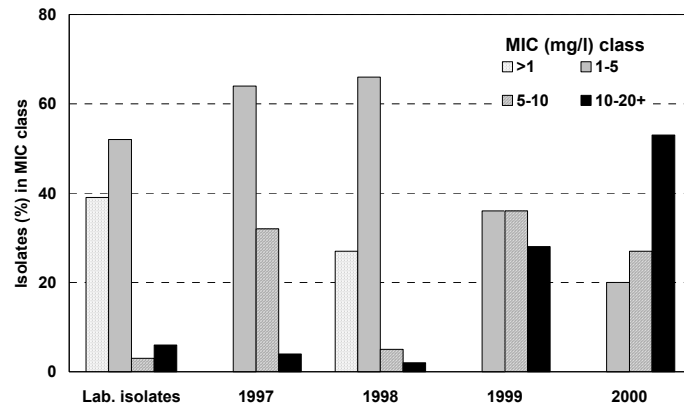


Figure 1. Sensitivity to zoxamide of *Phytophthora infestans* isolates from different years

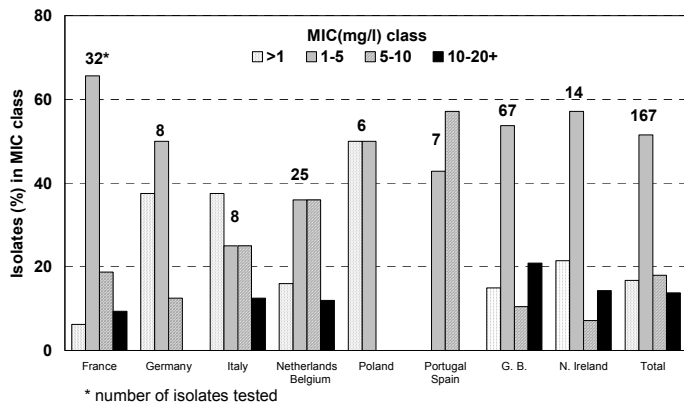


Figure 2. Sensitivity to zoxamide of *Phytophthora infestans* isolates from different countries

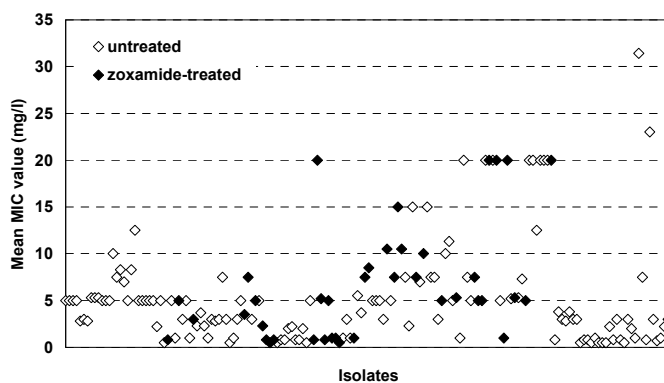


Figure 3. Effect of treatment on sensitivity to zoxamide of *Phytophthora infestans* isolates

Zoxamide sensitivity in vivo: effect of treatment, phenylamide resistance and mating type

Of the 169 isolates tested on leaf discs, 39 were obtained from zoxamide-treated plots. These isolates proved to have a very similar range of sensitivities to those from non-zoxamide-treated plots or crops (Figure 3), with mean MIC values of 6.7 and 5.3 mg/litre, respectively.

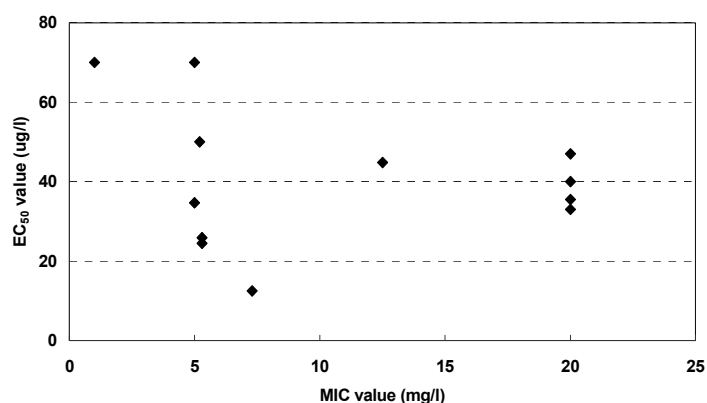


Figure 4. Comparison of *in vitro* (EC₅₀) and *in vivo* (MIC) sensitivity to zoxamide of *Phytophthora infestans* isolates

In phenylamide resistance tests, 46% of isolates were sensitive, 33% intermediate and 21% resistant. Almost all countries yielded a mixture of sensitive, intermediate and resistant isolates, except that all eight isolates from Italy were sensitive. There was no association between phenylamide resistance and zoxamide sensitivity, although there was a slight tendency for phenylamide-resistant isolates to be among the more sensitive to zoxamide (Table 2).

Of the isolates successfully transferred to axenic culture and tested for mating type, 154 were A1 and only 7 of the A2 mating type (from the Netherlands, Poland and the UK), so no conclusions could be drawn regarding zoxamide sensitivity and mating type.

Table 2. Phenylamide resistance status of isolates tested for sensitivity to zoxamide.

Phenylamide sensitivity	Number of isolates tested	Isolates (%)	Mean zoxamide sensitivity (MIC mg/l)
sensitive	75	46	5.9
intermediate	53	33	5.5
resistant	35	21	4.1

Zoxamide sensitivity in vivo and in vitro

In vitro sensitivity tests on 14 of the year 2000 field isolates showed that all were very sensitive to zoxamide. Mean EC₅₀ values ranged from 25 – 88 µg/litre. Comparison of mean EC₅₀ values with mean MIC values, where both were available (Figure 4), showed a lack of correlation between the *in vivo* and *in vitro* sensitivities.

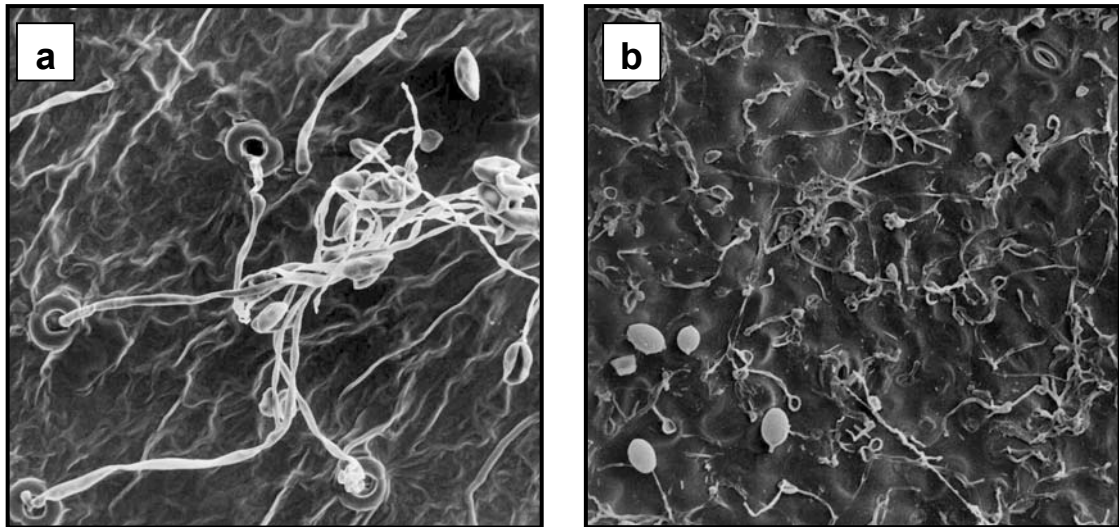


Figure 5. Development of *Phytophthora infestans* on the adaxial potato leaf surface 96 h after inoculation with a sporangial/zoospore suspension (indirect sporangial germination)

a) untreated: zoospores have infected the leaf and sporangiophores bearing the new generation of sporangia are now emerging from stomata

b) zoxamide-sprayed: after initial germination further development has ceased and sporangia and zoospore debris from the inoculum are seen on the surface

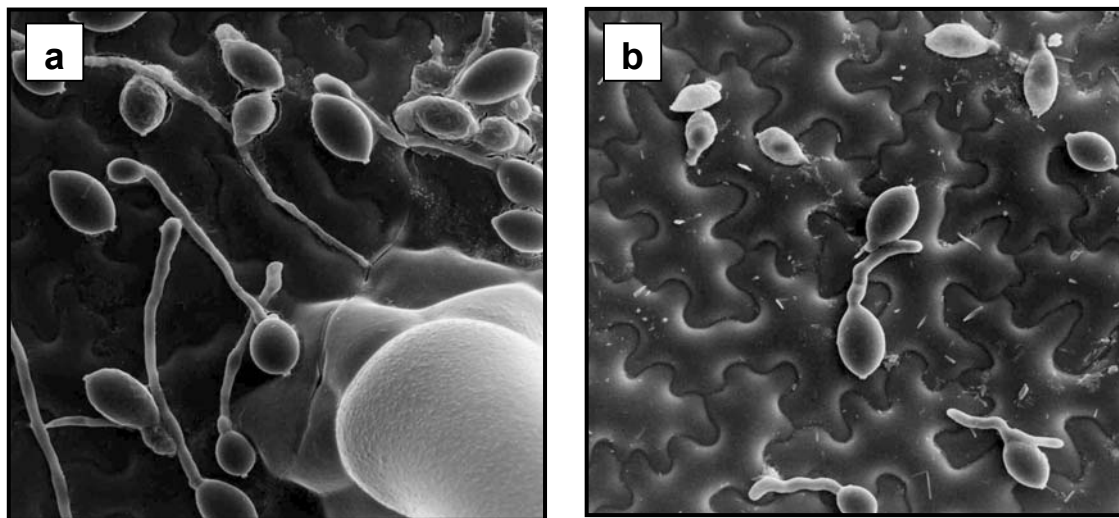


Figure 6. Development of *Phytophthora infestans* on the adaxial potato leaf surface 96 h after inoculation with a sporangial suspension (direct sporangial germination)

a) untreated: sporangia with elongating germ tubes clustered around a leaf hair (NB infection from direct sporangial germination is much slower than from indirect germination)

b) zoxamide-sprayed: sporangia with stunted and distorted germ tubes whose development has ceased

Scanning electron microscopy study of the effect of zoxamide on infection of potato leaves by Phytophthora infestans

Both zoospores and sporangia germinated on zoxamide-sprayed leaf surfaces, but was subsequently inhibited (Figures 5 and 6). No sporangiophores or new sporangia were observed on zoxamide-treated leaves whereas on untreated leaves inoculated with zoospores these had developed within 96 hours of inoculation.

Discussion

European isolates of *P. infestans* vary in their sensitivity to zoxamide as indicated by the concentration required to prevent sporulating growth on excised potato leaf discs with mean MIC values from 0.5 to over 20 mg zoxamide/litre. This is probably due to natural variation within the pathogen population, since the variation was as great among laboratory isolates never exposed to zoxamide in the field as among isolates collected from sites where zoxamide was applied. Variation in response of *P. infestans* populations to fungicides has similarly been found with propamocarb (Bardsley *et al.*, 1998).

Whilst *in vivo* techniques provide a more realistic measure of sensitivity of *P. infestans* to fungicides than *in vitro* methods, they are intrinsically more variable. This applies particularly to non-systemic compounds such as zoxamide, which must be applied as uniformly as possible to the leaf surface, in contrast to systemics, which can be added in solution and diffuse through the leaf tissue. Results from the *in vitro* tests on selected year 2000 isolates indicate that all were inherently very sensitive to zoxamide with EC₅₀ values <100 µg/litre.

Although the present study of 169 isolates failed to identify any which consistently exhibited reduced sensitivity to zoxamide, the possibility that such strains occur at low frequency cannot be excluded. Laboratory studies of the risk of development of resistance to zoxamide have indicated that it is much lower than for metalaxyl, although, as it is a single site inhibitor, an anti-resistance strategy should be adopted (Young *et al.*, 2001). Marketing zoxamide as a co-formulation with mancozeb is such a strategy and scanning electron microscopy has shown that the activities of mancozeb and zoxamide are complementary, mancozeb killing spores before germination and zoxamide inhibiting their subsequent development.

Acknowledgements

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Drop-Leg, on-target, application

Improving Crop-input Application Using Spray Boom Attached, Drop-legs

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Summary

Screening by the growing crop is a major cause of uneven crop coverage by boom spray applications, allowing re-infection or infestation from sheltered areas within the canopy, also aiding resistance build up through sub lethal dose selection.

The majority of systems currently used in dense canopy crops apply the spray from above the crop only. This leads to the crop shielding pests and diseases within the canopy. In addition, the above canopy spray application has to be a compromise between small drops for coverage and large drops to reduce drift.

Having largely overcome the major disadvantages of other drop-legs designs (machine or crop damage and boom attachment). The new design of drop-leg technology reported here allows a targeted application within the crop canopy and overcomes some disadvantages of previous systems. Drop-legs have been shown to produce very little drift when within the canopy and at levels well below that produced by a conventional hydraulic or a sleeve boom sprayer. This results in the double benefit of better targeting and the ability to select the most appropriate spray quality for the intended target. There is also a less obvious advantage, in that the boom can be treated as part of the system. The lower velocities and large drops of 'low-drift' nozzles can be used to keep the spray from the boom nozzles on the upper canopy, whilst smaller drops can be produced by the drop-leg to complete the crop cover. Crop coverage has been shown to be improved, particularly on the stems and lower leaves,

compared to conventional hydraulic and sleeve boom systems. Off target direct ground deposits of spray have also been shown to be lower from the drop-leg system compared to a sleeve boom system. It is possible to target deliberately any particular segment within the crop canopy. For example the nozzle can be directed at the ground if desired with a minimum of spray reaching the crop.

The development work has been largely conducted in potato crops. Drop-leg systems are not new and have been tried in a wide variety of crops but have never caught on for largely mechanical reasons. This new system has been shown to be practical and to have obvious technical and environmental advantages and is being adopted into other crops.

The choice of pesticide may change with less reliance on certain products, allowing it to fit well, into Integrated Pest Management systems. 'Dead pests and diseases do not re-populate crops, or pass on resistance genes'.

Key words: integrated pest management, drift, coverage, spray quality, pesticide application

Drift control

Screening by the growing crop is a major cause of uneven spray applications. Conventional boom applications have to be a compromise between small drops for coverage and large drops to reduce drift. Droplets of medium to coarse size tend to stay at the top of broad leaf crops leaving the lower plant unprotected. Fine drops will move in the air around the leaves and will give some improvement in crop cover, but with a considerably increased drift risk.

Using DADS a combination of drop-legs and boom nozzles, there is a double benefit of better targeting and the ability to select the most appropriate spray quality for the intended target. The lower velocities and large drops of 'low-drift' nozzles can be used to keep the spray from the boom nozzles on the upper canopy, whilst smaller drops can be produced by the drop-leg to complete the crop canopy cover including the stems and under leaf surfaces of the whole plant.

The drift results presented here are for the drop-leg combined with boom nozzles. This was chosen for presentation here, as this combination represents the application method most likely to be used for whole plant pest and disease control. The trial shown here tested several options. The drop-legs alone produced considerably less drift than the other systems and contributed little to the total recorded in the combination result shown. The upright leaf

structure of wheat will not hold spray from the drop-leg into the crop canopy as would a broad leaf crop.

WA Jeffrey and RG McKinlay - Scottish Agricultural College

Spray Drift Measurement in Wheat

The drift cloud was sampled by three masts at 10m intervals set in a line at right angles to the direction of travel. Each mast mounted 10 pairs of horizontally disposed pipe cleaners, spaced at 0.5m intervals at height from 0.7m to the mast top at 5.2m above ground.

The sprayers were driven along a path parallel to the masts on the upwind side, with the near boom end 5m from the line of masts. Four passes were made in each test (two in each direction), while a hand held hot wire anemometer with averaging facility monitored wind speed at boom height immediately up wind of the sprayer. The wind direction varied nominally from 45° to 75° from the sprayer path.

Spray Drift Collected at three Heights (figure 1):

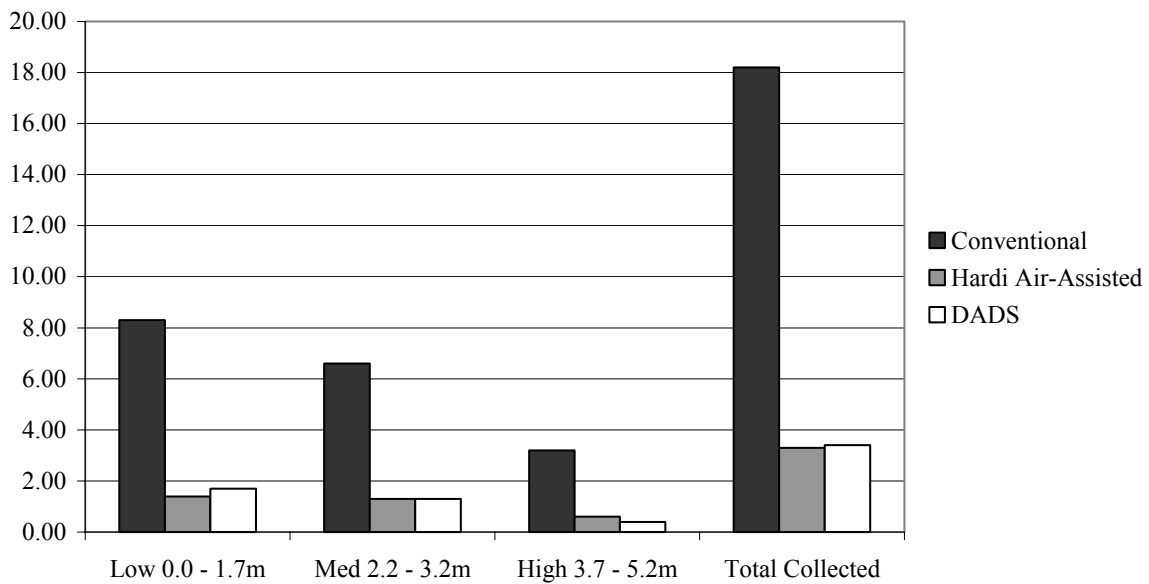


Figure 1. Spray drift of three sprayers collected at three heights.

Fluorimetric analysis determined the amount of spray captured on each pipe cleaner, based on solutions samples taken from the respective sprayers to calibrate the instrument. To

release the dye, each pipe cleaner was soaked in a standard volume of mild hydroxide solution.

From the wind speed coefficients of variation (C of V's) it is clear that the wind was pretty unsteady except during test 3, so small differences can be discounted. DADS produced a similar level of drift to the air-assisted system. The drift from both was less than half that produced by the conventional system.

Operating the drop-leg nozzles alone produced virtually no visible drift.

Pest control

Application systems currently used in dense canopy crops mostly apply the spray from above the crop only. As can be seen in the results here this leads to the upper-crop canopy shielding of pests within the rest of the canopy.

The aphid control results presented here show that DADS out performed the other systems in both initial knockdown and length of control. Demonstrating the importance of lower canopy cover, where control in the lower canopy is poor, the population has regenerated providing a source of reinfestation for the whole plant. It is believed that this will be the case for other pests & diseases.

Unlike the other systems the population remains below a treatable level. This is likely to have saved at least one application if not two. This leads to other major benefits. The economic and environmental benefit of potentially reduced pesticide use is obvious. The reduced risk of resistance build up by avoiding declining dose selection down the crop profile and minimising repeated doses of the same (or similar pesticides) in a short period to the same pest population is also a clear benefit. Less obvious is the benefit to Integrated Crop Management: the choice of pesticide may be wider, a contact product may be used in place of a systemic, a more selective material might replace a general one or a reduced dose may be used.

Comparison of DADS with Conventional and Air-Assisted Applications for Aphid Control in Potatoes

Summary of Results (Fig. 2)

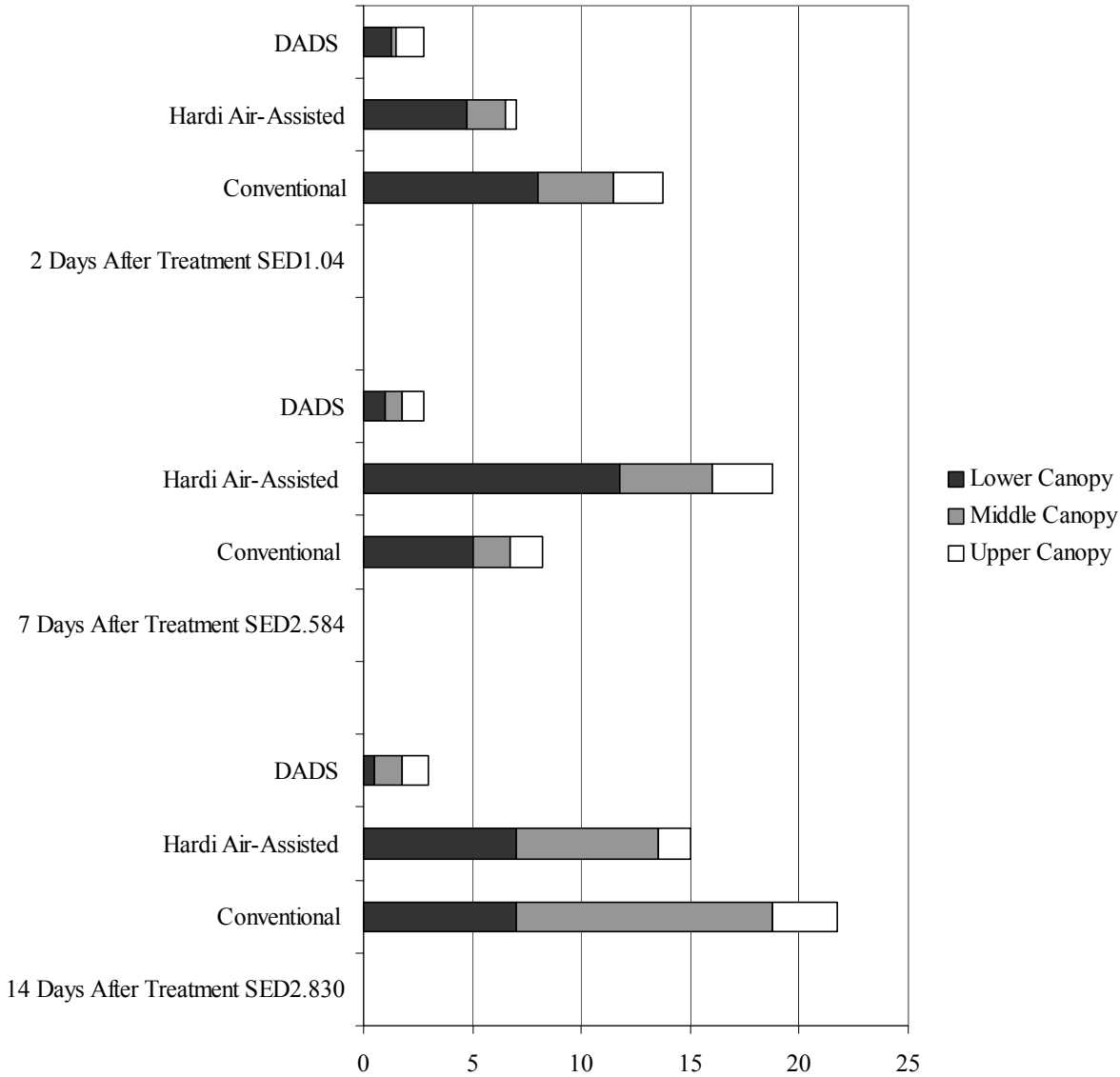


Figure 2: Aphid Count - *M. persicae* & *M. euphorbiae* at 2, 7 and 14 Days Post Application Assessment. Trial: 4 Replicate - Product: Decisquick @ 300ml/ha. Results: Aphids found per 20 leaf sample at each height.

Pre-spray sample - the sample found no significant difference ($P > 0.05$) in the distribution of aphids across the site of experiment. Total aphids averaged 28 aphids per 20 leaf sample,

numbers were evenly distributed between upper, middle and lower leaves. The dominant aphid species at the experimental site was *Macrosiphum euphorbiae* which made up more than 90% of the aphids found. The majority of the remaining aphids found at the experimental site were *Myzus persicae*, but *Aulachorthum solani* and *Myzus ornatus* were also found.

2 days post-spraying - the sample showed that all the spraying systems had achieved significant ($P < 0.01$) reductions in aphid numbers. For total aphid numbers plots treated with conventional systems, air-assisted and DADS achieved reductions of approximately 70%, 85% and 95% respectively when contrasted with untreated plots. For the two species analysed individually (*Macrosiphum euphorbiae* and *Myzus persicae*) the ranking of the three systems was identical and their performance, in terms of reducing aphid numbers, was similar.

7 days post-spraying - the leaf samples showed that all sprayer systems continued to have aphid populations significantly ($P < 0.001$) lower than untreated plots. The plots treated with DADS continued to have the lowest aphid populations.

14 days post-spraying - the leaf samples showed that all sprayer systems continued to have aphid populations significantly ($P < 0.001$) lower than untreated plots. The plots treated with DADS continued to have the lowest aphid and *Macrosiphum euphorbiae* populations. However populations of *Myzus persicae* had recovered and there was no significant difference ($P > 0.05$) between numbers of untreated and treated plots.

Crop spray cover

DADS, has been shown to improve crop coverage, particularly under the upper leaves (Basil, 1994) on all the stems and all over the lower leaves compared to conventional hydraulic and sleeve boom systems.

Off target direct ground deposits of spray have also been shown to be lower from the drop-leg system compared to a sleeve boom system. It is possible to target deliberately any particular segment within the crop canopy. For example the nozzle can be directed at the ground if desired with a minimum of spray reaching the crop.

The development work has been largely conducted in potato crops. This new system has

been shown to be practical and to have obvious technical and environmental advantages and is being adopted into other crops.

Having largely overcome the major disadvantages of other drop-legs designs (machine or crop damage and boom attachment). The DADS design of drop-leg technology reported here allows a targeted application within the crop canopy and overcomes some disadvantages of previous systems.

Morley Research Centre / Harper Adams - Howard Hinds

Spray Deposition Measurements of Application Systems in Potatoes

Methods

Application - dilute sodium fluouroskien dye was applied at 220 l/ha for each system. DADS applied: 80 l/ha from top jets and 140 l/ha from drop-leg. Samples were taken and the dye washed off, assessment was made by spectrophotometer.

Discussion

As might be expected, conventional application concentrates much of the spray in the upper part of the foliage and is not very successful at targeting lower leaves and stems which tend to be shielded by the upper leaf foliage (Fig. 3-6).

Air-assisted application does better than conventional at delivering spray to the bottom of the crop, however the improvement is less of a difference when lower stems and leaf terminals are considered (Fig. 4-5).

Application with DADS produced most uniformity of spray deposition throughout the canopy. Because the system divides the spray volume, the deposition on the top of the crop is lower than the other systems but is much higher in the bottom of the crop. Biological studies have shown (Ligertwood, 1996), that putting a lower dose volume (150 l/ha) on the top canopy with the drop-leg application does not affect the level of late blight control compared to conventional and air-assisted spraying (300 l/ha). The higher deposition levels in the lower canopy by drop-leg application, as shown in this trial, could also explain the increase control to this part of the crop in work referred to above (Fig. 3-6).

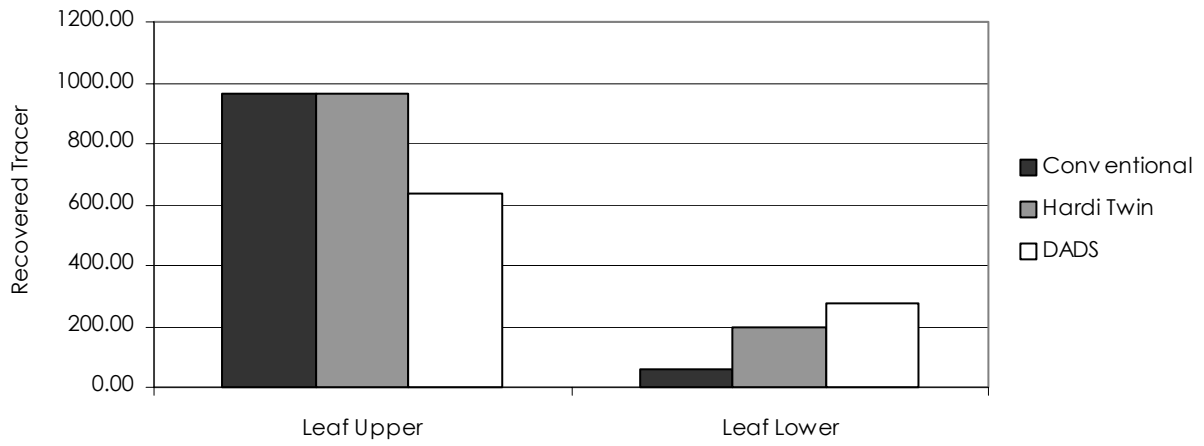


Figure 3. Mean Tracer Deposits on Potato Leaves

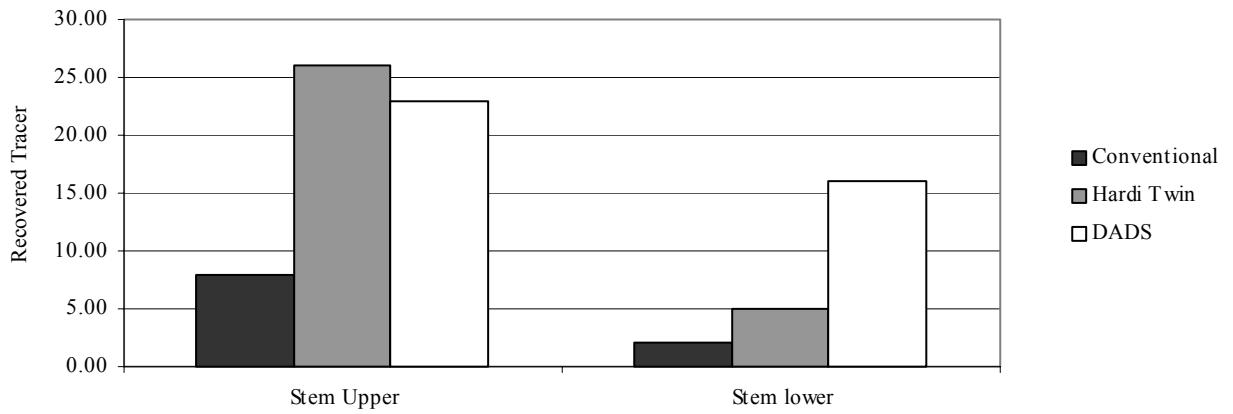


Figure 4. Mean Tracer Deposits on Potato Stems

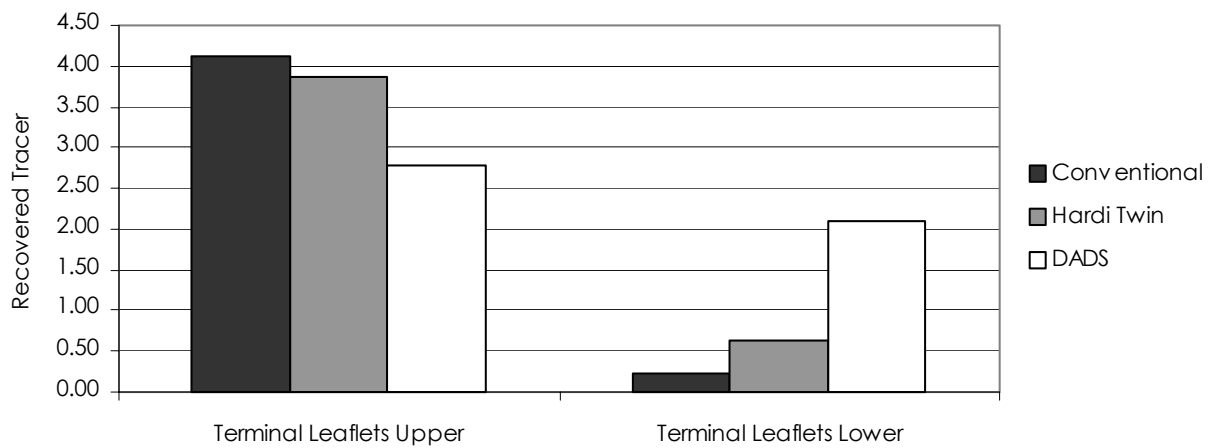


Figure 5. Mean Tracer Deposits on Potato Terminal Leaflets

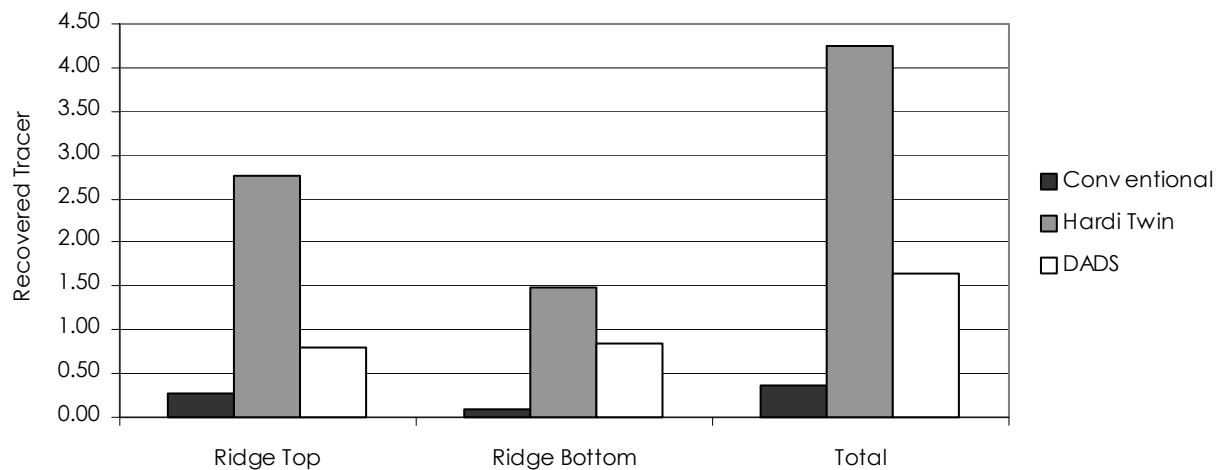


Figure 6. Mean tracer on Potato Ridges (Ground Deposits).

Spray deposition to the stem has particular significance in potatoes in relation to tuber blight infection (Fairclough, 1993). The increased levels of spray cover to the lower stem given by the drop-legs in this work, supports the theory that this factor is involved in reducing tuber blight infection (Ligertwood, 1995). The ground deposit results in this trial are interesting because of the relatively high levels achieved by the air-assisted sprayer. It is claimed that air-assisted sprayers use the ground to bounce off to hit lower foliage. If this is the case then some of this spray is remaining on the soil.

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Detection of *Phytophthora infestans* via PCR and serology in potato plants

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Summary

With a new syringe punching sampling procedure *Phytophthora infestans* was detectable in potato stems by using the alkaline extraction procedure and the “nested PCR”. The newly developed primers showed a 276 bp DNA fragment when *Phytophthora infestans* was present in the tissue. A bioassay on potato tuber slices performed in parallel was not as efficient as the “nested PCR”. However, there are some indications that *Phytophthora infestans* might occur latently in the tubers and show symptoms by growing up the stems and sporulate at the top of single plants. An indirect ELISA showed a potential evaluation of the resistance of the tested potato varieties by using artificially inoculated potato leaves. This might be in future a laboratory method to determine the resistance of potato plants.

Key words: “nested PCR”, cannula, syringe, indirect ELISA.

Introduction

The question of whether the initiation of a *Phytophthora infestans* epidemic in a field can start from latently infected tubers was tried to be answered by applying the PCR as a sensitive detection tool. A tandem repeat of the genome of *P. infestans* was chosen for the targets of the primer sequences. To further increase the sensitivity, the so-called “nested PCR” was applied, allowing an even more sensitive detection (Niepold and Schöber-Butin, 1999).

The latent occurrence of *P. infestans* in the tubers was investigated by taking samples from the stem during the early growth period of the potatoes until just before the first appearance of symptoms in the field. Due to the high sensitivity of the PCR, only small parts of the stems

were necessary for sampling, therefore allowing the plant to survive.

Routine detection of *P. infestans* before symptoms appear is also possible by serological methods. Here, the indirect ELISA has been used in combination with polyclonal antibodies, purified by using the mineral Kaolin.

Applying the indirect ELISA on artificially inoculated leaves, a detection was possible about 3 days before the first symptoms became visible. It could be shown that the indirect ELISA was also useful to determine the severity of the growth of *P. infestans* at different stages of the infection, allowing a better classification of the resistance to the fungus.

Material and Methods

For sampling, a cannula of a diameter of 2.5 mm and a length of 80 mm was used which was disinfected with alcohol and flamed preceding use. In combination with a syringe, filled with air, the cannula was used to punch out a round piece of the stems at the bottom of the potato plant (1 cm above the ground). Afterwards, this piece of the stem was pressed carefully into a sterile plastic tube. This procedure was repeated on the same stem but at a small distance from the first sampling. In this manner, 30 randomly selected potato plants of the variety “Eersteling” from a potato field in Braunschweig - where no fungicides were applied during the crop season - were sampled weekly, starting with plants having reached a height of 20 cm.

From the first stem tissue sampled, the DNA was extracted to perform a “nested PCR”. Using a pistil adapted to the plastic tube, the DNA was extracted by an alkaline DNA extraction procedure (Raeder and Broda, 1985). The second piece of the same stem was collected in a new plastic tube, for the modified Lapwood bio-test conducted in parallel (Schöber and Höppner, 1972) .

The PCR was performed with two primer pairs applying the “nested PCR” at their optimal annealing temperatures and cycles (Niepold and Schöber-Butin, 1999). The first primer pair generated a 389 bp DNA fragment and the second primer pair a DNA fragment of 276 bp in size. Niepold and Schöber-Butin (1999) described the sequences for the first primer pair (20mer) and for the second primer pair (18mer).

Polyclonal antibodies were generated by injecting an ammonium sulphate-precipitated fraction of the proteins from the mycelia of *P. infestans* into rabbits. After boosting, the

blood was taken and the serum was partially purified using the mineral Kaolin. After centrifugation at 6000 x g the supernatant was fractionated and stored for further tests (Knapova, 1995).

The following fourteen potato varieties were used for the serological experiments:

Christa	Velox
Junior	Karlana
Tomensa	Planta
Solara	Likaria
Ponto	Albatros
Aula	Producent
Bonanza	Sanira

Two parallel leaf inoculations were performed by using the same zoospore concentration, by spraying the suspension on the upper-side of the leaf (adaxial). The leaves were put into a plastic container, containing a water reservoir, where mutual contact of the leaves was prevented by a wire device. The plastic container was closed with a lid, retaining enough moisture until the end of the experiment (7 days).

Samples of the artificially infected leaves were collected the fourth day after inoculation and the soluble proteins were extracted by grinding the leaves. The fluid was collected in sterile plastic tubes. The indirect ELISA was performed in microtitre plates and the plant sap from uninfected potato tuber leaves was used to adjust the zero value.

An indirect ELISA was performed according to Knapova (1995), using the ELISA-reader (SLT, Austria). The plastic microtitre plates were obtained by Greiner, Germany. The leaves were pressed and the plant sap was used to measure the concentration of *Phytophthora infestans* antigens with the Kaolin-purified polyclonal antiserum. A graduation of the values could be found in comparison to the level of resistance, usually 2 days before the first symptoms were seen.

Results and Discussion

The use of the cannula and syringe turned out to be suitable for young and old stems. It could penetrate, due to its specially formed tip, even woody parts of the stems at a later stage of growth during the vegetation period. The advantage of the cannula is that the stems survive the treatment by immediately forming a wounding barrier, preventing an infection by other plant pathogens. In addition, the already sampled parts were stretching away from the soil due to the elongation growth of the stems.

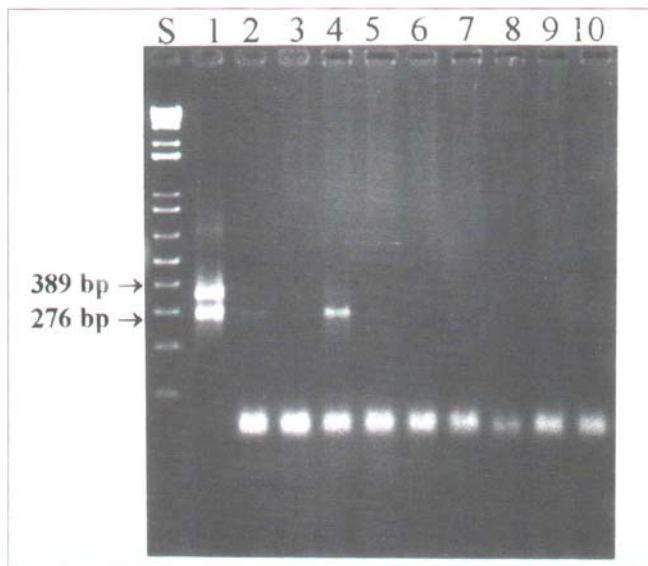


Figure 1. “Nested PCR” from stem samples which have been taken from randomly chosen plants in the field. Slot S is the molecular DNA standard and slot 1 the control, pure DNA extracted from *Phytophthora infestans*. Slot 4 represents a PCR signal which was obtained one week before the first symptoms were found in the field and which was also positive in the Lapwood bio-test. Weaker PCR amplicates than that of slot 4 did not yield a positive Lapwood bio-test.

Using a high concentration of *P. infestans* DNA, both amplicates of the size 389 bp and 276 bp were observed when applying the nested PCR. As Fig. 1 shows, there was a PCR signal at slot 1, representing the positive control. Slot 4 represents a positive finding, and a subsequent Lapwood bio-test revealed also *P. infestans* growth on the tuber slices. This strong band was obtained one week before the first symptoms on the upper leaves of the potato plants were seen.

Weaker bands were also found at an earlier stage, about two weeks before the appearance of the first field symptoms. However, no growth was observed on the tuber slices when similar, PCR positive samples were used at this stage of *P. infestans* growth. Probably the second sampling, which was used for the Lapwood bio-test was not directly hitting the mycelia of *P. infestans*, because, normally, smallest amounts of *P. infestans* are sufficient to generate a positive Lapwood test.

To avoid this problem, the puncture of the stems should be set in an angle of 90°, but still heeding the rigidity of the stem by leaving a long enough distance of the two wholes. However, since the puncture can hit the mycelium of *P. infestans* only by occasion there is always the possibility that no PCR signal is obtainable even though the fungus is growing in the stem. Another possibility is that the mycelium is distributed unevenly in the stem because of elongation growth.

At least, in one case out of 30 sampled plants there is an indication that *P. infestans* grows from an apparently latently infected tuber up to the tip of the potato plant. In our case, symptoms occurred on that particular plant at a later stage than on other plants in the field.

This means, however, that some infections are taking place by the outgrowth of *P. infestans* from latently infected tubers. Therefore, not only a potato field will be infected by already sporulating *P. infestans* from other places, but also an “in field” infection can occur. This can happen earlier or later, depending on the conditions for the growth of *P. infestans* in a particular situation.

The use of the precipitated soluble protein fraction of *P. infestans* as antigens and the application of Kaolin revealed a serum which was successfully used in the indirect ELISA since no cross-reaction was observed when using other, potato pathogenic fungi. However, only a slight cross-reaction was observed when using the closely related oomycete *Phytophthora erythroseptica*.

By testing different potato varieties with the indirect ELISA, preliminary results show that not only an earlier detection was possible, but also a quantification. This is important for the classification of the new breeding lines in comparison to the already existing potato varieties. The varieties used were shown to mostly correlate with the official test results of the Federal Office of Plant Varieties, and selected examples are presented in Table 1.

Table 1. Indirect ELISA reading values by using leaves of different resistant potatoes, inoculated with a highly infective *Phytophthora infestans* isolate.

Variety	ELISA*	BSA-List*
Christa	5.5	6
Velox	6.5	6
Junior	6.5	6
Karlana	4.5	5
Tomensa	3	3
Planta	2	3
Solara	3.5	4
Likaria	6	6
Ponto	4.5	4
Albatros	3.5	4
Aula	4	4
Producent	2.5	3
Bonanza	4	4
Sanira	3.5	3

* The ELISA values were transformed to a scale of 1 (no antigen detected) to 9 (high amount of antigens), corresponding to the visual evaluation of the Federal Office of Plant Varieties (BSA list), where 1 means highly resistant and 9 highly susceptible.

With this procedure it may be possible in future to obtain a resistance evaluation of the potato varieties no longer depending on the weather conditions and the inoculum densities of the natural occurring *P. infestans* in the field.

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Progress of suspected soil borne infection of *P. infestans* in potato as detected by quantitative PCR

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Summary

The progress of potato late blight fungus, *Phytophthora infestans* (*P.i*), from infected soil into potato plant was studied by measuring the DNA content of the pathogen by quantitative PCR- method in different parts of the plants at one week intervals during the growing period. DNA of *P.i* was first detected in the lowest leaves touching the ground before any visible symptoms were observed while stems below ground and mother tubers were free from *P.i* DNA. One week thereafter the highest concentrations were found from the upper leaves and stems and three weeks later *P.i* DNA was also found in tubers. Changes in DNA contents of *P.i* in single plants corresponded with development of visible epidemic in the crop.

Key words: Potato, Potato late blight, *Phytophthora infestans*, quantitative PCR, epidemiology, oospores

Introduction

Oospores in soil are a new source of primary inoculum for potato late blight epidemics (Turkensteen et al., 2000). There are several indications especially from Northern Europe (Stromberg et al., 1999; Zarzycka and Sobkowiak, 1997) and North America (Medina and Platt, 1999) that soil artificially inoculated with oospores can cause infection on potato.

There is limited knowledge how oospores spread from naturally infested soil and how the

epidemic proceeds in potato crop. The aim of this study was to investigate the development of soil borne late blight epidemic in potato crop by measuring the changes of *P.i* DNA in individual plants in comparison to the progress of visible symptoms in the foliage.

Material and methods

In spring 2001 potato was planted in a field where potato has been grown in monoculture since 1990. *P. infestans* was detected by using baiting technique developed by (Drenth et al., 1995) from the soil samples collected from the field in the beginning of May before planting. A block of four 32.5 m long rows of potato cv. Bintje were planted at 8th May in order to provoke early attack of *P.i*. The crop was covered with polythene cover which was removed 18th of June. Another block was planted 28th of May and left uncovered. Both blocks were irrigated regularly to maintain high soil moisture. The blocks were divided into eight 4.5 m subblocks each of them containing four rows of potato. The assessments of visible blight symptoms were made separately for each row in subplots two times a week.

Plants were sampled weekly since 12th of June. At each sampling 20 plants were taken from 4 fixed distinct rows at 5 m distance from each other. From 10 plants stem below ground, stem just above the ground, lower leaf touching the ground, stem in the middle, upper leaf, stem at the top, mother tuber and daughter tuber were analysed for their content of *P.i* DNA. DNA was extracted from plant material by using DNeasy Plant Mini Kit (Qiagen). Relative quantitative measurement of *P. infestans* DNA was performed by the Taqman-PCR assay with ABI PRISM 7700 Sequence Detector (PE Biosystems). The standard curve was made with the constant purified *P.i* DNA. The primers and FAM- labelled probe were planned into ITS1 area specific for *P.i*.

Results

The beginning of the growing season was cool and dry and in spite of irrigation expected early attack under fibre cover could not be produced. One blight lesion was observed on one lower leaflet on a plant grown under cover 2nd of July but weather conditions were still unfavourable for the onset of epidemic.

Next blight lesions were observed on 18th of July from lower leaves on three plants from the block grown without cover. Thereafter epidemic spread very fast and at 27th of July typical blight lesions were found in every plant. First symptoms in the block without cover were yellow mosaic like small lesions all over the lowest leaves and only later typical blight lesions appeared on upper leaves.

In the block which was covered with polythene in the beginning of the season first lesions appeared mainly on upper leaves as typical brown blight lesions. The disease progress was considerably faster in the block previously grown under cover than in the block without cover. By the 6th of August 80 % of leaf area was destroyed in the earlier covered and 50 % in the uncovered block. The whole crop in both blocks was totally defoliated by August 15th.

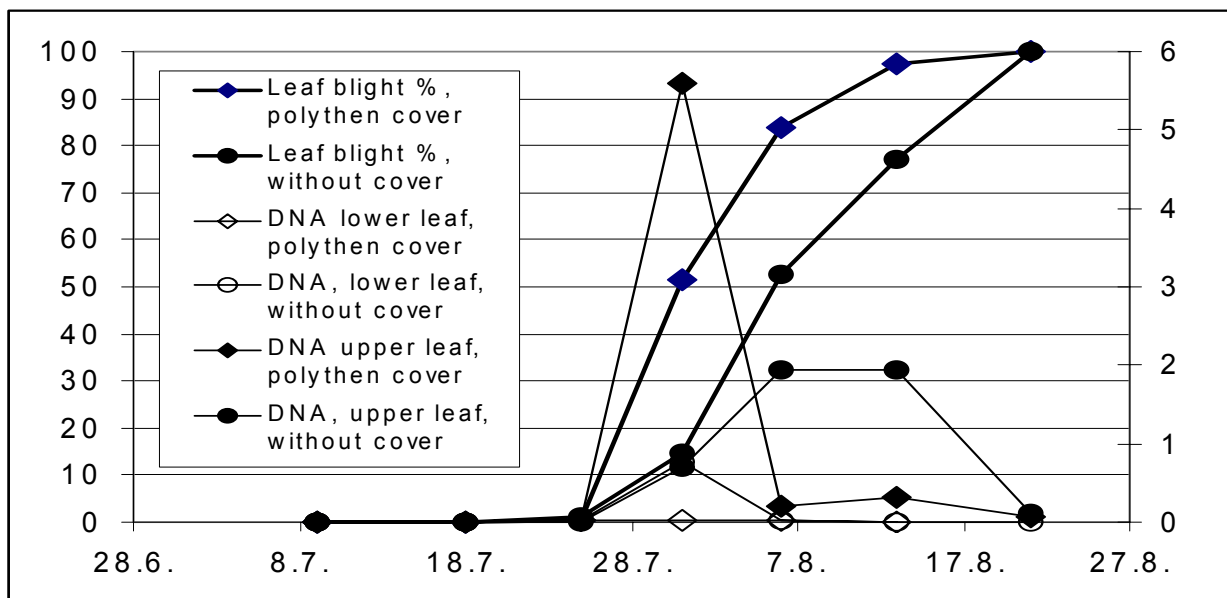


Figure 1. Progress of leaf blight and the relative amount of *P.i* DNA in lower and upper leaves of potato grown under polythene cover and without cover during season 2001.

The DNA of *P.i* was first time detected on lowest leaves at July 24th. The DNA was present in all 10 sampled lower leaves while visible symptoms were recorded only on three leaves. DNA was also found in upper leaves and stems without visible symptoms. The *P.i* DNA content in lower leaves was five fold higher than in upper leaves and 10 fold higher than in upper stems. Stems bases below ground and mother tubers were free from the *P.i* DNA but small quantities of the DNA was found in stem bases above the ground.

One week later the DNA content of *P.i* in lower leaves of plants grown without cover was increased dramatically while in plants grown under cover it had remained on the same level as July 24th. On the contrary DNA level in upper leaves of the plants previously grown under the cover had an enormous increase from July 24th to July 30th. At July 30th traces of *P.i* DNA was also detected from mother and daughter tubers.

Within next weeks lower leaves started to die and the DNA contents of *P.i* dropped down very rapidly. Although the *P.i* DNA was first detected in lower leaves of the plants grown without the cover, the rapid increase in the *P.i* DNA in upper leaves was recorded only one week later. By the end of the season the *P.i* DNA content was decreasing in stems and increasing in daughter tubers. Visible symptoms in tubers were not present in samples analysed and the DNA quantities in tubers were relatively low in comparison to that in leaves and upper parts of stems.

Discussion

Relatively high *P.i* DNA contents were measured in lower leaves one week before rapid development of visible symptoms. The DNA contents of *P.i* in individual potato plants corresponded to observations of blight lesion development in crop even though each consecutive sampling consisted of different plants. Highest DNA concentrations were found during the rapid development of the epidemic right before the appearance of the visible symptoms. Living pathogen also disappeared rapidly in the course of defoliation and finally found its way to daughter tubers towards the end of season.

In favourable conditions blight rapidly invaded upper parts of the plants and also surrounding plants and the primary inoculum foci could not be detected after one week of the onset of the epidemic. Also the physiological age of the crop had very clear effect on the progress of the epidemic. Due to the long sampling interval in relation to fast disease progress probably the maximal *P.i* DNA contents in lower leaves of plants grown under cover and upper leaves of plants grown without cover were missed.

Conclusions

The data provides evidence of the importance of soil borne inoculum in single experimental site. The soil samples yielded blight symptoms on detached leaves bioassay, first visible symptoms were observed on the lowest leaves touching the ground and the highest contents of the *P.i* DNA were measured in lowest leaves in the beginning of the epidemic. Mother tubers and stems below ground were free from *P.i* DNA which excludes seed borne infection. More information is needed on the frequency of heavily infested sites on potato production areas to evaluate general importance of soil inoculum. Also more information on the effect of soil moisture and other environmental factors in infection process is needed to predict the risk for onset of epidemic on infected sites.

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Infection potential and variation of soil borne *Phytophthora infestans*

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Summary

The ability of soil samples containing oospores to infect potato leaflets was studied in greenhouse by bioassay. The soil samples were taken in October 2000 and May 2001 from the field plot where potato has been heavily attacked by late blight during the past few years. The first symptoms on detached leaflets were typically observed 10 days after starting the test. The flooded soil samples remained infective up to 2 months. Isolates collected from leaflets showed similar mating type ratio as has been found in isolates collected from suspected soil borne disease foci. The results significantly support the hypothesis that apparent soil borne infections truly are oospore derived in Nordic countries. Oospore containing soil can remain infective in Finnish weather conditions for at least one winter.

Key words: Potato, Potato late blight, *Phytophthora infestans*, mating type, oospore

Introduction

In previous studies both mating types of *Phytophthora infestans* have been present in Finnish *P. infestans* population (Hermansen et al., 2000). Oospores have been found in leaflets collected from the field after incubation for one week in moist conditions. Oospores has also been found in stems examined directly after sampling from field (Andersson et al., 1998). These results have strongly indicated that sexual reproduction is present and is probably quite common in Finnish *P. infestans* population.

In spite of clear indication of oospore formation their role in suspected soil borne infections and

consequences for potato late blight epidemiology is still unclear. There is an increasing amount of undirect evidence that oospores have been responsible for soil borne infections: primary symptoms found in the leaflets at lower part of the canopy or touching the soil, untypical 'mosaic'-like symptoms in primary infected leaflets, oospore detection after incubation in almost all of these leaflets and an equal mating type ratio of isolates collected from disease foci (unpublished data). In this paper we present preliminary results demonstrating that soil collected from the potato field can infect detached potato leaflets in a greenhouse.

Materials and methods

In October 2000 four soil samples 10 litre of each were collected from the field where potato has been grown in monoculture since 1990. The crop on the field has been heavily infected by late blight during the last few years. Soil samples were stored in an unheated warehouse and they were placed at indoor temperature in February 2001. Additional five soil samples were collected 5th of May 2001 before planting of potato from the same field plot although not exactly from the same sites as in autumn. Before the first test each soil sample was carefully mixed in 50 litres container by hand with help of a small shovel to make a sample as homogenic as possible. Bioassays were carried out during the time course from February to June 2001.

The spore baiting bioassay was carried out as described by (Drenth et al., 1995)). Subsamples of one litre in size were placed in plastic containers (37x28x11 cm). Soil layer was flooded by tap water reaching no more than one centimetre above the soil surface. This amount of water made possible it to place leaflets abaxial (under) side up on the water when only a very small proportion of the leaflet was touching the soil. Containers were incubated under plastic transparent lid at 15°C and they were freeze-dried at - 20°C for 24 hours for 2 weeks to a month intervals. Leaflets were checked daily for infections except during the weekends. Each infected leaflet was taken out of containers immediately after sporulating lesion was found.

Single lesion isolates were collected from the sporulating leaflets. Mating type was confirmed by pairings on floating leaf disks and on rye agar. Virulence based on ability to infect differential set of R-gene clones (R0-R11, R9 not included) of potato was investigated on floating leaf disks (Hermansen et al., 2000).

Results and discussion

The first symptoms were detected within 5-26 (typically 10) days after starting the test. Majority of the subsamples were infective. Variation in the number of infected leaflets in tests between the subsamples was quite high even within one peculiar soil sample. This is probably caused by uneven distribution of oospores in soil samples, which depends on the presence of plant debris containing oospores. The soil sample, which yielded more infections than others remained infective for two months.

Only one of five samples collected in the spring 2001 produced infections in bioassay. Although the number of soil samples was limited, it is obvious that the amount of oospores decreased in soil during the winter due to germination in moist conditions at fall and spring. The phenomenon has also been reported by (Turkensteen et al., 2000).

The distribution of A1 and A2 isolates and isolates, which produced oospores with both testers was quite even, 34 %, 35 % and 31 % respectively. The result fits well to the theory according to which oospores produce progenies possessing both mating types in average at one to one ratio (Gallegly, 1968; Judelson et al., 1995). Similar mating type ratio has been observed in isolates from suspected soil borne disease foci described above. This supports strongly the hypothesis that the suspected soil infection foci in the field are truly oospore derived. In the course of the epidemics mating type ratio of the pathogen usually shifts sharply towards one or the other mating type (unpublished data). Isolates that produced oospores with both mating types were either mixtures of A1 and A2 or selffertile.

Single lesion isolates separated in different virulence races in similar relation to isolates collected from potato fields in Finland and in particular to isolates collected from field where soil samples were taken. 70 % of all isolates were included 1,3,4,7,10,11, 1,3,4,7,11 and 1,3,4,7,8,10,11 (Hermansen et al., 2000).

Conclusions

The results presented above give a significant support to the hypothesis that suspected soil borne infections are truly oospore derived in Nordic countries. Oospore containing soil can remain infective in Finnish climate for at least one winter and there for it is risky to grow potato on fields where blight has occurred previous years. Further studies are needed to specify climatic factors affecting survival and infectivity of oospores in soil in order to improve models used in blight forecasts.

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Studies on formation and survival of oospores of *Phytophthora infestans* in Norway

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Summary

Leaves infected by *Phytophthora infestans* were collected from potato fields in southern Norway in the growing season of 2000 and 2001. Oospores were found in 8 out of 9 fields, in different cultivars and in unsprayed and sprayed fields. Oospores containing leafdiscs were buried in soil under field conditions in 1998 and tested for viability. There was no decline in viability between burial for 20 and 31 months.

Key words: late blight, oospores, *Phytophthora infestans*

Introduction

The population of *P. infestans* in Norway is complex; both mating types A1 and A2 are present and the genetic variability is high (Brurberg *et al.*, 1999, Hermansen *et al.*, 2000). Both mating types were present throughout the growing season and were isolated from the same plant in several cases (Bergjord & Hermansen 2001). In 2001 both A1 and A2 were found in 9 out of 13 fields in southern Norway where more than three isolates were examined (unpublished data). Thus the potential for oospore production is evident. Oospores may cause an alternative way for the pathogen to survive between the growing seasons, and are possibly the cause of early infections in some regions in the Nordic countries (Andersson *et al.*, 1998).

The objectives of this study were to see how frequent oospores are produced in potato leaves and to find the potential for survival of oospores at Norwegian conditions.

Materials and methods

Oospore formation

Leaves with two or more lesions were randomly sampled from different fields (experimental plots or from farmers fields). In 2000 leafsamples were taken from 6 fields in 5 important potato growing areas, and in 2001 leafsamples were taken from 3 fields in 2 important potato growing areas, all in southern Norway. The leafsamples were incubated on moist filter paper in plastic boxes or on water agar in petri-dishes at 15 °C for at least two weeks. After incubation, sections (0.5 x 0.5mm) close to the borders of merging lesions were cut and put in a droplet of water on a microscope slide and examined under 10 x 10 magnification.

Oospore survival

Leafdiscs (18 mm diameter) of the cultivar Beate were inoculated with a sporangia suspension of a mixture of one A1 and one A2 isolate. These discs were incubated at 15 °C and 18h photoperiod for 14 days. Then the leafdiscs were air-dried and placed at about 3 °C before burial.

Seven or eight leafdiscs (1000-3000 oospores/disc) were placed in nylonbags and buried at 10 cm depth under grasscover in a moraine soil at Ås, Akershus county, in November 1998. Nylon bags were dugged out in July 2000 and May 2001, and the oospore viability was tested using tetrazolium bromide as a vital stain (Sutherland and Cohen 1983).

Results

Oospore formation

Oospores were found in 5 of 6 fields in 2000 and approx. 10 % of the leaves had oospores present. In 2001 all three fields examined had oospores, and they were found in approx. 85 % of the leaves. Oospores were registered both in different cultivars and in sprayed and unsprayed fields.

Oospore survival

Oospores of two crossings were evaluated after 20 months in soil and the viability, measured as pink and blue oospores, was 32.4 and 39 % respectively. The crossing with highest viability was examined after another winter in soil (31 months after burial) and about 40 % of the oospores were still viable.

Discussion

Cohen *et al.* (1997) found a higher level of oospore production at low (8-11 °C) than at high (18-23 °C) temperatures, and that long periods of moisture was important for oospore production. In Sweden some cultivars produced more oospores in a leaf disc assay at 10 °C than at 20 °C, but for other cultivars the results were the opposite. Under field conditions oospores were formed abundantly in several cultivars in a naturally infected field. At 20 August some cultivars had oospores in 100 % of the examined leaflets (Strömberg *et al.*, 2001). We observed oospores in about 85 % of the examined leaflets in 2001. However these leaflets had been incubated before examination.

Turkensteen *et al.* (2000) reported that oospores were readily detected in leaflets of field crops and volunteer crops of potato, but also in blight affected tomato leaflets and fruits in the Netherlands. Studies of survival of oospores showed that sandy and clay soil remained infectious for 48 and 30 months respectively, when oospore contaminated soils were flooded. In our experiment the viability of oospores did not decrease from 20 to 31 months in soil. Oospores buried for longer time has not been tested at our conditions.

Germination of *P. infestans* oospores seems to be low (Strömberg *et al.*, 2001). It is hard to tell how important oospores are in the soil as an inoculum-source, compared to inoculum from tubers. However they might act as primary inoculum under certain conditions (Andersson *et al.*, 1998). Germination and infections from oospores might however occur later in the growing season. It is evident that the genetic variability in the Norwegian and Finnish populations of *P. infestans* are high (Brurberg *et al.*, 1999). Therefore oospores seems to be important elements in the “strategy of diversity” of the late blight pathogen.

Effective control of the pathogen should be carried out to reduce the risk of oospore formation in potato leaves. Crop rotation is important to reduce the risk of soil borne inoculum. How many potato free years needed to “clean” the soil from oospores are still not clear, but both data from the Netherlands and Norway indicate that at least three years are needed at our conditions.

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Efficacy of the NegFry decision support system in the control of potato late blight in Ireland

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Additional key words: DSS, *Phytophthora infestans*, fluazinam, mancozeb

Summary

Field experiments between 1996 and 2000 compared the efficacy of fungicide programmes applied in accordance with the NegFry and Met Éireann (MÉ) decision support systems (DSS) for the control of late blight with 7- and 10-day routine fungicide programmes. The MÉ DSS reduced fungicide use by 68% and 54% respectively while NegFry reduced fungicide use by 49% and 27% compared with the 7- and 10-day programmes. The NegFry DSS was similar to the 10-day routine programme in terms of late blight control, quality and marketable yield. A similar result was found when the NegFry DSS was compared with a 7-day routine mancozeb programme (included for two seasons only). Within the NegFry DSS the use of fluazinam resulted in improved yield, foliage blight and tuber blight control compared with mancozeb, but this benefit was significant for tuber blight only. The MÉ DSS resulted in inferior disease control, yield and quality.

Introduction

Late blight, caused by the oomycete fungus *Phytophthora infestans* (Mont.) de Bary, is the most destructive disease affecting the potato worldwide. Annual losses in Ireland have been estimated at £8 m per annum (Copeland *et al.*, 1993). Routine disease control requires regular use of fungicides at high application rates and short intervals throughout the growing season.

However, consumers demand a continuous improvement in the health status of our foods by reducing the use of pesticides together with a less contaminated environment. This may be achieved by the use of decision support systems.

Recent developments in information technology have made it possible to log weather data continuously for specific locations and to use this information in computer-based decision support systems (DSS) such as NegFry to predict the date of disease outbreak and to determine the most suitable intervals between sprays. The first part of NegFry is based on the negative prognosis (Ullrich & Schrödter, 1966) which calculates the epidemic-free period for *Phytophthora infestans* and then recommends the first spray at the end of this period. The second part of the model is based on a method developed by Fry *et al.* (1983) and calculates subsequent spraying intervals based on blight units. The blight units are calculated on the length of any humid spell, the air temperature during the humid spell and the cultivar susceptibility to late blight. The NegFry model requires the following as inputs for the calculations: air temperature, relative humidity, rainfall, cultivar susceptibility and crop emergence date.

The Met Éireann (MÉ) blight warning service follows the Irish Rules. It uses data supplied by its automatic weather stations to calculate the severity of blight spells and uses synoptic weather charts to predict spells of blight weather and then issue a spray warning (Keane, 1986).

From 1996-2000 the NegFry DSS was compared with both the Irish Rules and with routine fungicide application programmes at the Crops Research Centre, at Oak Park, Carlow. The overall objective was to achieve acceptable disease control with minimum fungicide use.

Materials and methods

Fungicide treatments.

Routine fungicide applications were compared with fungicide applications as dictated by the Met Éireann (MÉ) blight warnings and the NegFry decision support system. The routine programmes consisted of mancozeb (Dithane DF, Rohm & Haas) at 10-day intervals (1996-2000) together with mancozeb at 7-day intervals (1999-2000) and fluazinam (Shirlan, Zeneca) at 10-day intervals (1998-2000). Mancozeb and fluazinam fungicides were used in conjunction with NegFry in all years while mancozeb alone was used in conjunction with MÉ. In all

programmes, mancozeb and fluazinam were used at their recommended rates of 1.68 kg a.i. and 0.20 kg a.i./ha respectively.

Weather data recording.

An in-crop weather station (Hardi Metpole) was used to record humidity, temperature and rainfall. The data was recorded every 10 minutes and the average of 3 readings was transmitted by radio signal to a receiver and transferred to a computer where it was stored for final analysis using the NegFry decision support software.

Field experiments.

Trials were conducted at The Crops Research Centre, Carlow, Ireland, using certified seed of the maincrop potato cultivar 'Rooster' which has a rating of 4 for foliage blight resistance and 6 for tuber blight resistance (Dowley & Kehoe, 2000). The preceding crop was winter barley and the soil was a free draining medium loam with low clay and organic matter content and a pH of 6.6 (+/- 0.2). Paraquat (600 g a.i./ha) and simazine (600 g a.i./ha) were applied as pre-emergence herbicides.

The design was a randomised complete block (RCB) with 4 replications per treatment. The trials were planted into pre-formed ridges 81.28 cm wide and the distance between tuber centres was 31.75 cm. Each plot was made up of 6 drills 7.69 m long. The total plot size was 37.5 m², from which 25 m² were harvested across the centre 4 drills. A 3 m divider strip was left between each plot to facilitate mechanical harvesting. An unsprayed inoculator plot was planted at each end of the trial. Artificial inoculum of *P. infestans* (5,000 sporangia/ml) was applied to the under-surface of 5 leaflets/plant in the inoculator strips at either end of the trial area if no disease was apparent within 10 days after disease onset was predicted by the NegFry DSS.

Spraying was carried out with an ATV drawn Hardi conventional sprayer mounted on a Logic chassis with an independent power source. Machinery access was by unplanted spray paths to prevent crop damage. Spraying commenced when the plants were beginning to meet along the drill or as determined by the two decision support systems. The spray volume was 250 l/ha and the spray pressure was 3 bars using Hardi flat spray nozzle number 4110-20, delivering 1.59 l/min at 7.6 km/h. During the growing season, disease levels were

assessed at weekly intervals up to desiccation using the B.M.S. foliage blight assessment key (Cox & Large, 1960).

The experiments were desiccated with full rate diquat in September and harvesting took place in November. The produce was stored at a temperature above 10°C for at least two weeks to allow tuber blight symptoms to develop. The tubers were then graded into the following grades:- < 45 mm, 45-65 mm, 65-85 mm, > 85 mm, blighted tubers and tubers with other diseases. After grading the tubers were weighed and the yield expressed in tonnes/ha. A 2-kg sample was taken from the 65-85 mm grade in each plot and assessed for dry matter content.

Results and discussion

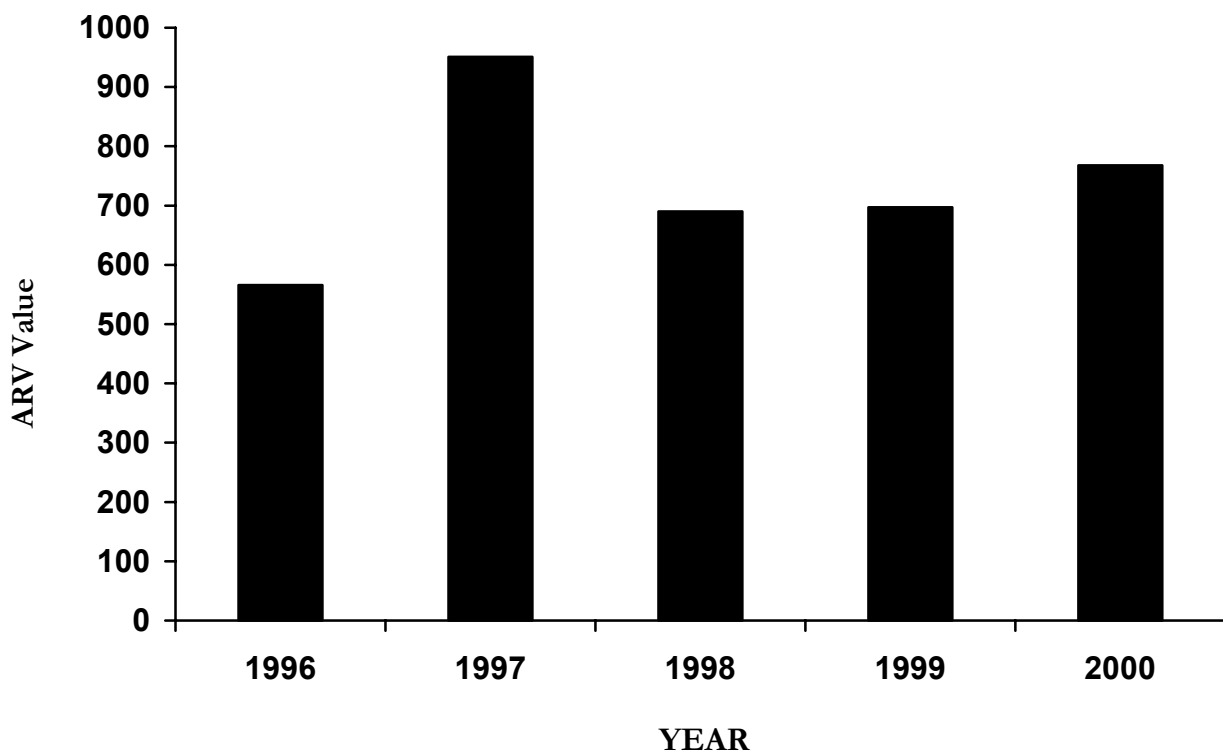


Figure 1. Variation in the accumulated risk values (ARV) 1996-2000

Variation in disease severity between years.

The accumulated risk value as measured by the NegFry decision support system is a good measure of the conditions suitable for the spread of foliage blight during the course of each season. It also provides a consistent and scientific comparison between years. The

accumulated risk values for the years 1996 to 2000 are given in Fig. 1. The highest accumulated risk value was recorded for 1997 with the second highest recorded for the year 2000. In both of these years conditions suitable for the spread of blight were above average while the remaining years would be regarded as average. This information is consistent with the levels of foliage blight at the end of each season (Table 3) and the area under the disease progress curve (Table 4).

Number of fungicide applications.

Routine fungicide application started in mid-June and continued at 7- or 10-day intervals up to the date of desiccation. The number of applications were dictated by the date of desiccation. The number of fungicide applications for the decision support systems was determined by either NegFry or M \acute{E} . The number of fungicide applications for each programme in each of the five years is given in Table 1.

Table 1. The number of fungicide applications following different control programmes 1996-2000.

Treatment	1996	1997	1998	1999	2000	Mean
7-day routine programme	13	13	14	14	14	13.6
10-day routine programme	9	9	10	10	10	9.6
NegFry programme	4	7	8	8	8	7.0
M \acute{E} programme	3	5	4	5	5	4.4

Over the five-year period of the experiment there were averages of 9.6 and 13.6 fungicide applications in conjunction with the 10- and 7-day routine programmes. Over the same period the NegFry and M \acute{E} systems recommended averages of 7 and 4.4 applications respectively. When compared with the 10-day routine programme, the NegFry decision support system reduced the use of fungicide by 27% but when compared with the 7-day routine programme the saving was 49%. The greatest reduction in fungicide use was recorded following the M \acute{E} programme where there were average savings of 54 and 68% respectively. While the two decision support systems represent a considerable saving in fungicide use, they would need to be combined with an acceptable level of disease control. These savings may be improved by using more up-to-date epidemiological parameters in the decision support systems.

Effect on foliage blight.

The effects of the fungicide programmes on the incidence of foliage blight were compared using the delay in disease onset as compared with the untreated control, the level of foliage blight at the end of the season and the area under the disease progress curve (AUDPC).

The delay in disease onset for all sprayed treatments is given in Table 2. The shortest delay in disease onset was consistently recorded following the MÉ treatment and this was significantly shorter than the routine mancozeb treatment at 10-day intervals in 1997 and 1998. When the NegFry programmes were compared with the 10-day routine programme there was no significant difference in the delay in disease onset irrespective of the fungicide used. In general the best NegFry results were achieved with fluazinam and this was significantly better than the mancozeb 10-day control treatment in 1996.

The levels of foliage blight at the end of the growing season are given in Table 3. In all 5 years, fungicide treatment significantly reduced the incidence of foliage blight at the end of the season compared with the untreated control. In all years the mancozeb 10-day routine treatment resulted in better disease control compared with mancozeb applied as per the MÉ warnings. These differences were significant for 1997, 1999 and 2000 and confirm that the MÉ programme resulted in inadequate foliage protection, except in 1996 when disease pressure was least severe.

Table 2. Effect of different fungicide programmes on the delay in disease onset in days (1996-2000).

	1996	1997	1998	1999	2000
Mancozeb DF at 10 days	12.75	24.50	59.75	14.00	21.50
Mancozeb DF at 7 days	-	-	-	24.75	30.50
Fluazinam at 10 days	-	-	44.25	23.00	28.50
Mancozeb DF MÉ	15.50	3.50	26.25	14.00	18.00
Mancozeb DF NegFry	17.00	15.75	44.75	17.50	21.50
Fluazinam NegFry	25.50	12.25	59.75	17.75	30.25
S.E.	3.06	4.81	6.65	5.24	3.71
LSD (5%)	9.76	15.34	20.51	15.73	11.16

When comparing the NegFry programmes with the mancozeb 10-day routine programme there was no significant difference between the programmes in any year, irrespective of the fungicide used. This confirms that over the 5 years of the experiment both NegFry programmes resulted in similar foliage blight control to the mancozeb 10-day routine

programme. Within the NegFry programmes, the use of fluazinam consistently reduced the level of foliage blight compared with mancozeb but in no year was this difference significant. These results are better than those achieved in Scandinavia in 1994 when the NegFry DSS was equal to or better than routine fungicide application in 6 of 14 trial sites (Hansen *et al.*, 1995). However, it must be realised that there have been some beneficial modifications to the NegFry DSS since 1994.

Table 3. Effect of different fungicide programmes on the % foliage blight at the final assessment date 1996-2000

Treatments	1996	1997	1998	1999	2000
Unsprayed	96.25	100	68.75	93.75	100
Mancozeb DF at 10 days	14.00	43.75	0	1.53	1.78
Mancozeb DF at 7 days	-	-	-	0.30	0.55
Fluazinam at 10 days	-	-	0.025	0.05	1.55
Mancozeb DF M ^É	15.00	93.75	14.25	27.50	56.25
Mancozeb DF NegFry	3.00	62.50	0.025	2.55	8.00
Fluazinam NegFry	0.78	62.50	0	0.30	0.33
S.E.	3.98	6.14	7.94	6.48	5.02
LSD (5%)	12.23	18.86	23.83	19.17	14.87
LSD (5%) Excl. untreated control	14.20	22.04	14.63	18.06	16.27

The AUDPC measures the development of disease over the whole season and is a more accurate assessment of differences between treatments over the entire course of the epidemic. All fungicide treatments significantly reduced the AUDPC compared with the untreated control (Table 4). In all years, the mancozeb 10-day routine application resulted in lower AUDPC values compared with mancozeb applied according to the M^É warnings. These differences were significant in all years except 1996, the year with the lowest accumulated risk value (Table 4). This again confirms that the application of fungicides as per the M^É warnings did not provide adequate control of late blight during the course of this experiment.

When the NegFry programmes are compared with the mancozeb 10-day routine programme it can be seen that there was no significant difference between the programmes except in 2000. In that year the mancozeb applied as per NegFry resulted in a significantly higher AUDPC. Within the NegFry programmes, the use of fluazinam consistently reduced the AUDPC compared with mancozeb and in 2000 this difference was significant (Table 4). This

confirms that in most years of the experiment the NegFry/fluazinam programme gave similar or better foliage blight control when compared to the mancozeb 10-day routine programme. This is consistent with the results from earlier trials at Oak Park which confirmed that fluazinam gave better blight control than mancozeb (Dowley & O'Sullivan, 1995). With significantly reduced fungicide use it would be important to use the most effective fungicide and this could be particularly important in relation to tuber blight control.

Table 4. Effect of different fungicide programmes on the area under the disease progress curve (AUDPC) 1996-2000

Treatments	1996	1997	1998	1999	2000
Unsprayed	1782	2981	1522	1114	3,100
Mancozeb DF at 10 days	215	364	0	18.5	18
Mancozeb DF at 7 days	-	-	-	1.6	10
Fluazinam at 10 days	-	-	0.6	0.7	15
Mancozeb DF MÉ	198	1505	18.72	171.7	896
Mancozeb DF NegFry	33	778	1.48	13.1	84
Fluazinam NegFry	11	596	0.00	5.1	11
S.E.	131	164	316	5	83
LSD (5%)	401	503	949	15	247
LSD (5%) Excl. untreated control	242	498	13.97	16	241

In the two years where a mancozeb 7-day programme was used it reduced the AUDPC when compared with the 10-day routine programme and this difference was significant in 1999. However, in neither year did it significantly differ from the two NegFry treatments.

Earlier experiments at Oak Park confirmed the superior performance of phenylamide fungicides for late blight control (Dowley & O'Sullivan, 1994). During the period of these trials the systemic fungicide Ridomil (mancozeb + metalaxyl) was also used according to the NegFry decision support system. However, results with this fungicide were not encouraging (Dowley, unpublished). Earlier work at Oak Park confirmed that the best results with systemic fungicides are obtained when they were applied early in the season (Dowley, 1994). Since the main effect of NegFry was to delay the application of the first spray, this could explain why systemic fungicides were not effective when used with this decision support system.

Effect on yield.

The total and marketable yields are given in Tables 5 and 6. The yield varied considerably between years with the highest yields recorded in 1996 and the lowest in 1999. In general yields tended to be highest in the years that were most suitable for disease spread. All fungicide treatments resulted in significantly higher total and marketable yields compared with the untreated control in all years except 1998 when only some of the differences were significant. In both 1997 and 2000, the two most severe blight years, the marketable yield from the M^É programme was significantly lower than the 10-day mancozeb routine programme. This is consistent with the poor foliage blight control achieved by this programme.

Table 5. Effect of different fungicide programmes on total yield (t/ha) 1996-2000

Treatments	1996	1997	1998	1999	2000
Unsprayed	45.86	33.91	32.38	15.66	35.26
Mancozeb DF at 10 days	54.93	52.56	40.46	22.82	52.92
Mancozeb DF at 7 days	-	-	-	20.14	60.00
Fluazinam 0.4 l at 10 days	-	-	40.44	20.72	55.12
Mancozeb DF M ^É	58.58	44.27	44.98	19.49	45.48
Mancozeb DF NegFry	56.43	46.08	34.33	20.26	57.20
Fluazinam 0.4 l NegFry	56.29	49.42	44.27	21.24	54.10
S.E.	1.98	2.09	3.23	1.44	2.87
LSD (5%)	5.80	6.42	9.71	4.27	6.80
LSD (5%) Excl. untreated control	6.11	5.43	8.94	4.01	7.40

When the 10-day routine treatment with mancozeb is compared with the two NegFry treatments there was no significant difference in the marketable yield of the three treatments in any year. In 1999 and 2000 a similar result was found when the NegFry treatments were compared with 7-day programmes of either mancozeb or fluazinam. This would confirm that the use of the NegFry DSS had no detrimental effect on marketable yield. Within the NegFry programmes there appeared to be a consistent benefit from using fluazinam, but this benefit was not significant.

Table 6. Effect of different fungicide programmes on marketable yield (t/ha) 1996-2000

Treatments	1996	1997	1998	1999	2000
Unsprayed	39.16	29.70	24.53	13.96	28.84
Mancozeb DF at 10 days	47.78	47.91	34.24	20.83	48.68
Mancozeb DF at 7 days	-	-	-	18.09	56.48
Fluazinam 0.4 l at 10 days	-	-	34.64	18.64	51.12
Mancozeb DF MÉ	51.86	39.54	38.39	17.49	40.24
Mancozeb DF NegFry	49.02	41.94	27.13	18.44	53.32
Fluazinam 0.4 l NegFry	49.64	44.77	37.95	19.46	50.68
S.E.	1.92	2.06	3.93	1.35	2.36
LSD (5%)	5.91	6.32	11.80	3.98	6.97
LSD (5%) Excl. untreated control	6.15	5.55	11.19	3.75	7.60

Effect on tuber blight.

The incidence of tuber blight following the different fungicide programmes is given in Table 7. Despite the existence of good conditions for tuber infection in some years, the overall level of disease during the course of this experiment was low. There was no significant difference in any year between the NegFry programmes and the 10-day mancozeb routine control. This would confirm that the NegFry programmes resulted in equivalent tuber blight control to the 10-day routine application of mancozeb. However, when the two NegFry programmes are compared, it is clear that the fluazinam programme gave consistently better control of tuber blight than the mancozeb programme. These differences were significant in 1996 and again in 2000. It must be noted that the variety Rooster, which was used in these trials, has good tuber blight resistance. The control programme described might not be as effective in controlling tuber blight in varieties with lower tuber blight resistance.

Effect on Quality.

In 1998 and again 2000 the untreated control resulted in tubers with significantly lower dry-matter than the sprayed treatments. Within the sprayed treatments the differences in dry-matter were small with no significant differences between treatments. This would confirm that use of the NegFry DSS had no detrimental effect on the dry-matter content of the tubers.

Table 7. Effect of different fungicide programmes on yield of blighted tubers (t/ha) 1996-2000

Treatments	1996	1997	1998	1999	2000
Unsprayed	0.01	0.19	0.10	0.20	0.04
Mancozeb DF at 10 days	0.05	0.29	0.04	0.07	0.04
Mancozeb DF at 7 days	-	-	-	0.10	0.00
Fluazinam at 10 days	-	-	0.00	0.01	0.12
Mancozeb DF MÉ	0.02	0.34	0.01	0.25	0.08
Mancozeb DF NegFry	0.18	0.36	0.02	0.06	0.16
Fluazinam NegFry	0.00	0.22	0.02	0.03	0.00
S.E.	0.04	0.19	0.02	0.04	0.05
LSD (5%)	0.13	0.29	0.07	0.13	0.15
LSD (5%) Excl. untreated control	0.15	0.34	0.05	0.12	0.16

Farm validation.

During 1999 and 2000 validation tests were conducted with the cultivar Rooster at farm level using the NegFry/fluazinam programme compared with the growers routine programme. Over the two-year period validation tests were carried out on 5 farms in different geographical areas. The results support the conclusions derived from the field experiments at Oak Park Research Centre.

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Don't call us, we call you

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Summary

In The Netherlands, the future of potato growing is threatened by the intensive usage of fungicides. Therefore the farmers organisation LTO started the “Masterplan Phytophthora” The mission of the Masterplan is to co-ordinate all actions aimed at effectively controlling Late Blight. Together with Dacom PlantService a project was designed to contact each of the 14702 registered potato growers by phone each time a Late Blight infection event was to take place in their region. The objectives are to alert farmers and to make them consider actions to protect the potato crop. The conclusion after the first operational season is that the objectives were achieved.

Keywords: Late Blight, infection event, PLANT-Plus, communication

Introduction

In the Netherlands, some 187000 HA of potatoes are grown each year. Due to weather conditions and the more aggressive strains of *Phytophthora infestans*, more and more fungicides are used to control this disease. Environmental restrictions and the loss of many fungicides from the authorized list threaten the future of Dutch potato growing. Therefore the farmers organisation LTO started the “Masterplan Phytophthora” The mission of the Masterplan is to co-ordinate all actions by commercial companies, research and information services and by the government aimed at controlling the Late Blight problem. The Masterplan is payed for by farmers per hectare potatoes and also sponsored by an insurance company.

Dacom PlantService is a company that started in 1987 to develop systems for the plant production. In 1994 the PLANT-Plus system was developed as an integrated system for crop recordings, weather information and DSS modules. In The Netherlands, Dacom operates a network of over 100 weather stations covering most potato growing regions. All systems were developed within the company. The PLANT-Plus potato models are now successfully used in most European countries and also in Egypt, Poland, Japan, South Africa and Canada.

Already Dacom carried out a number of projects with The Masterplan. These projects involved the mapping of observed disease outbreaks and the accurate determination of outbreaks in the beginning of the season.

During a brain storming session to develop new actions to prevent Late Blight outbreaks especially in the beginning of the season, the idea occurred not to wait on farmers actions but to be pro-active and call all the potato growers as needed. At first it looked like an impossible task to do but for Dacom a challenging project to tackle. In May 2001, a contact between the Masterplan and Dacom was signed.

Gathering data

In order to gather all the information as needed for the calculation of a infection event, different types of information have to be gathered about the farmers, the weather and about infected area's . As the basic system, the PLANT-Plus infrastructure for data management and communication was used. All extra systems are designed and built by Dacom staff.

Farmers

On the basis of a central registration all potato growers contribute to the Masterplan. This database was used to fill the Dacom database. Because of privacy reasons, only the postal code and the telephone number was supplied. From the postal code, the first four digits relate to the location of the address. In total 14702 telephone numbers were supplied. Because of different reasons such as having a farm manager, another 517 numbers were added during the beginning of the season bringing the total to 15219 numbers The average distance of a farmer to a weather station is 7,2 KM and 76% of the growers is within 10 KM of a weather station. For the distribution of the farmers over NL, see fig. 1, the small dots of the farmers and the big dots of the weather stations.

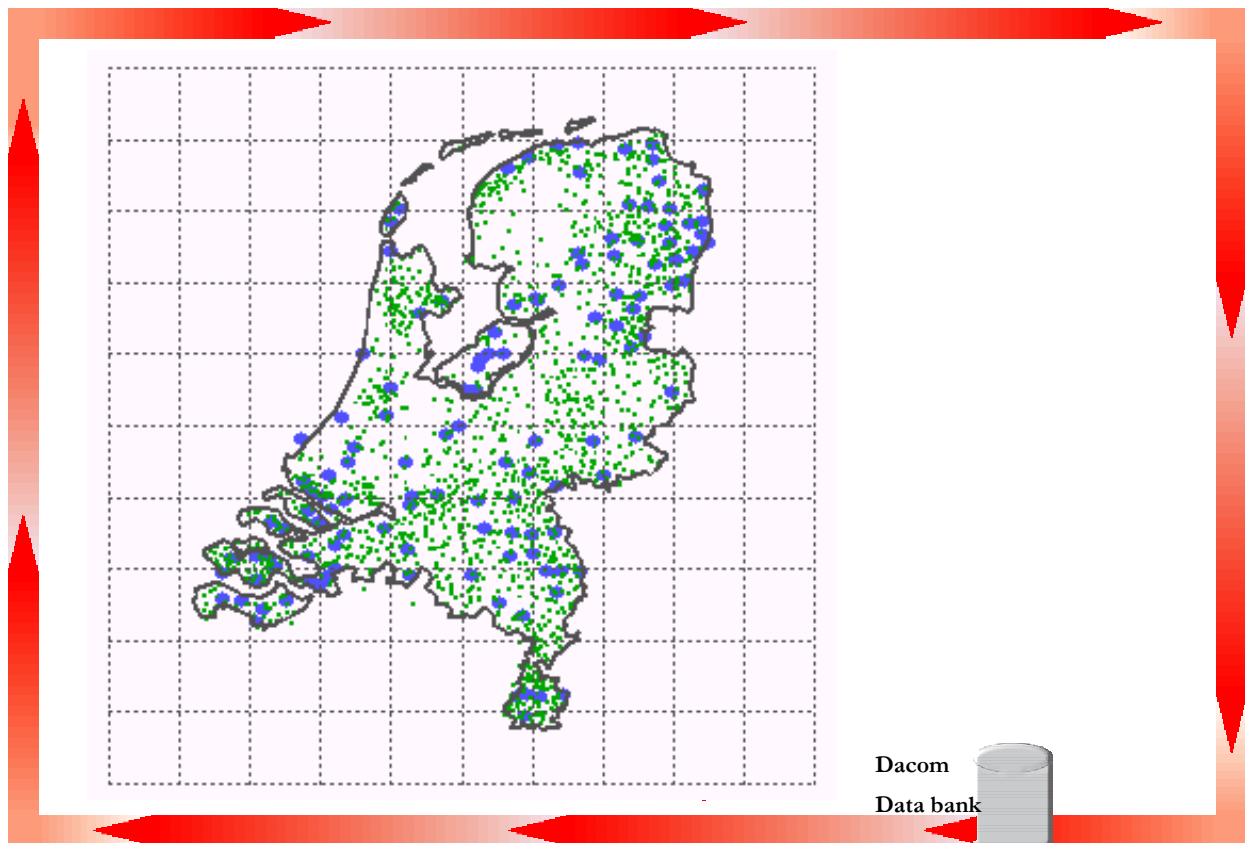


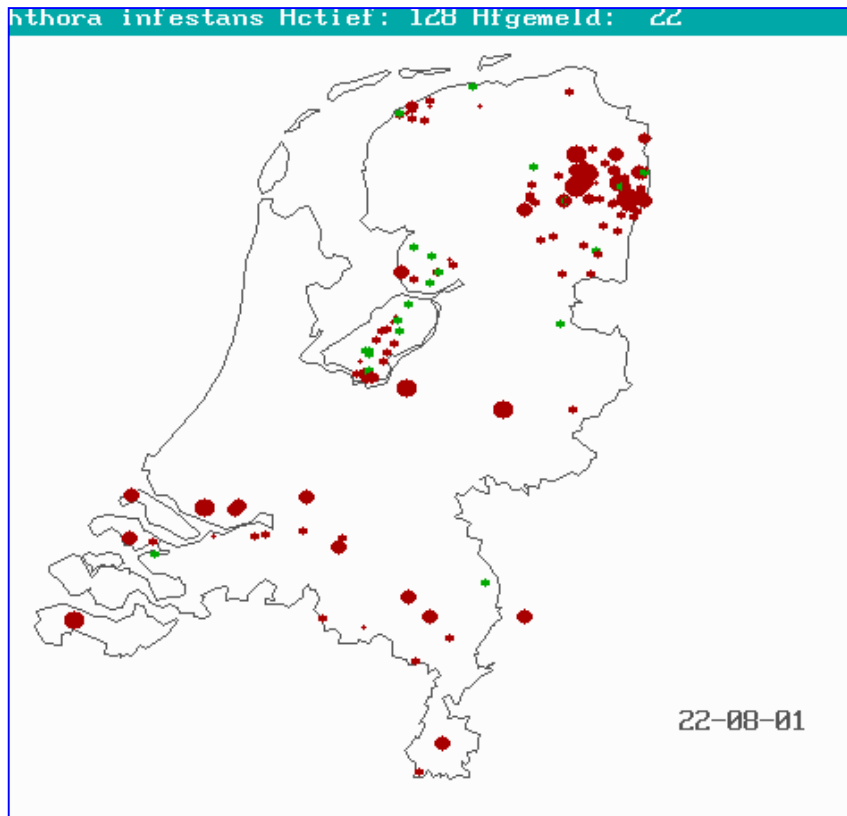
Figure. 1.: location of farmers and weather stations

Weather data

In the Netherlands, Dacom manages a network of weather stations that covers most of the potato growing area's. In some regions, agreements with other weather station owners were made to purchase this data. All the data is stored in the Dacom databank. For the weather forecast, Dacom purchased a 5 day forecast for all regions in the Netherlands from the Dutch weather office HWS. Based on the geographical information the weather stations and the weather forecast regions are matched with the postal code of the farmers.

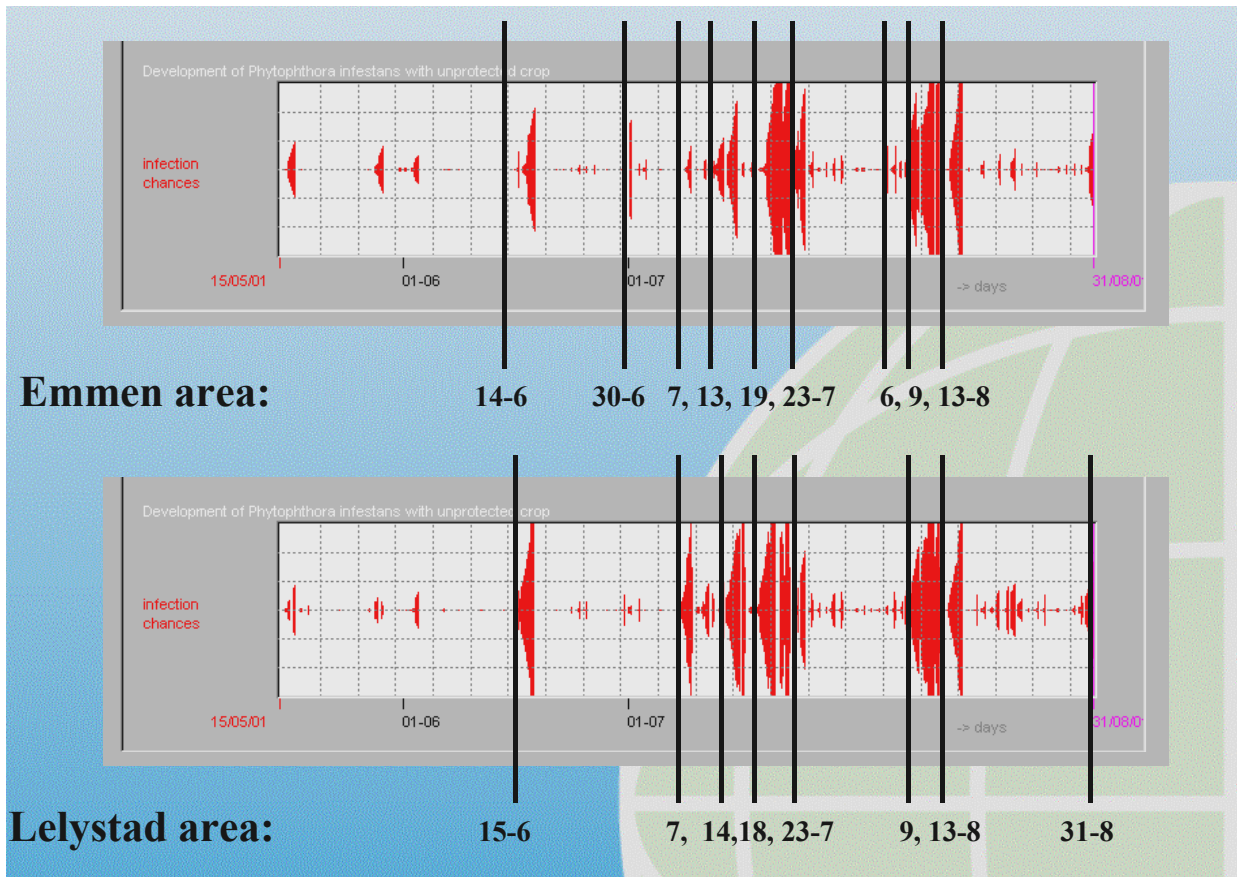
Infected fields

In the Netherlands, Dacom has been active for many years to organise the central registration of Late Blight infected spots. In principle, all people involved in potato growing can report an infection. This infection is then recorded by date, location (co-ordinates) and the severity of infection. In this way, a good picture of the presence of spore in a region can be calculated. Based on internal judgement, a basic safety figure will be recorded at a weather station region. In the figure, the situation at the end of August is shown. The real problems started in September because of a very intensive rainy period.



Infection event

A infection event is a successive series of events that result in the possible infection of an unprotected crop. Within the PLANT-Plus model, these successive events are: spore formation, spore release and spore dispersal, germination and penetration of a spore in a leaf. For the calculation of the penetration time of the spores, the susceptibility of the variety Bintje is used. The combination of the number of spores present and the duration of the penetration period defines if the threshold of a infection event is reached. Because Dacom does not know the grower or his crop, a standard, fixed value for unprotected leaf area is used. The graph below shows for the Weather stations Emmen and Lelystad the calculated infection events (black triangle area's) and the dates that the call went out (vertical lines with dates underneath).



Decision making



Calculation of “infection events”

The calculation of a infection event takes place every time a new set of weather data is received which happens between every hour to a few times a day. This interval depends on the type of weather station. The results are displayed on a monitor as a coloured dot per weather station on the Dutch map. Red coloured weather station mean that an infection event has been calculated for that particular region.

Observation of the levels of a possible infection event.

On the monitor, the results of the calculation of 6 days is presented: yesterday, today and 4 days of forecast. If red coloured weather stations show up on a given day, tables with exact data are examined by the responsible person.

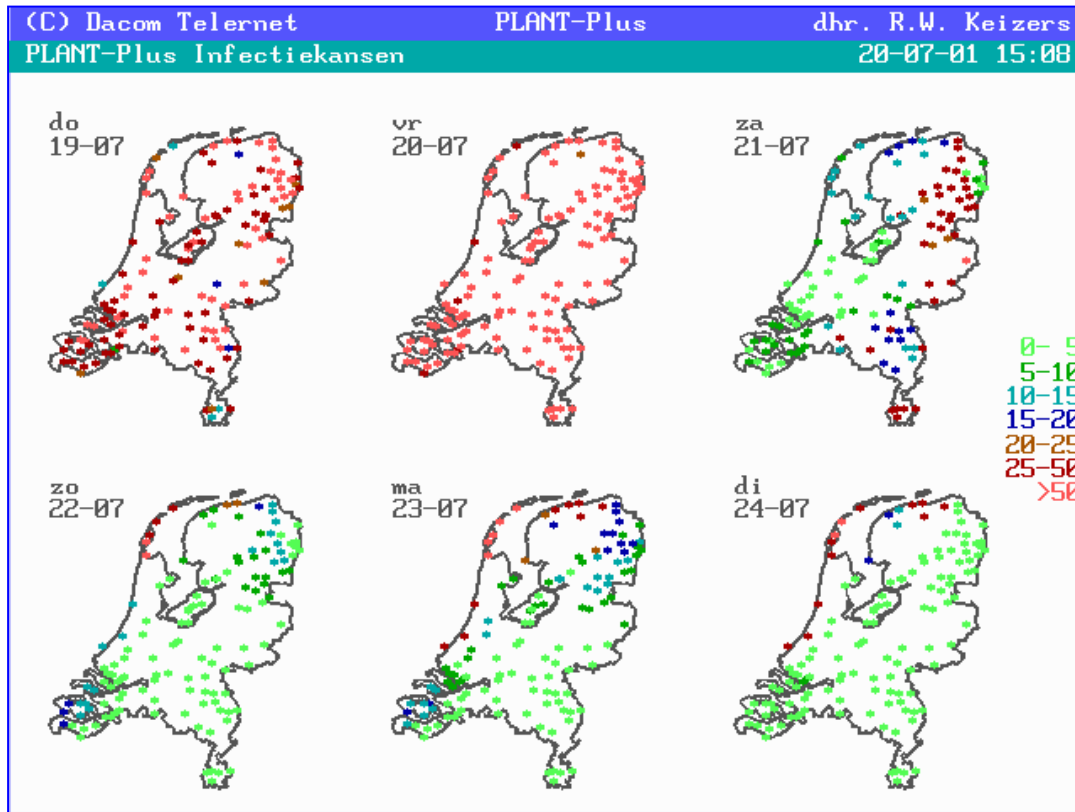
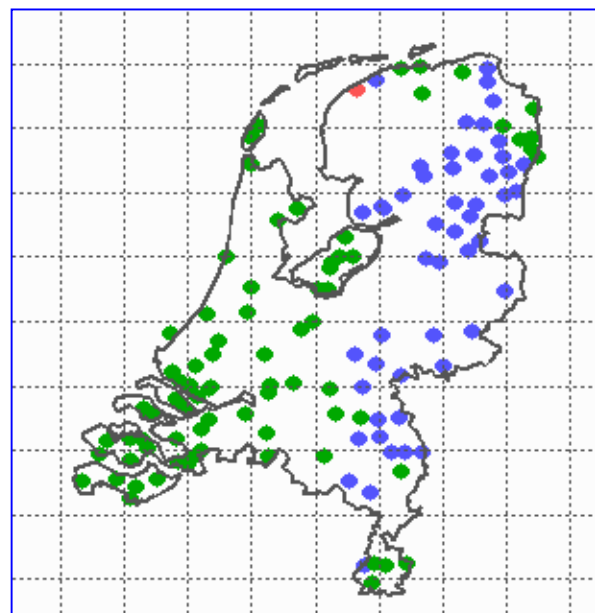


Figure 2. screenshot of the Late Blight situation, top left is “yesterday” bottom right is 4 days ahead

Manual decision of a warning calls.

Based on the exact information, the decision can be made to phone the numbers connected to the specific weather station. The record in the database will be marked for a “preventive” or a “curative” call. If the weather forecast shows a infection event coming up, a manual decision will be made if a “preventive” call will be placed. The decision will depend on the level of the



East part low level of occurrence.

infection event in combination with the probability of the forecast. Also special days, like the Sunday, are taken into account for the decision of the exact moment of the call. Sometimes, a forecasted period of bad spraying weather will trigger an earlier call. In these cases, a number of Dacom experts are involved in the decision making. Sometimes deliberation with the Masterplan takes place. If a infection event was missed by the weather forecast but recorded by the weather station, a “curative” call will take place. This happened one time during this season.

Automatic dialling.

After the region have been marked with the type of call, the “start calling” button is activated. The calling process is fully automatic. For this process, some 40 machines are used. In practice this will do for calling all growers within the day. In most cases, infection events would start in one part of the Netherlands and move across to other parts in one or two days so not all growers had to be called at the same time. Only on July 24, all growers were called within one day. In the graph on the left the number of calls on the specific day.

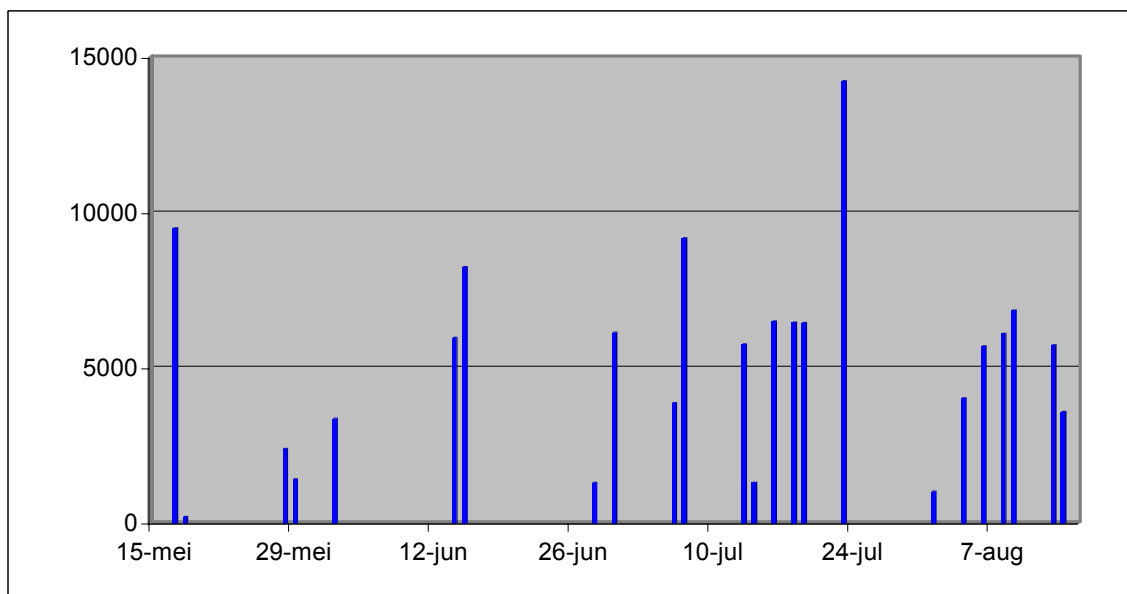


Figure 4. Number of calls on specific days from May till August in 2001.

Analysing score

All actions of the automated process and all the reactions of the farmers are recorded in a database. Every week, a complete review of this information was send to the Masterplan.

The Call

After a number is dialled, the system will let it ring for 12 times. If the phone is not answered, this number will be placed at the end of the calling queue. After 9 trials, the call will not be placed anymore and recorded as an “unable to execute” call.

After the telephone is picked up, the message will start after something is spoken. For the message, a male voice has been digitalized. The message is:

“Dear potato grower. You are listening to an automated Phytophthora warning of the Masterplan Phytophthora. In your region, the coming 24 hours, the weather conditions are favourable for Phytophthora. There is a big chance that the disease will infect an unprotected crop. We urge you to take this into account in your disease control actions in your potatoes. If you want more information about the disease pressure for the coming occurrence, you can consult your advisory system or your crop advisor. If after three days again a big change of an infection is calculated, you will receive another call of this warning service.

In order to listen to this message again, press the 1. If you rather receive this message next time by SMS, press the 2. If you rather receive this message next time by FAX, press the 3. If you don't want to receive these warning calls anymore, press the 9.”

(Action of the called person)

1 → see above

2 → “enter the mobile phone number and close the bracket.”

3 → “enter the 10-digit fax number and close the bracket.”

9 → “Are you sure you don't want to receive this message anymore? Push the 1 if you are sure, press 2 to listen again to the message.

Thank you for your interest. The Masterplan Phytophthora wishes you a successful and disease free potato crop. We cut the connection now.”

The fax message is in general the same the the above message, with the extra reference to the ALPHI telephone number. The SMS message is kept very short: “Message Masterplan Phytophthora: Weather coming 24 hours favourable for infection. Make allowance for this. More info? Call for example ALPHI 0800-8585000”

Results

The balance in the end shows that 120.485 calls were made during the first part of the season. The project was stopped at Oct 1st. Apart from the budget, it was decided that the farmers were well aware of the Late Blight situation at that moment. In total 120485 messages were delivered. The table shows the type of message.

<u>METHOD</u>	<u>NUMBERS</u>
Telephone	98.524
SMS messages	6.116
Fax messages	15.845
TOTALS	120.485

Discussion

Controlling Phytophthora in potatoes is as in any country, an exciting job in the Netherlands. The consequences of a mistake are far-reaching, specific in ware potatoes. Under those conditions, getting farmers away from some kind of calendar spraying to precision spraying just before or after a infection event is not easy. Introducing a system that makes uninvited calls to unknown farmers needs careful planning and introduction. Else the results could be the opposite of the proposed objective. In this case, the introduction was flanked by publications in farmer magazines and an on-going communication with farmer representatives, specifically in the first weeks of the project. After the first three calls, the joke at farmer meetings was that you didn't need to get a call anymore, you could judge a infection event coming by the number of farmers in the field spraying their potato crop after a received call. A system like this is a unique way of alerting ALL potato growers even the in-active ones. Also the system operates in a very open playing field. A number of growers is beforehand negative about any action taken by anybody. They could cloud the impression the majority of the growers have about this system. The independent inquiry that was carried out brought their numbers down to reality. The warning calls have to be executed very careful: one wrong call or a for growers inexplicable call will influence the intended results.

The advantage for the Netherlands to set up a warning system like this is the availability of an extensive weather station network and the possibility to use the basic infrastructure of PLANT-Plus. Based on this, the system could be developed in a very short time and could go

into operation without any noticeable start up problems. Also the cost of the system could be kept inside the budget.

Conclusion

The objectives were to alert farmers and to make them to consider action to protect their potato crop. Based on the reactions of the members of the Masterplan Phytophthora, the results of a questionnaire put to a number of farmers and general reactions in the potato growing field, the conclusion is that the objective were achieved.

NOTE: with this conclusion, the Masterplan Phytophthora decided to continue this service in 2002.

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Results of DSS trials in the Netherlands in 2001

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Summary

The EPPO guidelines for efficacy evaluation of plant protection products are not suitable for trials to validate Decision Support Systems to control potato late blight (PLB, *Phytophthora infestans*). The DSSs try to keep the level of incidence zero or very low. In these cases it is not possible to estimate a percentage of infected leaves. Differences between trial treatments can only be assessed by counting the number of infected leaflets. Untreated control plots should be desiccated before a high disease pressure on surrounding plots occurs.

Although the relationship between the dose of fluazinam at the end of the season and the incidence of tuber blight does not have to be a causality, it is quite obvious that leaf blight and dose of fluazinam both affect strongly the incidence of tuber blight.

Introduction

This article focuses more on 'materials and methods' for trials to validate DSSs than on results. In 2001 in the Netherlands three DSSs were compared. Simphyt was not included in the trials because of the poor results in 1999 and 2000. In the trials two Dutch systems Plant-Plus and Prophy were compared with NegFry. An essential difference between the Dutch systems and NegFry is the fact that we could not include the weather forecast in NegFry.

Materials and methods and discussion

Assessment of potato late blight

In the EPPO guidelines (OEPP/EPPO, 1997) the type of assessment is described as:

PPO-Special Report no.8 (2002), 103-110

“Plots are assessed for the extent of blight spots on the leaves. Each plot is scored as a whole for % disease severity, for example: by rating the plot in relation to the appropriate % disease category described below in terms of average number of spots per plant, number of leaflets attacked, the form of the plants and the general appearance of the plot, or else by reference to a pictorial key.

Percent disease:

- 0 = no infection
- 1 = up to 10 spots per plant or up to 1 leaflet in 10 attacked
- 5 = around 50 spots per plant or up to 1 leaflet in 10 attacked
- 10 = up to 4 leaflets in 10 affected; plants still retaining normal form
- 25 = nearly each leaflet with lesions but plants still retaining normal form; plot may look green though every plant is affected
- 50 = every plant affected and about half of leaf area destroyed by blight; plot looks green, flecked with brown.”

Time and frequency of assessment is described as:

“First assessment: when the first disease symptoms appear on leaves in the trial.
 Following assessments are made just before each further application and when necessary.
 Last assessment: just before harvest.”

Jörg and Kleinhenz (1999) propose to use these guidelines in DSS-validation trials. In DSS-validation trials the main aim is to have a very good control of potato late blight (PLB). The guidelines are made for efficacy evaluation of fungicides. So, the purpose the guidelines are written for, is quite different. The first problem that occurs is the fact that trial treatments according to DSSs can lead to up to three sprays a week within one experiment. In the worst scenario assessments have to be made three times a week. To our opinion assessments should be made once a week from the start of the epidemic of PLB.

Table 1. A plot is 14 ridges wide; the ridges 1, 2, 3, 12, 13 and 14 are gross; on the ridges 4 and 11 there are no potatoes seeded or desiccated after emergence; the ridges 5, 6, 9 and 10 are used for observations; the ridges 7 and 8 are used to assess yield and tuber blight.

Ridge:	1	2	3	4	5	6	7	8	9	10	11	12	13	14
	gross			no	observation		yield		observation		no	gross		

Another problem that occurs is that the infection rate is on a very low level. On a very low level it is absolutely not possible to have a good estimation of a percentage of infected leaves or leaflets with PLB by just looking at a plot. In our trials we counted the number of infected leaves on about 100 plants. For this observation we observed 2 rows at each side of a plot for a length of 8 m (Table 1).

Because a DSS tries to control a start of an epidemic, besides trying to prevent an infection, it is important to make a distinction in lesions of active PLB and lesions without active PLB on which in fact the disease is stopped. In our trials we tried to count only the lesions with active PLB. In this way usually an infected leaflet is counted only once. Only during very favourable circumstances double counts might occur. In our three trials we distinguished only once in one trial a period like that. For accumulation of the total number of infected leaflets we took this into account.

For calculation of the percentage of infected leaflets we divided the number of infected leaflets by 50.000, assuming that on one plant 500 leaflets were present at the period with infections. This calculation could be improved by weekly counting of the number of leaflets on a plant.

Desiccation and Untreated

In the EPPO guidelines (OEPP/EPPO, 1997) is written about desiccation: "... if % infection levels above 25 occur in a plot, further assessment serves no useful purpose and such plots may be treated with a quick-acting desiccant." For DSS-validation trials this level is far too high. Plots with such a high infection will result in a very high disease pressure on neighbouring plots or on the total trial. DSSs are not made to prevent an infection of PLB at such unnaturally high disease pressures. For our trials we decided to desiccate a plot when the percentage infected leaflets exceeded 0.3 to 1 %. Specially at the start of the season a low threshold is necessary. Into account have to be taken that under Dutch circumstances very often the infection risk is high. The decision to desiccate also depended on the level of infection for the whole trial. In the case that all plots are already infected, a higher threshold can be used.

Because we wanted untreated plots all season, we conducted untreated plots at four levels. Level 1 was untreated from the beginning of the season, whilst the other levels were treated according to the trial treatment ‘farm manager’. From about the moment untreated level 1 was desiccated level 2 was kept untreated, and so on.

Trial sites and experimental set-up

Trials were set up on three locations in the Netherlands. Trial site information is given in Table 2. All trials included beside untreated and ‘farm manager’ the DSSs Prophy, Plant-Plus and NegFry. For Prophy different modules are available since 2001. In our trials we used the standard module and the module ‘active ingredient’ (Prophy-ai). This module focuses on a low input of the quantity of active ingredient. In fact this means for the current available products in the Netherlands that this leads towards a single use of Shirlan (fluazinam). Sometimes earlier than standard an advice will be given to minimise the change of infection that causes the necessary use of e.g. cymoxanil.

Table 2. Trial site information of three locations in 2001.

Location	Lelystad	Vredepeel	Valthermond
Soil texture	Loamy soil	Sandy soil	Sandy soil
Plot size (gross)	10,0 * 10,5 m	10,0 * 7,5 m	12,0 * 9,0 m
Plot size (net)	8,0 * 4,5 m	8,0 * 4,5 m	10,0 * 4,5 m
Cultivar	Bintje	Asterix	Karakter
Susceptibility leaf	susceptible	medium susceptible	medium susceptible
Susceptibility tuber	susceptible	resistant	susceptible
Distance between ridges	75 cm	75 cm	75 cm
Planting space	32 cm	33 cm	32 cm
Planting date	May 10	April 20	May 1
Emerging date	May 30	May 21	May 17
Distance to weather station			
- Opticrop	in trial	20 km measured in strawberries	less than 2 km
- DACOM	less than 1 km	less than 1 km	less than 1 km

All trials were set up as randomised block treatments with four replications. The crops were grown and all sprayings were carried out according to good agricultural practice.

Weather data and irrigation

Distance to the automatic weather stations is mentioned in Table 2. Hourly values of air temperature, precipitation, relative humidity, wind direction and wind speed at 150 cm height measured by Dacom stations were used for Plant-Plus and NegFry. Hourly data as mentioned before and on temperature and relative humidity in the crop measured by Opticrop stations were used for Prophy. Because no measured weather data nearby the trial at Vredepeel were available for Prophy, data of a station measuring in strawberries were used. Prophy and Plant-Plus both used hourly successively 3-hourly regional weather forecasts for five consecutive days.

Irrigation was only applied in Vredepeel on June 15 with 25 mm and on June 24, July 2, 11 and 29 with 30 mm each time.

Results and discussion

Infection of leaves

Spraying schedules and infection percentages of leaves are shown in the figures 1, 2 and 3. Because the results of these trials are also discussed in the co-ordinated article in this proceedings no further explanation or discussion on these results is presented in this article, besides the relation between tuber blight and dose of fluazinam.

Tuber blight and dose of fluazinam

In the trial in Lelystad the percentage of tuber blight was very high. This gave the opportunity to look at the relation between the sprays with fluazinam and the infection rate. Correlations between tuber blight and dose of fluazinam in the period from the beginning of the season, August 1 or August 15 to August 29, 30, 31, September 5 or 6 were compared. Of these 15 periods the period between August 15 and September 6 gave the highest correlation. Apparently the start of the epidemic in the trial treatments on August 15 (first observed) plays an important role. Taking into account the period at the beginning of September, it includes a period with high precipitation. So, the present spores had the possibility to reach the tubers.

In figure 4 the relation between leaf blight for the above mentioned period and tuber blight is shown. Regression analysis showed us that accumulated leaf blight for this period and the trial treatment (corresponding with a dose of fluazinam) both had a similar and very strong significant effect on tuber blight (F-prob. < 0.001). Interaction did not occur.

At a low level of leaf blight a dose of 0.8 fluazinam corresponded with a lower level of tuber blight than the dose of 0.35. Plots with a dose of 0.6 fluazinam and more leaf blight than the 0.35 plots corresponded nevertheless with the same level of tuber blight. Plots with 0.4 fluazinam and a little less leaf blight corresponded with more tuber blight than the 0.6 plots. Nevertheless a causal connection between the dose of fluazinam and tuber blight incidence is not proven by the mentioned comparisons.

Conclusions

In DSSs-validation trials assessments should be made once a week.

At low levels of infection by potato late blight it is necessary to count the number of infected leaflets to have a good estimation of a plot.

Plots with a percentage infected leaflets of 0.3 to 1 % should be desiccated to prevent an unnaturally high disease pressure on other plots.

The use of a DSS reduced the number of sprays.

With the Prophy module 'active ingredient' the quantitative input of fungicides was reduced towards the other four trial treatments, but in two of three trials leaf blight incidence at the end of the season was higher than with Prophy-standard.

If late blight occurs in the crop and the variety is sensitive for tuber blight and there is a lot of rain than it might be very important to use enough fluazinam to prevent tuber blight.

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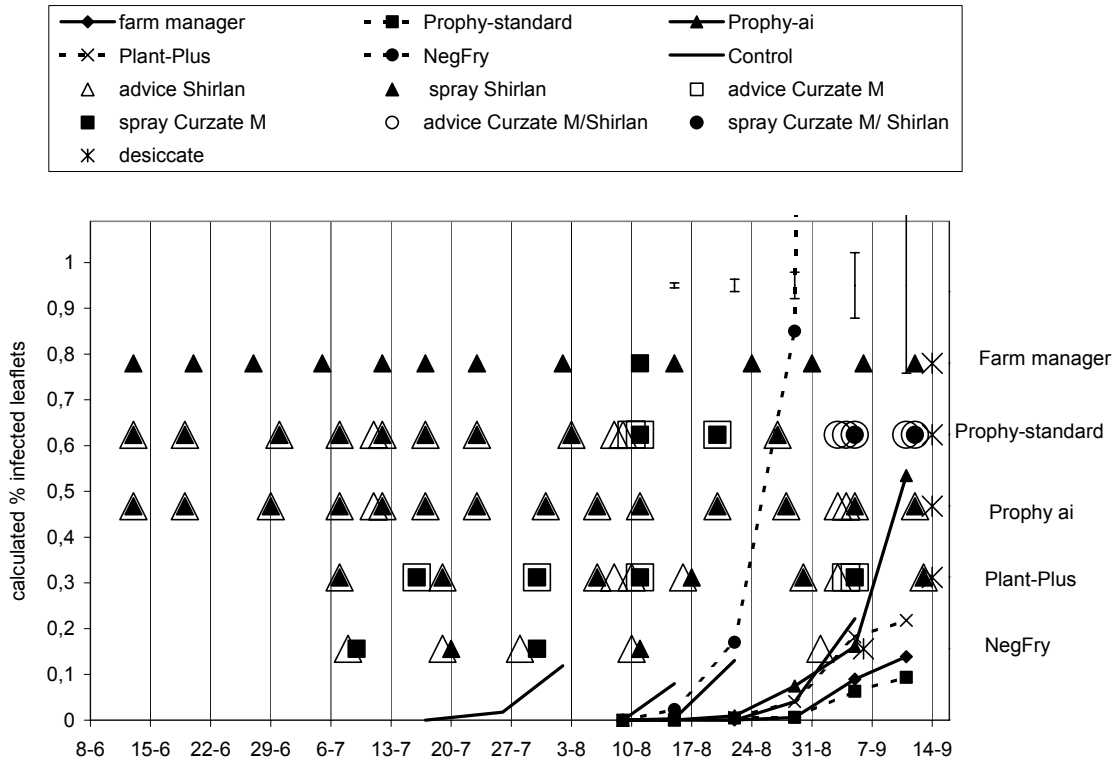


Figure 1. Advises, spraying schedule and calculated percentage infected leaflets for all trial treatments; stripes for LSD on August 15 and 22 for all treatments; on August 29, September 4 and 11 calculated without NegFry; Lelystad.

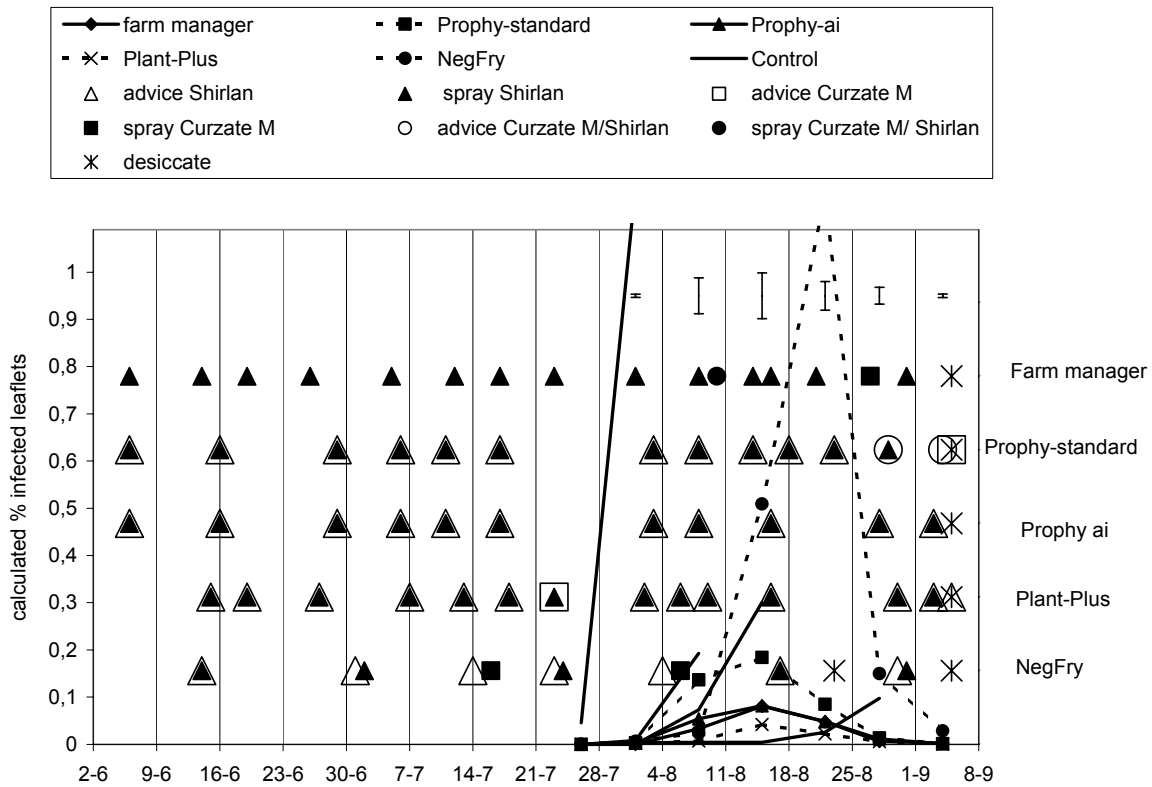


Figure 2. Advises, spraying schedule and calculated percentage infected leaflets for all trial treatments; stripes for LSD on August 1, 8, 28 and September 4 for all treatments, on Aug 15 and 22 calculated without NegFry; Vredepeel.

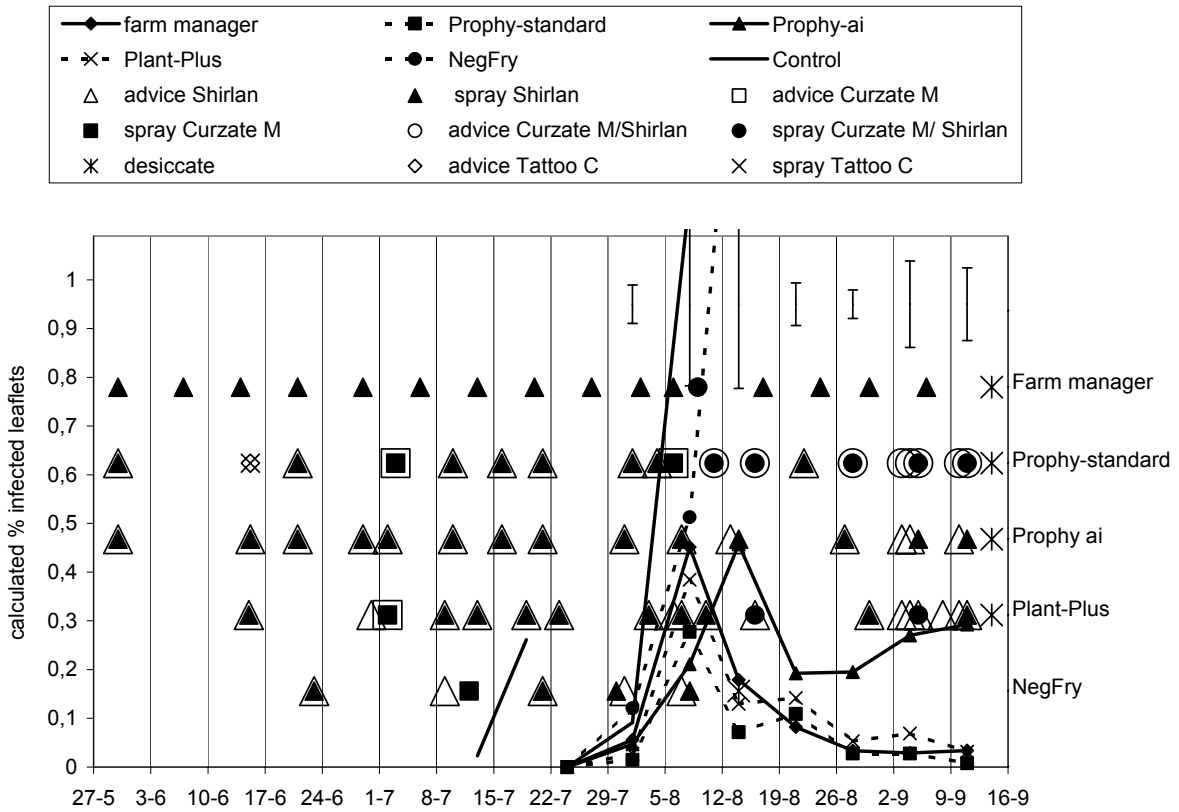


Figure 3. Advises, spraying schedule and calculated percentage infected leaflets for all trial treatments; stripes for LSD on August 1 and 8 calculated for all trial treatments, on August 14, 21,28, September 4 and 11 calculated without NegFry; Valthermond.

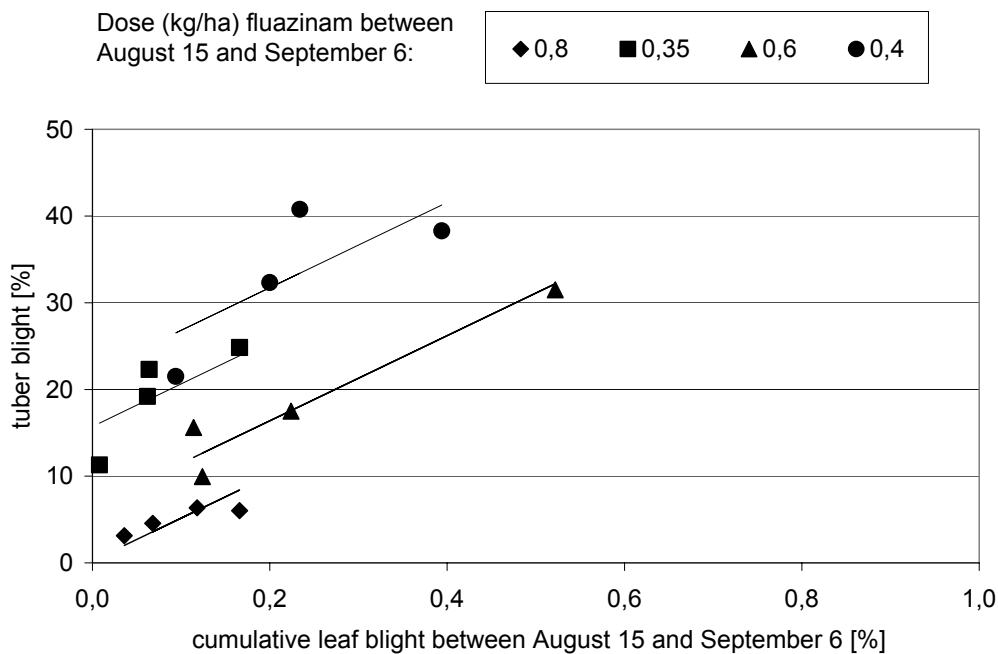


Figure 4. Effect on tuber blight by leaf blight cumulated for the period of August 15 and September 6 and the dose of fluazinam sprayed in this period (R^2 adj. = 91 %).

Implementation of variety resistance in control strategies of potato late blight

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Summary

Varieties with high level of resistance are widely used for starch production in Denmark. Results from observation trials under field conditions and DSS validation trials indicate that the resistance in these varieties is determined by a combination of partial and race-specific resistance. A new approach on exploitation of race-specific resistance in a late blight DSS is proposed. This approach was implemented in two Danish DSSs and tested in field trials with the varieties Dianella and Kuras. Results showed that fungicide input to control potato late blight in Kuras could be reduced considerably compared to routine strategies. Exploitation of race-specific resistance in control strategies can be dangerous due to the risk of sudden erosion of resistance. In Denmark, the present level of fungicide use is 9-12 applications in starch potatoes and 5-7 applications in ware potatoes. If fungicide use has to be reduced further, information about both partial and race-specific resistance must be exploited and implemented in our decision support systems.

Keywords: Resistance, late blight, control strategies, NegFry

Introduction

In Denmark, a political action plan called “Pesticides Action Plan II” demands the agricultural society to reduce the input of pesticides (<http://www.mst.dk>). The use of fungicides in potatoes makes up approximately 21% of the total fungicide consumption in all field crops

although potatoes account for only 1.3% of the total agricultural area (Anon., 2000; Anon., 1998). In 2000, the area with potatoes covered about 40.000 ha, 22.000 ha of which were used for starch production. Varieties with a high level of resistance are now used for 60-80% of the starch producing area. Results from variety observation trials and DSS validation trials in 2000 indicated that the resistance in some of these varieties is based on an unknown mixture of partial and race-specific resistance (<http://www.web-blight.net>; Nielsen & Bødker, 2001). In conventional potato growing, highly resistant varieties are often protected with the same amount of fungicides as susceptible varieties. In this article, the resistance of Kuras is evaluated based on results from variety observation trials in 2000 and 2001. A new approach on the exploitation of both race-specific and partial resistance in a late blight DSS is proposed. This approach was implemented in two Danish DSSs and tested in field trials in 2001.

Methods

Observation trials for evaluation of variety resistance

Several varieties with varying levels of resistance were evaluated in 2000 (Jyndevad and Tylstrup) and in 2001 (Jyndevad, Tylstrup, and Flakkebjerg) under natural conditions. Tylstrup is located in Northern Denmark, Jyndevad in Southern Denmark, and Flakkebjerg in Southeastern Denmark. The experiments consisted of randomised blocks including four replications. Plot sizes were 25 m². Disease assessments were made every third to seventh day during the season. In the DSS validation trials, the varieties Dianella and Kuras were used. In this article, only results for these two varieties and Oleva will be presented. Results for all trials and all varieties can be found on the Internet (<http://www.web-blight.net>).

The results from the observation trials were evaluated by computing several epidemiological parameters in Web-blight. The apparent infection rate (AIR) represents the slope of the disease progress curve, assuming that this curve can be approximated by a logistic function. This slope is estimated by calculating the regression of $\ln(x/(1-x))$ where x is the proportion of tissue affected (Fry, 1977). Regressions are calculated in Web-blight for the intervals in which the disease (x) progresses from 1% to 99%. The area under the disease progress was calculated as given by Shaner & Finney (1977):

$$\text{AUDPC} = \sum [(x_{i+1} + x_i) / 2] [t_{i+1} - t_i]$$

where x_i is the proportion of tissue affected at the i^{th} observation and t is the time in days. The index i runs from 1 to n , where n is the total number of observations. Values for AUDPC were normalised by dividing the AUDPC by the total area of the graph, i.e. the number of days from inoculation to the end of the observation period. This normalisation results in the relative AUDPC (Fry, 1978).

DSS validation trials

Several control strategies were tested at Borris and Flakkebjerg in 2001. Borris is located in Mid-western Denmark in an important potato producing area. The trials were randomised with four replications and with a net plot size of approximately 25 m². The same strategies were tested for two starch varieties: Dianella (susceptible) and Kuras (moderately resistant). In this paper we show results from four out of ten strategies tested:

1. Seven-day routine treatment using only Dithane DG (4 kg/ha)
2. Ten-day routine treatment using only Shirlan (0.4 l/ha)
3. Modified PC-NegFry (Shirlan, varied dosage)
4. Blight Management on Internet (Shirlan, varied dosage)

The original PC-NegFry DSS takes crop resistance into account by extending the spraying intervals for more resistant varieties. In the modified NegFry, resistance was taken into account by reducing the dosage of Shirlan and, at the same time, by keeping short intervals similar to susceptible varieties. Blight Management is a new Internet based DSS under construction in Denmark. A prototype in English can be found in PlanteInfo (<http://www.planteinfo.dk>). Fungicide use is calculated as Treatment Frequency Index (TFI) corresponding to the number of applications in a normal dosage. For example, if ½ a dosage of Shirlan is used four times the TFI is 2. The fungicide use and the control effect obtained by the two DSSs, were compared with two reference treatments, a seven-day routine strategy with Dithane DG (Mancozeb) and a ten-day routine strategy with Shirlan (Fluazinam). Normal dosages were 4 kg/ha for Dithane DG and 0.4 l/ha for Shirlan.

Approach for exploitation of resistance in DSS strategies

A general approach for the exploitation of race-specific resistance in a DSS was defined based on experiences from untreated observation trials (Web-blight) and validation trials carried out earlier (Nielsen & Bødker, 2001). Only Shirlan was used as contact fungicide in the trials:

1. Use a disease forecasting system to start control strategies in susceptible varieties.
2. When first attacks are recorded in susceptible varieties in the region, then start with 0.2 Shirlan in race-specific resistant varieties.
3. When first attacks are recorded in race-specific varieties in the region, then raise dosage according to predicted infection pressure and the length of the late blight favourable period.
4. Use a weather-based DSS including a weather forecast for the timing of subsequent applications.

Results

Variety resistance

Results for Dianella, Oleva, and Kuras are shown as disease progress curves (Figures 1-5) and computed epidemiological variables (Table 1).

Results 2000: In 2000, first symptoms were found about middle of July at both Tylstrup and Jynde vad. The obtained epidemiological parameters for Dianella and Oleva were similar between the two varieties and between the two trials, except for the fact that the apparent infection rate for Dianella at Jynde vad was relatively lower than for the other two varieties (Table 1). First symptoms in Kuras were delayed 5 and 23 days at Tylstrup and Jynde vad, respectively. The RAUDPC for Kuras was lower than for Dianella and Oleva, but the apparent infection rate was relatively high, even higher than for Dianella at Jynde vad.

Results 2001: Again, the obtained epidemiological parameters for Dianella and Oleva were similar between the two varieties and between the trials at Tylstrup and Jynde vad. For Kuras the relatively low RAUDPC at Tylstrup was due to a 14-day delay of first symptoms, and to a minor extent, to a low apparent infection rate. At Jynde vad, the RAUDPC for Kuras was the lowest obtained for the three varieties. At the same time, Kuras had the highest apparent infection rate. At Flakkebjerg, the results for Oleva were similar to the results for Sava, a moderate susceptible ware potato. The first symptoms in Kuras were delayed 28 days and the

disease developed very slowly all through the season. Final disease rating was 4.4% severity. This result is similar to results obtained in variety observation trials in the Baltic countries (Hansen *et al.*, this proceeding).

DSS validation trials

Borris, Dianella: First spray in Dianella was applied on June 21th based on the NegFry forecast. Late blight was found in the region on July 3rd but not until July 25th in the trial. Maybe primary inoculum was not present at the trial site. Using the two DSSs the fungicide use was reduced by 20-40% compared to the reference treatments (Figures 6 and 7). The levels of disease at the end of the season were lower for the DSS treatments than for both the 7-day routine, Dithane and the 10-day Shirlan treatment. (Figure 7).

Borris, Kuras: First sprays in Kuras were applied in the two reference treatments on June 21st according to the NegFry forecast (T₀) (Figure 8). According to the DSSs, first treatments were applied on July 6th (T₁) with ½ a dosage of Shirlan. This was a few days after late blight was found in the region. Dosages were raised to full dosage when late blight was found in untreated Kuras in the trial (T₂). Using the DSSs the fungicide use was reduced by 40-60% compared to the 7-day routine treatment with Dithane and by 15-30% compared to the routine treatment with Shirlan. At the same time, the levels of disease at the end of the season were significantly lower for the DSSs than for to the reference treatments (Figure 9).

Flakkebjerg, Kuras: First sprays in Kuras were applied in the two reference treatments on July 2nd according to the NegFry forecast (T₀) (Figure10). Artificial inoculation was carried out in other experiments at the trial site on June 25th. Late blight was found in the trial in Dianella on July 6th. On the same day, ½ a dosage of Shirlan was applied in both DSS treatments (T₁). The dosages were raised to full dosage late July, but symptoms found at that time turned out not to be late blight. Due to the lack of infections in Kuras, infection rows were artificially inoculated on August 13th with sporangies collected at Borris (in Kuras plots) on the same day. Infections in the untreated plots were found on August 21st (T₂). Using the DSSs, the fungicide use was reduced by 50-55% compared to the routine treatment with Dithane and by 30-35% compared to the routine treatment with Shirlan. At the same time, the levels of disease end of season were lower for both DSSs than for the Dithane reference treatment and at the same level as the Shirlan reference treatment (Figure 11).

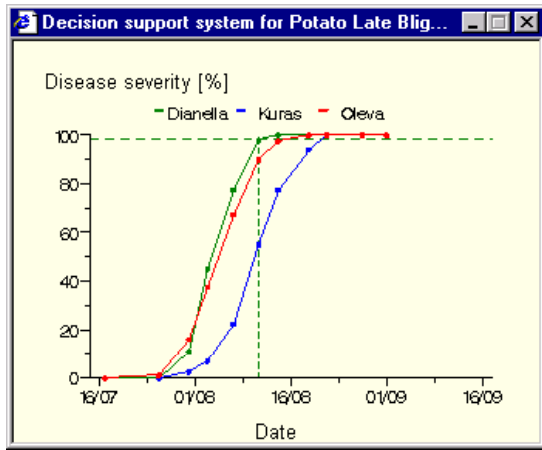


Figure 1. Tylstrup, 2000

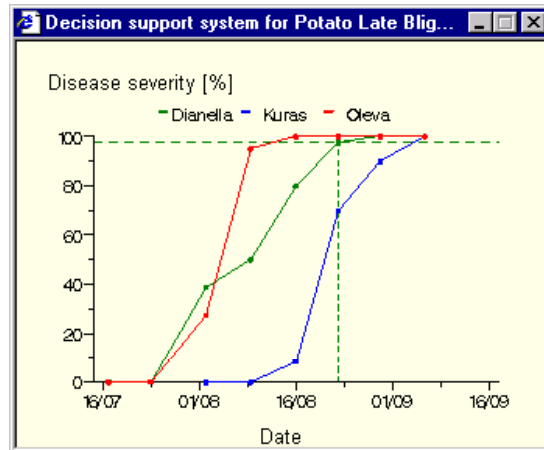


Figure 2. Jyndeved, 2000

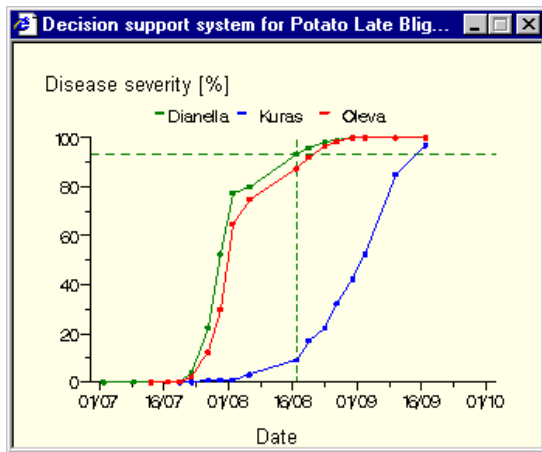


Figure 3. Tylstrup, 2001

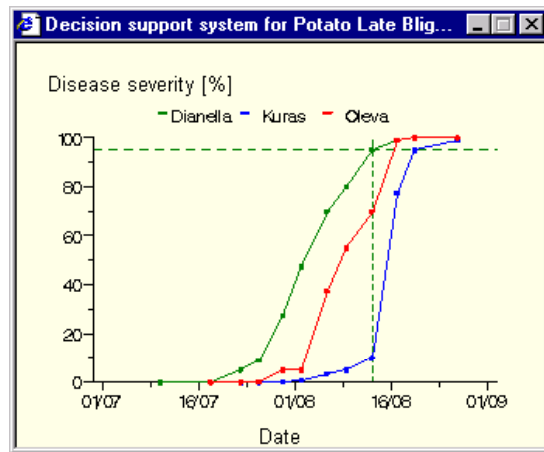


Figure 4. Jyndeved, 2001

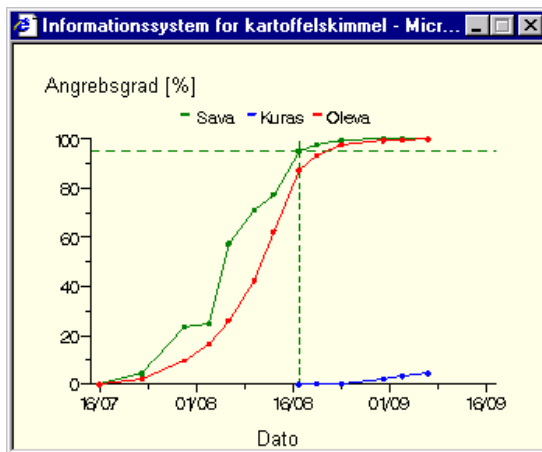


Figure 5. Flakkebjerg, 2001

Figures 1-5. Disease progress curves for Dianella, Oleva and Kuras in untreated observation trials at Tylstrup, Jyndeved, and Flakkebjerg. Curves from left to right always represent Dianella, Oleva, and Kuras in that order.

Table 1. Results as epidemiological parameters obtained from untreated observation trials at Tylstrup (2000, 2001), Jyndevad (2000, 2001) and Flakkebjerg (2001). For the variables "Delay of first symptoms" and "Disease rating when rating of reference variety $\geq 90\%$ ", the reference variety was Dianella except at Flakkebjerg where Dianella was not included in the trial.

Location and variety name	Delay of first symptoms [d]	Disease rating when rating of reference variety $\geq 90\%$	Final disease rating [%]	Apparent infection rate (AIR)	Relative area under the disease progress curve (RAUDPC)
<i>Tylstrup, 2000</i>					
Dianella	0	98.0	100	0.52	0.57
Oleva	0	90.0	100	0.41	0.56
Kuras	5	55.0	100	0.34	0.44
<i>Tylstrup, 2001</i>					
Dianella	0	93.5	100	0.19	0.67
Oleva	8	87.5	100	0.19	0.64
Kuras	14	9.0	97	0.16	0.24
<i>Jyndevad, 2000</i>					
Dianella	0	97.5	100	0.20	0.58
Oleva	0	100.0	100	0.56	0.65
Kuras	23	70.0	100	0.33	0.30
<i>Jyndevad, 2001</i>					
Dianella	0	99.0	100	0.29	0.60
Oleva	5	99.0	100	0.40	0.46
Kuras	8	77.5	99	0.42	0.29
<i>Flakkebjerg, 2001</i>					
Sava	0	95.3	100	0.24	0.61
Oleva	0	87.5	100	0.24	0.53
Kuras	28	0.00	4.4	0.10	0.01

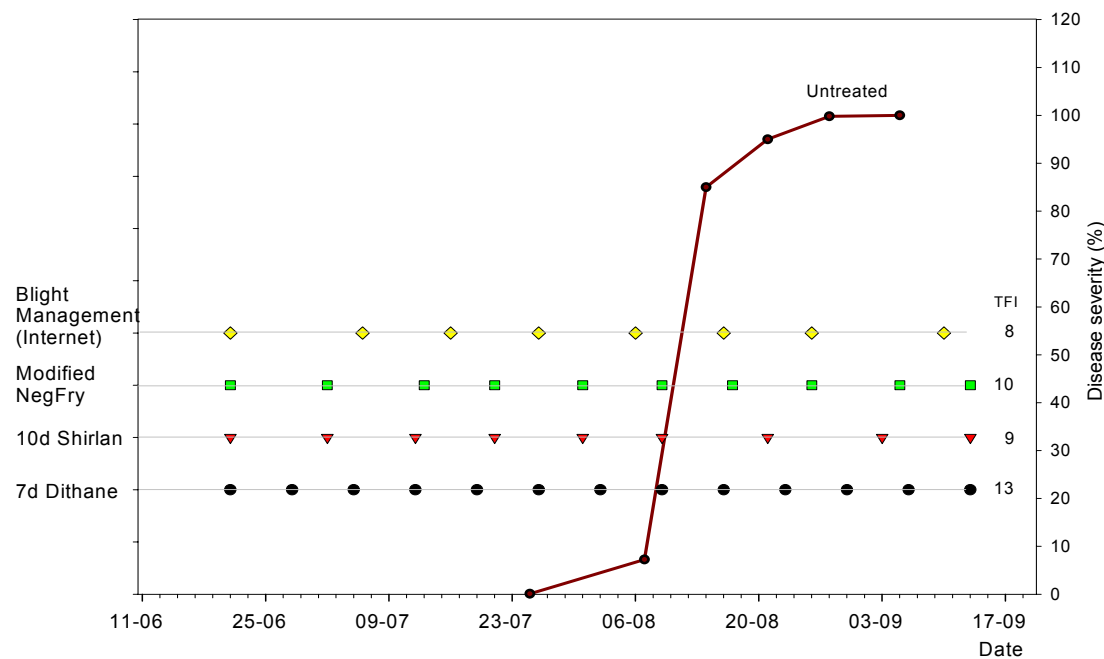


Figure 6. Borris, variety Dianella. Application dates and TFI obtained.

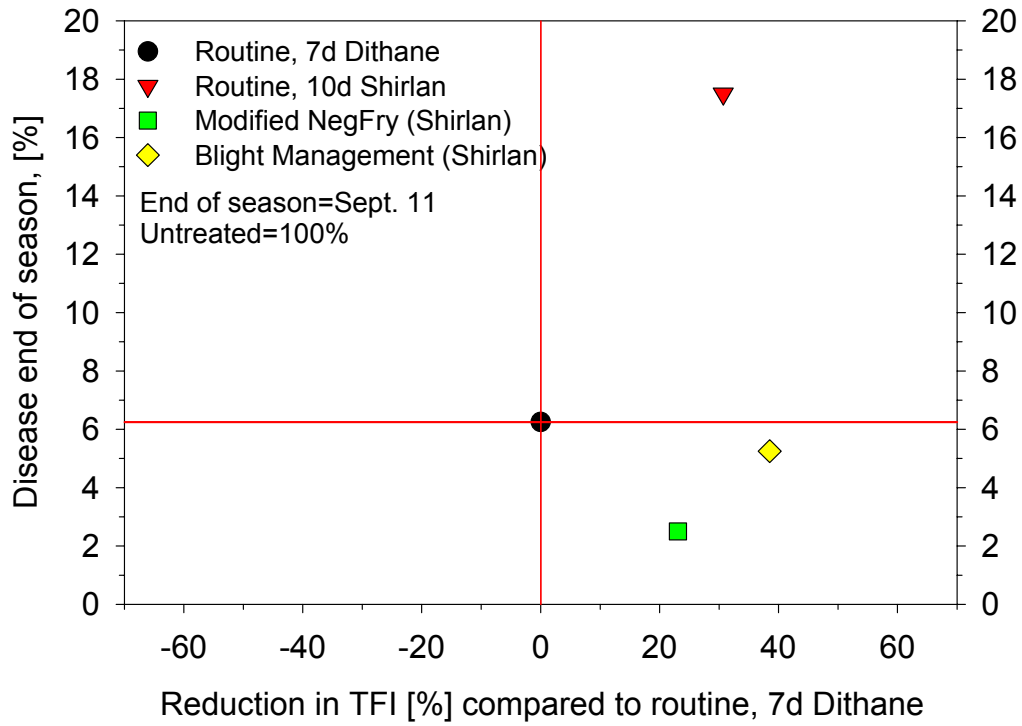


Figure 7. Borris, Dianella. Red. in fungicide use, TFI (%), and disease end of season (%)

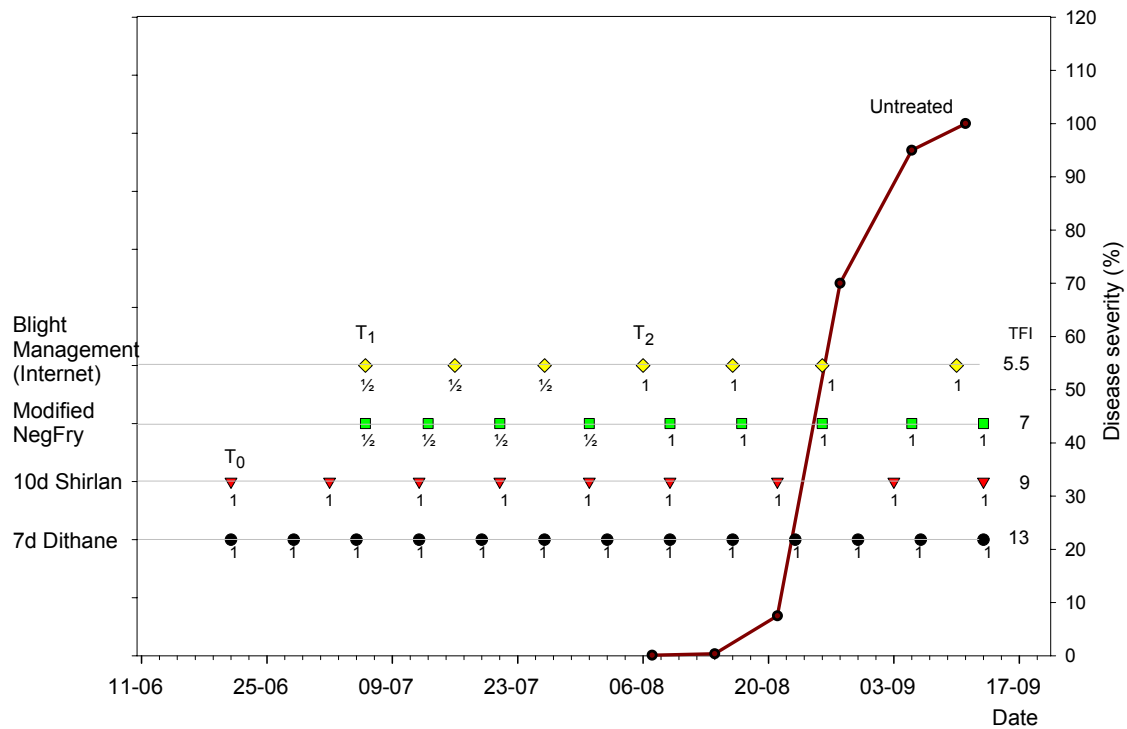


Figure 8. Borris, variety Kuras. Application dates and TFI obtained.

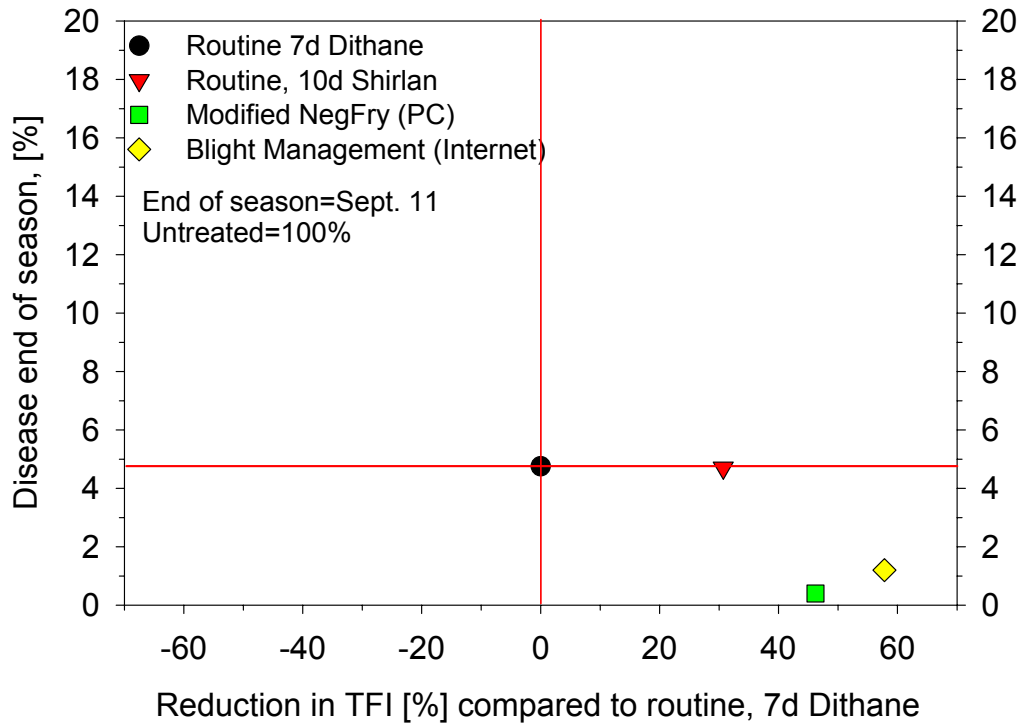


Figure 9. Borris, Kuras. Red. in fungicide use, TFI (%), and disease end of season (%)

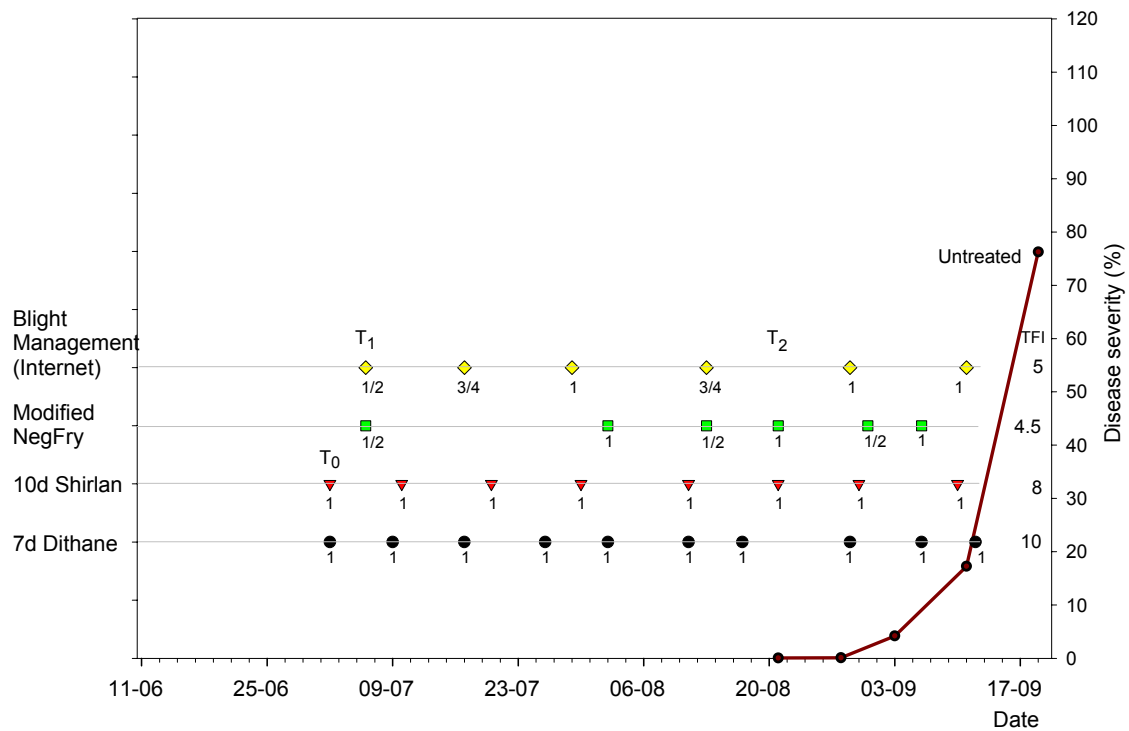


Figure 10. Flakkebjerg, variety Kuras. Application dates and TFI obtained.

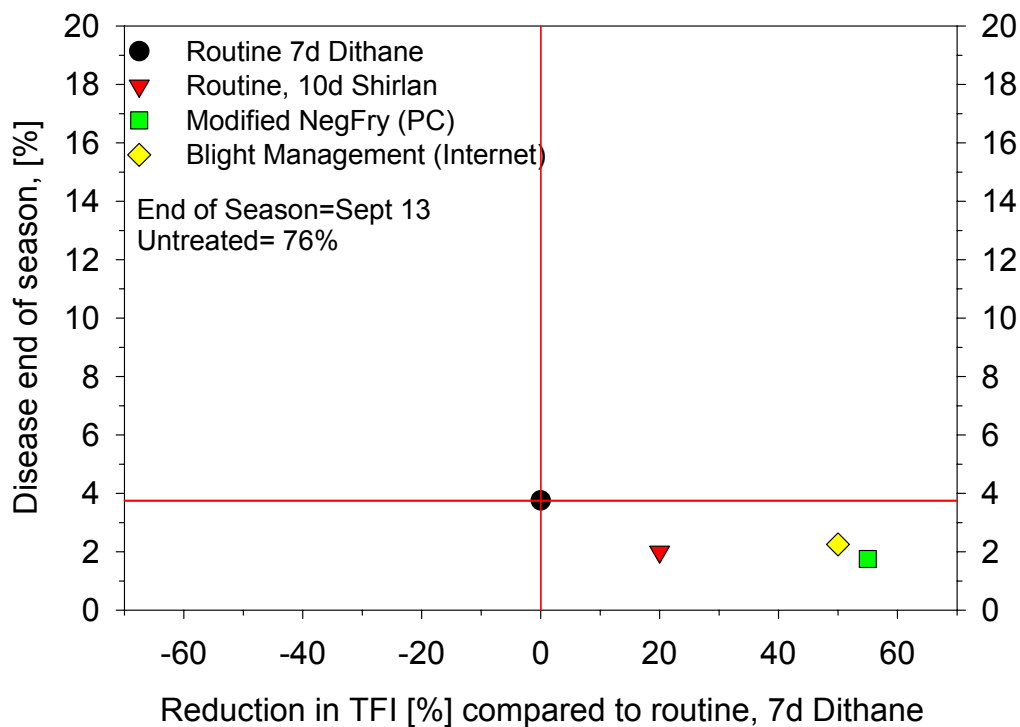


Figure 11. Flakkebjerg, Kuras. Red. in fungicide use, TFI (%), and disease end of season (%)

At Borris and Flakkebjerg, the onset of the epidemic development in untreated plots of Kuras was delayed by 2-4 weeks compared to Dianella. Subsequently, the disease developed rapidly in late August at Borris and early September at Flakkebjerg. These results indicate that the race-specific part of the resistance in Kuras was effective in the 2001-growing season at Borris and at Flakkebjerg. When the race-specific resistance eroded, the underlying partial resistance seemed not to be very effective (Figures 8 and 10). Even intensive use of fungicide could not keep late blight at a low level (Figures 9 and 11). Due to the delay of first symptoms in Kuras, the two DSSs considerably reduced the fungicide input compared to routine treatments. Until late blight was found in untreated Kuras, the DSSs recommended four applications in 1/2 dosage (2 TFI) at Borris and 0.5-1.25 TFI at Flakkebjerg (Figures 8 and 10).

Discussion and conclusion

Combining the results from all variety field tests it seems that the resistance in Kuras is determined by a combination of partial resistance and race-specific resistance. We make this conclusion because the results as computed epidemiological parameters are quite stable

between locations and years for Oleva and Dianella, but not for Kuras. According to Flier (2001) there are strong indications for the presence of specificity between *P. infestans* isolates and potato varieties with partial resistance. It is therefore not known whether partial resistance, or a combination of both partial and race-specific resistance, causes the presence of different host-pathogen interaction at different locations in the variety Kuras. However, the considerable variation in epidemiological variables between locations, a significant delay of first symptoms and often high apparent infection rates, indicate both presence of race-specific and partial resistance. At Flakkebjerg, the final disease rating for Kuras was 4.4% in the observation trial (Table 2) and 76 % in untreated plots in the DSS validation trial (Figure 10). For the observation trials at Jyndevad and Tylstrup in 2000 and 2001, and for the DSS validation trial at Borris, final disease ratings for Kuras was close to 100% (Table 2 and Figure 8). Tylstrup, Jyndevad, and Borris are located in major potato producing areas where also Kuras is widely grown. In the Flakkebjerg region, hardly any potatoes are produced and absolutely no starch potatoes. Local *Phytophthora* populations (compatible races of *Phytophthora infestans*) might have adapted to Kuras as a host at Jyndevad, Tylstrup, and Borris, but not at Flakkebjerg. This hypothesis corresponds with the results from tests of Kuras in seven observation trials in the Baltic countries in 2001 (Hansen *et al.*, 2002, this proceeding). Disease was always at very low levels for Kuras in these trials. Hardly any potatoes for starch production are grown in the Baltic countries and local *P. infestans* populations could not have adapted to the integrated resistance present in Kuras.

In Denmark, the distribution of mating types in commercial fields were found to be approximately 50:50 during a survey in 1998 (Bødker *et al.*, 1998), and indications on oospore activity in commercial fields have been found since 1997. Sexual reproduction in populations of *P. infestans* in Denmark probably acts as the driving force behind an increase in genetic variation as observed in recent years in the Netherlands and the Nordic countries (Flier & Turkensteen, 1999; Brurberg *et al.*, 1999). Sexual reproduction has therefore led to genetically more diverse populations of *P. infestans* which is marked by an increased adaptability to the host and the environment (Flier, 2001). The erosion of resistance is a threat for the use of late blight DSSs taking resistance into account in fungicide control strategies. The durability of partial resistance in “well known” varieties may be unstable and the risk of erosion of race-specific resistance has increased. Therefore, to keep DSSs updated on variety resistance

parameters, it is vital that varieties widely grown are monitored in time and space for their stability of resistance. The Web-blight network on resistance information was established for that reason (<http://www.web-blight.net>). The virulence of local *P. infestans* populations has not been monitored yet, but this kind of information will be helpful for future evaluation of results.

The results from experimental trials and experiences from commercial fields have indicated erosion of resistance in Kuras in Denmark. We proposed a new approach for the control of late blight in varieties with a resistance like the resistance in Kuras. In 2001, results showed that this approach was effective in two trials. The use of fungicides was reduced considerably and at the same time, the control effect was improved compared to reference treatments. It is not possible to predict exactly if, and when, erosion of race-specific resistance will occur. Therefore, first spray is recommended when late blight is found in susceptible varieties in the region. In the untreated observation trials and in the DSS validation trials, late blight was always found relatively late in Kuras. The use of half a dosage of Shirlan applied at relatively short intervals is supposed to complement the integrated resistance in Kuras until the race-specific resistance may be eroded. Then, the use of full dosages during the late part of the season will complement the underlying partial resistance and, at the same time, reduce the risk of tuber blight infections.

This study was a part of a research project aiming at developing tools to reduce the fungicide use in potatoes in Denmark. The present level of fungicide use is 9-12 applications in starch potatoes and 5-7 applications in ware potatoes. If fungicide use has to be reduced further, information about both partial and race-specific resistance must be exploited and implemented in our decision support systems.

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Potato resistance to late blight – an important element of the protection strategy

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Summary

The intensive potato fields protection against late blight is expensive and has negative effects on environment. Genetic resistance of varieties to the late blight is an important element to be used in plant protection against that disease. Results indicate that late blight susceptible varieties (Karlana) require protection at full recommended fungicide rates each year, regardless of pathogen infection pressure. Highly resistant varieties (Meduza) can be left unprotected in some years (late appearance of the disease) or be protected at fungicide rates reduced even to 50%. The rates of fungicide for the protection of medium resistant or medium susceptible varieties depend on the infection pressure in a given year. At a high fungus infection pressure (high rate of disease development), the effective protection can be provided by the full recommended fungicide rates. At a lower disease intensity, the protection can be effective with rates reduced to 75%. Different varieties can react in various ways to the reduction of fungicide rates.

Key words: potato, late blight, reduction of fungicide use

Introduction

Wide spread of *Phytophthora infestans* fungus and its great variability are the reasons why late blight is still a problem in potato production. Yield reduction in unprotected fields are estimated at 70% (Hoffman, Schmutterer, 1983). The average yield losses in Poland (long time observations), due to late blight, amount to 20-25% (Pietkiewicz, 1989).

The intensive plant protection against late blight is one of the main elements of potato production technology. Under climatic conditions of Poland, the average period of necessary protection is 2.5-3 months what means 8 -12 fungicide treatments.

So intensive protection is expensive and, more important, has negative effects on environment. One of the more cost-effective elements of potato protection from the late blight is the utilization of the genetic resistance:

In the areas where the disease is most common and severe, the use of resistant varieties reduces the risk of early occurrence and quick development in the field.

The advantage of using the resistance of varieties to the late blight can supplement the fungicide action by: the reduction of fungicide rates, extension of intervals between treatments.

The aim of the study undertaken at PBAI Bonin was the assessment how much the rates of fungicides used for potato protection from late blight can be reduced by the utilization of the genetic resistance, without compromising the protection efficiency.

Material and methods

The experiments were carried out at Bonin, in the years: 1998-2000, on 3 potato varieties: Karlena – susceptible (foliage resistance of 3), Panda - medium resistant (foliage resistance of 5) and Meduza - resistant variety (foliage resistance of 8). plot size was 25 sq. meters in 4 replications. Each year the same protection schedule (6 sprayings): S + T + C + C + C + C, was applied (where: S - systemic fungicide, T- translaminar fungicide, C- contact fungicide).

The four combinations of the same schedule, applying the various rates of fungicides, were compared in the experiments: recommended rate (100%) and two treatments of rates reduced to 75 and 50%. An unprotected plot was included as a control.

The infection degree was estimated weekly since the date of first disease appearance, on 9-degree scale. As a criterion of fungicide efficiency was accepted the rate of late blight development as infection regression coefficient against time (Van der Plank, 1963) and tuber yield.

Results

The different weather conditions in 1998-2000 resulted in different severity and potential threat of late blight to potatoes. Season on 1998 was intermediate in respect to the disease intensity. On standard variety Atol (susceptible to late blight) the late blight appeared at Bonin 62 days after planting. The curve of disease development in 1999 was quite different. The late blight appeared very early (57 days after planting), but due to the weather conditions, its development was very slow. The disease started to develop only during the third decade of August. Even at the end of growing season the plants in unprotected plots were not completely destroyed. The rate of disease development remained moderate. The growing season of 2000 was characterized by the highest pathogen infection pressure. The disease appeared relatively late, but developed quickly. The total destruction of plants in unprotected plots was observed about August 20. Despite late appearance (81 days after planting), the rate of development was very high in that year.

The conducted experiments confirmed that the significant factor affecting the rate of disease spread in experimental plots was:

- the resistance of variety (LSD=0.044 at $p=0.01$)
- the year (growing season) (LSD=0.011 at $p=0.01$)
- combination of chemical protection - the rates of fungicides applied (LSD=0.017 at $p=0.01$)
- the interaction of varieties and fungicide rates (LSD=0.021 at $p=0.01$).

Influence of the resistance of variety was particularly visible on the varieties extremely resistant to the pathogen. In all years, regardless of the pathogen infection pressure, the lowest increase of destruction during a time unit was observed on the Meduza variety, while the largest one – on Karlena. The intensity of the disease in particular years was similar to that on standard variety. The rate of disease spread on all varieties studied was highest during the season of 2000. The rate of disease development was significantly higher in comparison both to 1998 and 1999.

The factor mostly affecting the rate of late blight development in the plots of varieties studied was the interaction of varieties and fungicide rates (Table 1).

Table 1. The intensity of late blight development (rate of disease spread) on three potato varieties

Variety	Year	Combination of protection (rates)				LSD
		Control	50%	75%	100%	
Karlana	1998	0.257	0.220	0.212	0.183	0.020
	1999	0.213	0.219	0.211	0.183	
	2000	0.355	0.331	0.318	0.22	
Panda	1998	0.181	0.124	0.047	0.032	0.020
	1999	0.181	0.068	0.047	0.032	
	2000	0.254	0.159	0.143	0.104	
Meduza	1998	0.031	0.031	0.023	0.008	0.030
	1999	0.031	0.023	0.016	0.0	
	2000	0.042	0.043	0.052	0.034	

On the more susceptible varieties, particularly on Karlana, the change of rate of disease development was observed after each change of fungicide rate applied (particularly in 1998 and 2000). On the resistant variety Meduza, no significant differences in the rate of disease development were observed neither in plots protected with different fungicides nor in unprotected control.

On the level of tuber yield produced, the significant influence had: the seasons (LSD=13.41 at $p=0.01$), variety factor (LSD=36.96 at $p=0.05$) and interaction of varieties and years (LSD=26.82 at $p=0.01$). No direct significant effect of the protection combination (rates) on the tuber yield was observed. The data concerning the level of yield obtained each year, from the plots of different varieties protected according to various combinations, are presented in Table 2.

On the level of tuber yield produced, the highly significant influence had the seasons. Generally the highest yield was obtained in 2000, despite the high intensity of the disease. The late blight appeared late in 2000 (81 days after planting), but before the epidemics developed in the field, the majority of varieties produced the yield already. It was particularly the case with the medium early, susceptible to late blight Karlana variety. In case of late variety Meduza, its genetic resistance to the pathogen prevented the late blight development to such an extent that the disease had little impact on the yield. The lowest tuber yield was obtained at Bonin in 1999. The meteorological conditions during the early growing season (drought in May and June) were unfavorable both for late blight development and for yield production.

Table 2. The change of yield of different potato varieties in comparison to control in %.

Variety	Year	Combination of protection (rates)				LSD
		Control (dt/ha)	50%	75%	100%	
Karlana	1998	167.3	+ 37.1	+ 35.9	+ 59.8	15.8
	1999	156.0	- 6.1	+ 10.9	- 5.8	13.7
	2000	327.0	+ 1.8	+ 8.6	+ 13.5	10.1
Panda	1998	239.3	+ 19.2	+ 25.9	+ 6.7	11.1
	1999	203.0	+10.8	+ 8.1	+ 1.5	10.5
	2000	255.0	+ 62.4	+ 81.6	+ 74.3	12.9
Meduza	1998	302.0	- 15.5	- 13.8	- 14.3	8.8
	1999	191.5	- 3.1	+ 2.9	- 1.3	11.1
	2000	393.0	+ 9.7	+ 5.3	+ 4.3	8.4

On the level of yield produced, the significant effect had also variety factor and interaction of varieties and years. The different meteorological conditions of a given year variously affected the yield of varieties of different earliness.

In 1999, no significant differences in the yield level of all varieties, either protected with different fungicide rates or unprotected at all. Among other things, it was due to the mild pathogen infection pressure. The plants even in unprotected plots were not destroyed to such an extent as to cause a large yield reduction. In 1998, no differences were observed in the yield of such varieties like Meduza. On this resistant variety, no such foliage destruction was observed as to cause the reduction of the yield produced.

In some years, however, a significant effect of interaction of such factors like variety and fungicide rates on the yield level was observed. It was particularly visible in 2000, when the chemical protection of Karlana, conducted at full recommended fungicide rates, allowed to save the yield. In case of Panda variety, the significant differences in tuber yield were observed in protected and unprotected plots, regardless of fungicide rate used.

Conclusions

On the ground of conducted study one can say that the resistance of varieties to the late blight is an important element to be used in plant protection against that disease.

Susceptible to late blight varieties (Karlana) require protection at full recommended fungicide rates each year, regardless of pathogen infection pressure.

Highly resistant varieties (Meduza) can be unprotected in some years (late appearance of the disease) or protected at fungicide rates reduced even to 50%.

The rates of fungicide for the protection of medium resistant or medium susceptible varieties depend on the infection pressure in a given year:

At a high fungus infection pressure the effective protection can be provided by the full recommended fungicide rates.

At a lower disease intensity, the protection can be effective with the rates reduced to 75%.

The level of yield produced is modified by many factors.

Taking into account the genetic resistance of potato varieties to the late blight allows the reduction of fungicides applied, without compromising the protection efficiency, and this can be important for the environment.

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A late blight forecasting project for FL1953 (Courlan), a blight sensitive processing cultivar

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Summary

A blight forecasting project using the PLANT-Plus system was carried out commercially in 4 UK regions for the processing company Frito-Lay. The project involved seven sites of the variety Courlan, a blight sensitive cultivar.

Infection pressure in all regions was low in June and increased to be high for the remainder of the season. The North East region gave the lowest risk, compared to other regions. Significant local variations in pressure were seen between inland and coastal sites in East Anglia. Most sites produced a similar number of sprays and costs, but there were large variations in the product type used between sites. Spray programmes at sites in the North East, West and East Midlands showed a relatively high use of contact products (Shirlan) compared to sites in East Anglia.

No blight infection was observed in the North East, West and East Midlands. In comparison most East Anglia sites were infected with foliar or tuber blight. These sites showed more missed infection days than other regions, which was a result in treatment application delays. In East Anglia slow reaction by spraying teams to recommendations and bad weather conditions were the main causes of spray delays.

This project showed the benefits of integrating a blight forecasting system into processing potato production. It also highlighted the improvements required by some farms in blight control management in order to grow sensitive varieties.

Key-Words –sensitive, infection variation, contacts, spray delay, management

Introduction

The pre-dominant crisping varieties in the UK are Saturna, Lady Rosetta and Hermes. In respect to foliar and tuber blight resistance, these varieties score 4&5, 4&4 and 3&4 respectively in ratings (NIAB 1999), where 1 is low and 9 high resistance. Recently Frito-Lay, the largest UK crisp producer, introduced several North American varieties because of their improved processing and taste qualities. One such variety, 1953 or Courlan under went pre-commercial trials in 2000. Courlan is rated 3 for foliar blight and only 2 for tuber blight on the NIAB ratings. 1999 was a season of very high blight pressure in the UK and severe blight infection was experienced at most of the Courlan sites. One site, however in Nottinghamshire was blight free. The spray programme at this site differed to others in that a disease forecasting system (PLANT-Plus) was implemented.

The result of the improved disease control with PLANT-plus initiated Frito-Lay in conjunction with Plantsystems to set up a project to use this decision support system on all UK Courlan crops, where possible. Experiences and results of this project are given in the following report.

The Sites

Maincrop Courlan was planted at 8 commercial sites in 2001. These sites were distributed around 4 regions of the UK, East Anglia, East Midlands, North East and West Midlands. The PLANT-Plus forecasting system was set up at 7 of the sites. 1 of the 8 sites was sprayed conventionally. In East Anglia the 4 sites running with the forecasting system used data from 4 separate weather stations. The other regions all had 1 Courlan site, each using a single weather station for data. All weather stations were within 3km of the Courlan fields.

System Support

At 5 of the forecasted sites Plantsystems were responsible for running the PLANT-Plus systems which included installing weather stations (Adcon), setting up data transfer, managing crop recording data, interpreting data and advising on spray recommendations. 2 sites were run by the farm operation, although one of these (East Midlands) used Plantsystems for general support.



Spray Applications

At each site a farm crop manager or agronomist was responsible for implementation of spray recommendations from the model advice. At the East Midlands and North East sites crops were treated with farm managed sprayers and spray teams. The South West site used a combination of farm sprayers and contractors. In East Anglia, a group of farms were involved, and spraying was done by the farms on which the crops were grown, or by contractors.

Results

2001 blight risk

The blight risk in 2001 was generally moderate to high. Most regions experienced low pressure in June, moderate to high pressure in July and high pressure in August and September.

Regionally blight risk (according to PLANT-Plus accumulated risk values) varied from lower pressure in the North East to higher risk in the East Midlands and East Anglia (Table 1). Locally variations were seen in East Anglia where pressure was highest on coastal sites compared to 5km inland. This difference was as great as some of the regional variation.

Table 1. PLANT-Plus monthly regional blight risk values (accumulated) for Frito-Lay sites

Region	Site	June	July	August	September	Total Risk
North East	N. Yorks.	767	1923	3276	4333	10290
W. Midlands	Shrops.	821	2135	4571	3783	11310
East Midlands	Notts.	764	3283	4397	4062	12506
East Anglia	N. Norfolk (coast)	484	3559	4440	3727	12210
	N. Norfolk (inland)	851	2720	3019	3784	10374

Courlan spray programmes

The number of sprays was similar at all sites (except Trimmingham which was harvested early), however there was a marked difference in the type of products used between sites (Table 2). Those sites in the North and Midlands (N. Yorks., Shrops. and Notts.) applied a high percentage of contacts (mainly Shirilan) in relation to translaminar and systemic products. East Anglia site (Norfolk) programmes were predominantly translaminar treatments. Costs between all sites were similar.

Table 2. Courlan treatments; spray number, type and cost.

Site	Total Sprays	% Contact	% Translaminar	% Systemic	*Cost £/ha
N. Yorkshire	12	66	34	0	230
Shropshire	12	42	50	8	250
Nottinghamshire	12	50	33	17	250
Norfolk – E. Somerton	11	18	72	10	248
Norfolk – Gresham	11	18	82	0	243
Norfolk – Trimmingham	8	0	100	0	180
Norfolk – Knapton	12	25	75	0	255

* Based on £20/ha for systemics, £15/ha for translaminars & £10/ha for contacts. Application cost was £7.5/ha.

Courlan disease control

At three of the sites, N. Yorkshire, Shropshire and Nottinghamshire sprays were timed so that few significant infection chances (according to PLANT-Plus) were missed (Table 3). As a result no foliar blight or tuber infection was observed. At the Norfolk sites (E. Somerton & Knapton) there were 5 to 6 days in July when large infection periods were missed. Blight at these sites was first observed in early August, and consequently serious infection levels of blight in the foliage and tubers developed. Note infection chances were also missed at Trimmingham, but the crop was harvested before any blight was observed. At one Norfolk

site (Gresham) no foliar blight was observed but a number of missed infection chances in August, resulted in tuber blight developing in store.

Table 3. Disease incidence and missed infection chances at Courlan sites

Site	Number of days infection chances were missed			Date foliar infection first observed	Date tuber infection first observed
	June	July	August		
	N. Yorkshire	0	0	0	No infection
Shropshire	0	0	0	No infection	No infection
Nottinghamshire	0	1	1	No infection	No infection
Norfolk – E. Somerton	0	5	3	Early August	Early Sept.
Norfolk – Gresham	2	2	5	No infection	Late Sept
Norfolk – Trimmingham	2	7	Harvested	No infection	Processed Aug.
Norfolk – Knapton	2	6	0	28 July	Late August

Discussion

The regional and local variations in blight pressure seen in 2001 show the importance of using site-specific weather data. In some local situations differences in climatic conditions can be significant. In order to run a robust commercial forecasting system a good network of weather stations is required to take account of as many of these variations as possible.

Blight sensitive varieties, such as Courlan give very little margin for error. Sometimes just a few missed days of infection chances can be enough to allow blight to develop, as was seen in Norfolk. With sensitive varieties the use of decision support systems becomes more important as a tool for minimising the chance of missed infection days.

This project has however highlighted the differences in performance of implementing the advice from a DSS, as is seen in Table 3. It must be noted that 2001 produced few good spray days and without doubt the Norfolk coast saw the worst of the rain and wind in July. Even so there was a big difference in disease control between sites, so what were the disease free farms doing correctly, that others failed at? The following are suggestions for the differences in results;

The high use of contact sprays (Table 2) at disease free sites indicates that these farms were able to react in good time to forecasted pressure approaching. This kept them one step ahead, whereas the infected sites tended to be reacting to pressure with translaminar treatments. This second approach can control blight, however it only requires one or two

days delay before the curative activity of translaminar products are lost. Table 3 shows this is exactly what happened to some Norfolk sites in July when infection chances were missed.

When sprays were delayed at the infected sites there was also a reluctance to change to more expensive systemic products, which may have given some added curative activity.

Reaction to spray recommendations is critical in seasons where spray days are at a minimum. Even with PLANT-Plus, which gives a few days warning of approaching risk (*Hadders 1996*), there were at times few opportunities available to spray. What was noticeable between sites this year was that managers who had total control of their sprayers, tended to take better advantage of the limited spray days (*Hinds 2000*). Those operations, which relied on contractors or other farms to do the spraying, were less successful at hitting these spray days and, as result of subsequent bad weather, critical delays were caused.

The disease free sites tended to have a manager on the farm with time to look at the model. Once a spray recommendation was generated by the model or passed on by the adviser, they were already well prepared.

In potato processing (as with the fresh market) the trend is for consumer preference to dictate the selection of improved quality potato products. In some cases the cultivars required to achieve this quality are more disease sensitive, for example the use of Russet Burbank for McDonald's French fries. Along with this trend the commercial use of DSS's in the production of processing potatoes is likely to increase, as pressure for improved crop quality and crop assurance increases. Some farms will be able to take this change in their stride, however others must look to change their traditional thinking and methods of blight protection. To be successful they must also realise that DSS's are adding another level of management support to their potato production and not a hindrance.

Acknowledgements

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Field experiments with seed treatment against potato late blight

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Summary

The impact of seed tuber treatment on *Phytophthora infestans*-infection in potato fields was studied. For this purpose seed tubers were inoculated with zoospores of phenylamidresistant isolates of *Phytophthora infestans* and dressed with different fungicide solutions before planting.

The fungicides differed in a.i., dose and formulation.

Assessments were made weekly in order to observe the occurrence and the spread of the fungus within the differently treated variants.

Keywords: fungicide formulation, late blight, *Phytophthora infestans*, primary inoculum sources, tuber dressing

Introduction

Today in years with high soil moisture we can recognize, that stem infections appear earlier and more often than in the past. Why did this phenomenon change during the last years?

Possible sources of infection for P.i. are:

cull piles

potato volunteers

latent infected seed tubers

Cull piles and potato volunteers cause secondary infection in potato fields, because at first the potato late blight develops at these places (e.g. on cull piles). The consecutive secondary infection in potato fields results from zoospores, developed on those sources and causing mainly leaf infection in the field.

Today latent infected seed tubers overwinter in storage without any symptoms, because of improvement of storage conditions and (possible) change in population aggressiveness. So these tubers are not eliminated and used as seed tubers. Depending on soil type and rainfall in spring, the latent infected tubers cause early stem infection, which means primary infection [Appel *et al.*, 2000].

There is an increasing importance of seed tubers as source of infection, compared to cull piles and potato volunteers. It is indispensable to suppress primary infection, developing from seed tubers. So a field trial with treated tubers was established!

The field trial was located in Freising-Weißenstephan this year.

Some facts about the site:

The soil was sandy clay with a valuation index of 65. We have 750 to 800mm rainfall each year. Each plot consisted of 84 plants and was replicated three times.

Material and methods

Potatoes were inoculated artificially with *Phytophthora infestans* eight days before planting. The used inoculum was a mixture of phenylamiresistent isolates. For inoculation tubers were penetrated with a syringe and zoospore-solution was injected. The concentration of inoculum in the tuber was ten to fifteen zoospores. After that, tubers were stored in a dark climate chamber at 15 degrees.

Tubers were coated with different fungicides directly before planting. In advance they were heated up to room temperature. The fungicide solutions were mixtures of the different compounds and products with water. These solutions were sprayed on tuber surface by a pressure-sprayer from GARDENA. Finally tubers were dried by the air.

We chose the cultivar “Agria” and planted potatoes at 23rd of May. All in all we had 17 variants, replicated three times in a randomised block. The size of each plot was 21 square meters. Plots consisted of 84 tubers, which were planted in six ridges.

The different fungicides, which were sprayed on tuber surface are shown in table 1.

Table 1: material and method (variants)

variants	treatment
1	control, without tuber dressing (<u>not</u> inoc.)
2	control, without tuber dressing (inoc.)
4	Mancozeb [1500g a.i./ha] (inoc.)
6	Metalaxyl [80g a.i./ha] (inoc.)
B	Metalaxyl [120g a.i./ha]+ liquid polymers (inoc.)
8	2,5 Exp (inoc.)
10	5,0 Exp (inoc.)
12	10,0 Exp (inoc.)
20	Dimethomorph [500g a.i./ha] (inoc.)

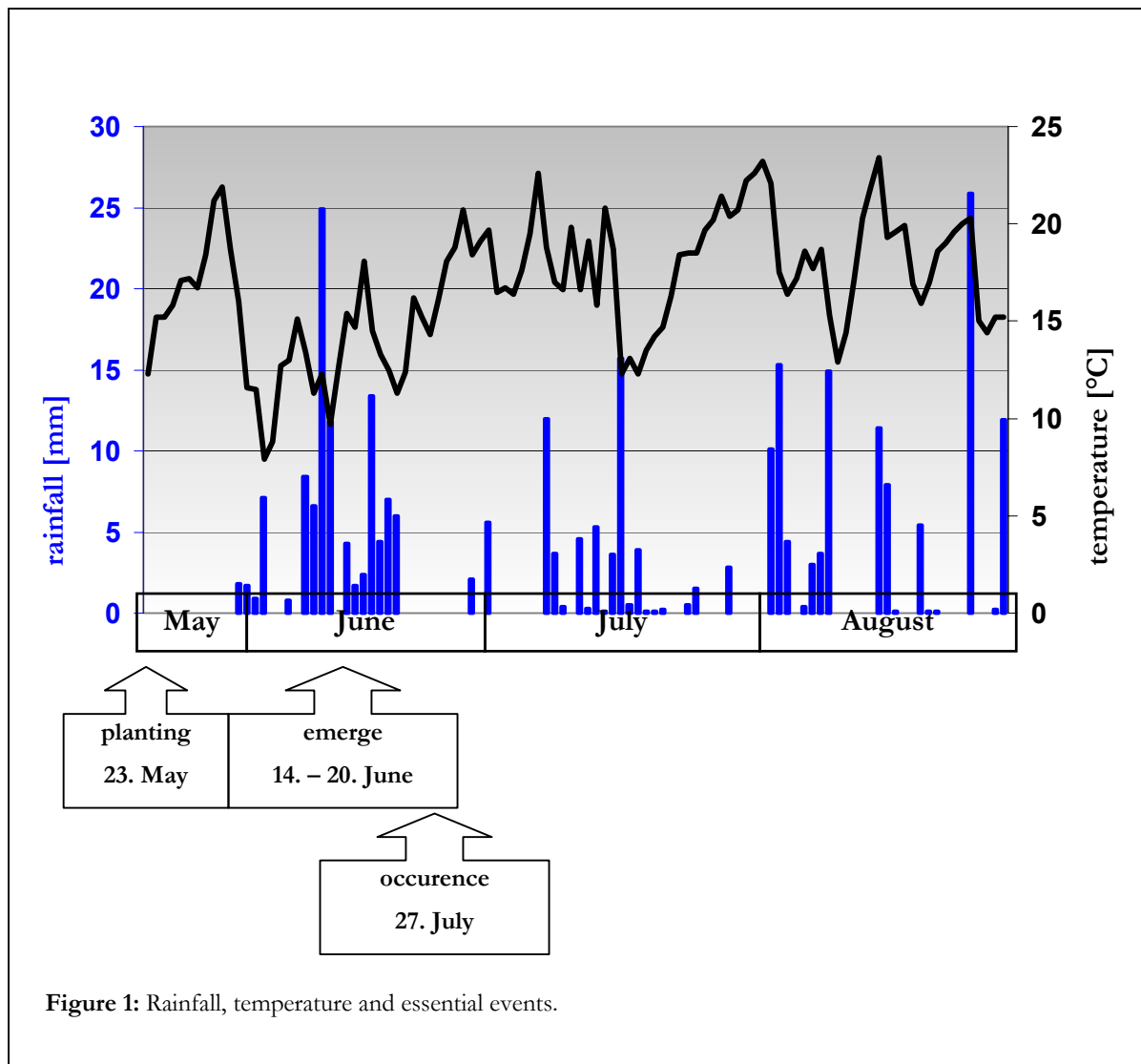
Results

In figure 1 rainfall, temperature and essential events are described. The columns represent daily rainfall and the line shows temperature. Also date of planting and emerge are described. The first visible stem infection appeared two weeks after the first plants had emerged!! The results of stem infection of both controls showed the expected development. The inoculated variant had higher infestation than the not inoculated one. This got visible at 14th of August.

To show a trend, we can summarize, that all variants increased in infestation since 10th of August. For a better understanding we had to point out two main effects. We found a dose-response in the variants treated with experimental fungicide. At 10th of August there was a decreasing stem-infection according to increasing fungicide-dose.

The second point shows the most amazing result of the whole trial:

If we compare the Metalaxyl-variants we see, that Metalaxyl with liquid-polymer showed only 19.8% infected plants at 23rd of August. This means a decrease of infestation for about 80.2% (figure 2)!



Despite the higher dose of Metalaxyl this effect cannot only be a result of dose response.

The second part of results deals with leaf infection. We call these symptoms “secondary infection”.

This time the inoculated control also showed higher infection.

In the following we will have a look at leaf-infections, that were estimated at 23rd of August and presented in columns

Figure 3 is an overview of the leaf-infection of all variants. Every treated variant showed lower infestation than the untreated control. Now let us have a look at dose response of leaf infection.

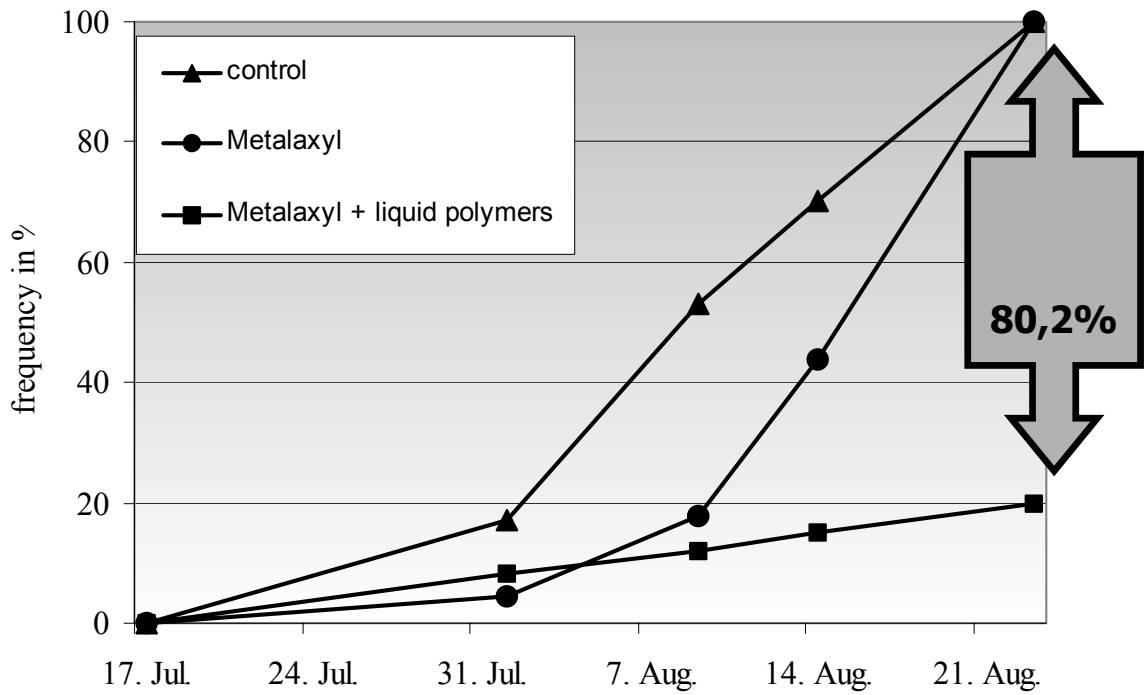


Figure 2: development of stem infection (include slow release)

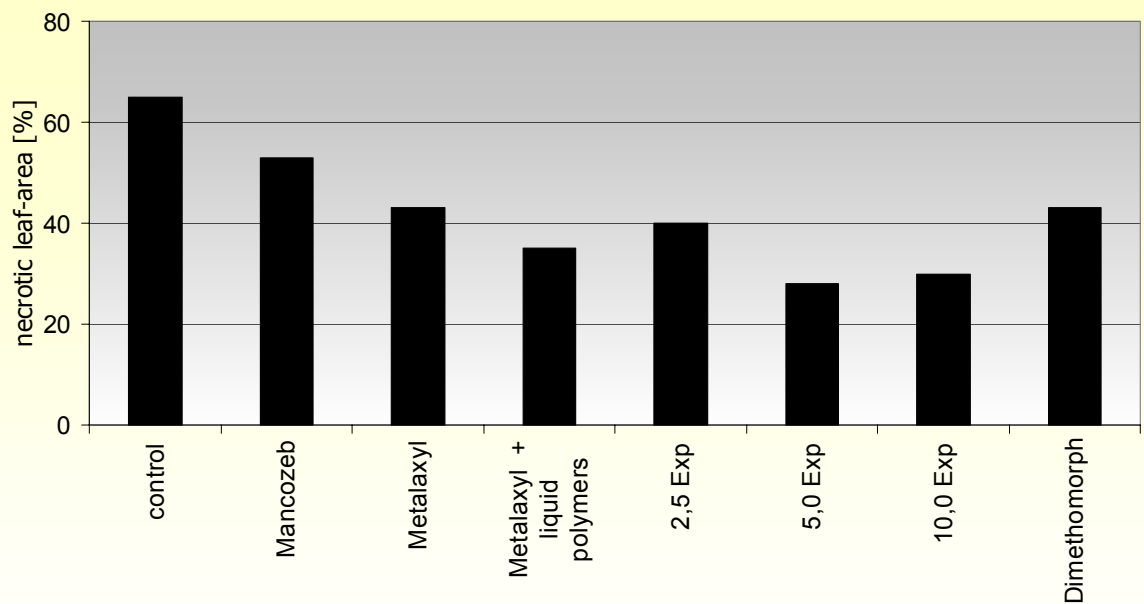


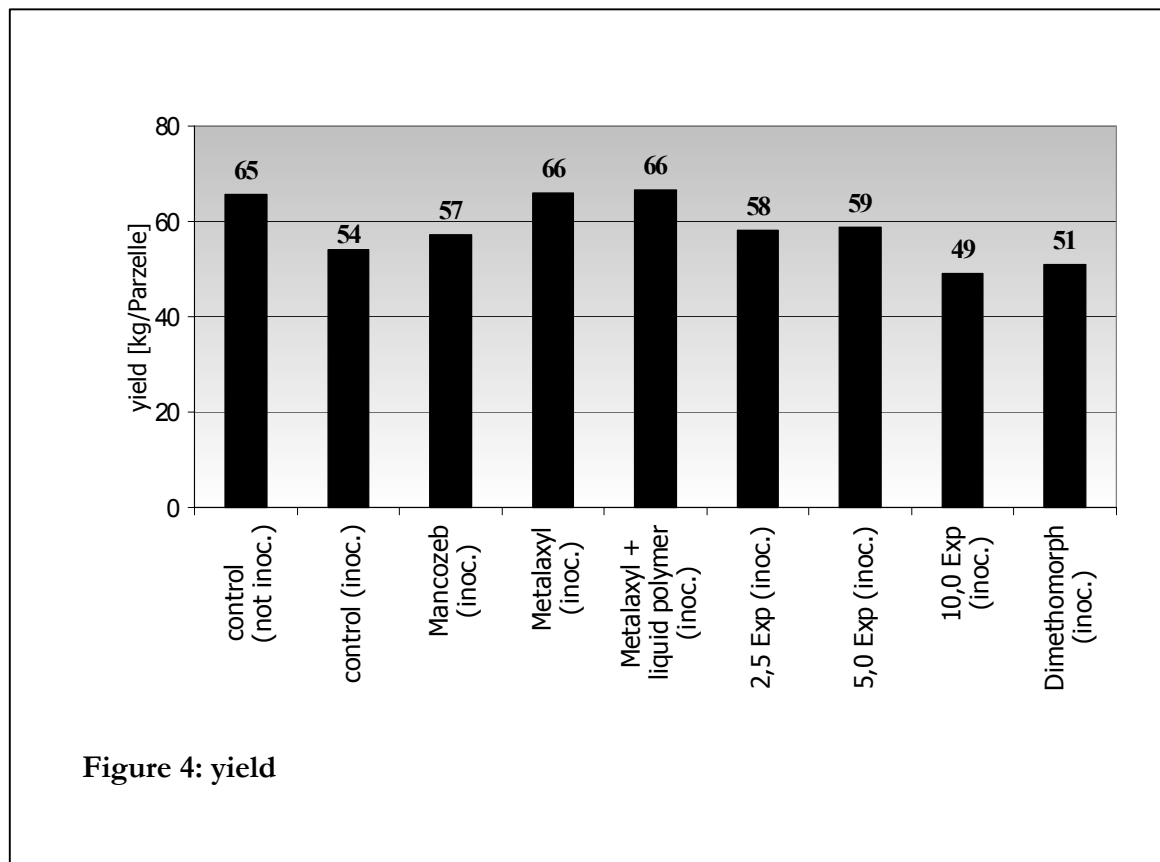
Figure 3: Leaf-infection at 23rd of August

In contrast to stem-infection we couldn't see a clear dose-response at the leaf-valuation. So the variant with 10 Exp had a higher infestation than the one with 5 Exp.

Also at leaf-infection the mixture of Metalaxyl and liquid-polymer provided the best results.

The last part of the results contains with the yield of the variants. The potatoes were harvested by hand and weighted in summary of all three replications. After that the middle value was calculated. All yields in kg per plot are shown in figure 4.

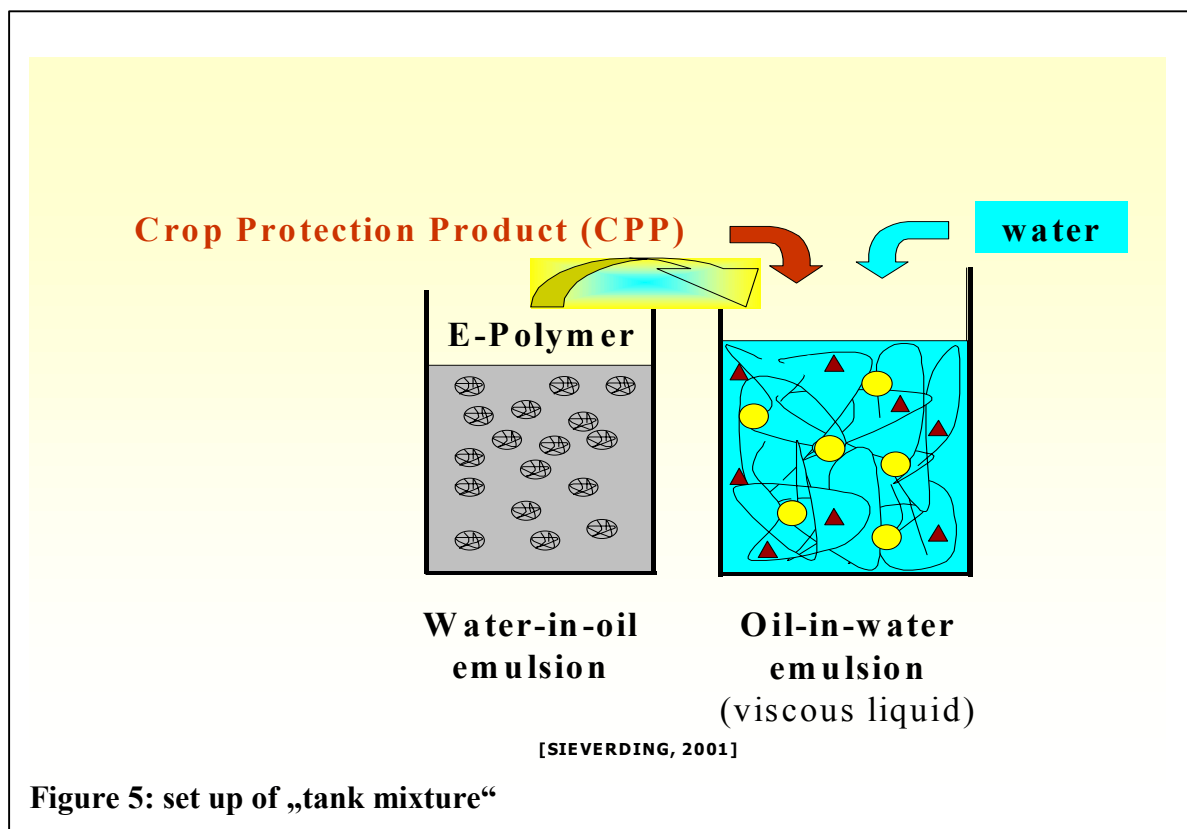
Compared to the untreated variant all tuber dressed potatoes were able to build up a higher harvest-value.



Formulation technology (slow release)

Now a few words about the liquid-polymers, which are characterized by the following points: It concerns a water-in-oil emulsion polymer, a viscous liquid superabsorber. This polymer is able to absorb many times the amount of its own weight.

The polymer consists of a mixture of superabsorbent polymer, esterified seed oil and water in a ratio 1:1:1. Additionally it contains emulsifiers. All in all it is a "water-in-oil-emulsion".



The set up of the “tank mixture” is presented in figure 5. It includes the emulsion-polymer, a crop protection product and water. Putting these compounds together, we will get an “oil-in-water-emulsion”, that is viscous liquid.

The points describe the oil-drops.

The triangles stand for the crop protection product.

The lines show the polymer.

The fungicide-molecules attach to the polymer in a reversible way. In the field fungicides slowly desolve and can be taken up by the plants.

Benefits of slow-release formulation are:

the continuous release of a.i. over a prolonged time period

the improvement of residual activity of a.i.

better selectivity by reducing phytotoxicity

the decrease of chemical reactivity of a.i.

the decrease of leaching of a.i.

Discussion

To summarize we can say, that tuber treatment was able to reduce primary infection in potato field there was a delay of outbreak of late blight during the season in spite of phenylamid-resistant population Metalaxyl showed high stem activity in combination with liquid-polymer Metalaxyl was able to suppress stem-infection with highest efficiency. The liquid-polymer showed amazing long-time effects although phenylamid resistant population existed.

Exp showed the best protection against leaf-infection, so it is possible, that the population of *Phytophthora infestans* shifted during the vegetation period (more resistance).

Outlook

After describing the results and the summary there are some effects, which could be possible with slow-release formulation:

Stem-infections could be suppressed with high efficiency for a long time

The period of first spraying application could be saved

An experimental design for other pathogens could be created

Possible phytotoxic consequences of a.i. could be reduced

Tuber treatment could be combined with other disease-control-strategies (e.g. *Rhizoctonia solani* + late blight + aphids).

At the end we have to realize, that further research in dose, formulation and possible fungicide-mixtures is necessary.

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Stems lesions of potato late blight: Biological features and fungicidal control of early-season infections

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Summary

Stems lesions of potato late blight appear throughout the growing season. When they develop late in the season, they often result in increased tuber blight. However, stems lesions also may appear very early in the season, usually a result of infection through contaminated tubers, airborne sporangia or overwintering oospores. Early-season stem lesions are dangerous to the potato grower because they serve as a focus of initial infection within the potato field. Laboratory bioassays reported here demonstrate that stem lesions develop more slowly than foliar lesions but sporulate longer, especially at lower temperatures (<18° C). Early in their development stem lesions are difficult to detect and deceptive in their symptoms. After infection and penetration into the stem, the pathogen initially infects the superficial hypodermal, epidermal and cortical tissues near the major vascular bundles, and grows longitudinally inside the stem along the major vascular bundles. Laboratory and field bioefficacy tests confirm that two cymoxanil-containing fungicides from DuPont, Tanos[®] 50DF and Curzate[®] M68, are very effective in reducing both size and sporulation of stem lesions and are useful components in an early-season late blight control program.

Key words: potato, late blight, *Phytophthora infestans*, stem lesions, early-season infection, fungicidal control, Tanos[®] 50DF, Curzate[®] M68, cymoxanil, famoxadone

Introduction

Late blight is familiar to most potato growers because of its numerous, rapidly expanding foliar lesions and its devastating effect on infected tubers. But the fungus causing this disease *Phytophthora infestans* also will infect all of the other parts of the potato, including the stems. Stem lesions may appear any time during the growing season. When they develop late in the season, stem lesions often are associated with increased risk of tuber blight (Bain *et al.*, 1997; Lapwood, 1977). But they also may appear very early in the growing season, soon after crop emergence (Van der Zaag, 1956). In some cases, the first observed symptoms of late blight in the crop have been stem lesions (Kapsa and Osowski, 1999).

There are several explanations for an apparent increase in the incidence of early-season late blight infection in general and especially in the form of stem lesions. First, new isolates in both the USA and Europe are becoming more aggressive, resulting in more rapid and destructive spread of disease (Kato, 1997; Turkensteen & Mulder, 1999). Increased infection efficiency and adaptation to low temperatures may result in earlier infections (Flier *et al.*, 1999). It is possible that another component of this evolution may involve more extensive colonization of parts of the host plant like the stem. This has been confirmed for tubers (Flier *et al.*, 1998) but not for stems. Second, research in the USA and Europe also has indicated that transmission of late blight may occur by contaminated tubers (Lambert *et al.*, 1998; Appel *et al.*, 2001). Diseased sprouts that develop from contaminated tubers often are characterized by stem lesions. Finally and more speculative, the potential for sexual recombination also means the threat of overwintering oospores, another source of early-season infections (Fernandez-Pavia *et al.*, 2001). Although little observational data is available, it seems likely that oospores may infect stems of emerging sprouts in contact with contaminated soil as well as leaves in the lower canopy.

The first objective of this research was to develop a better understanding of the basic biological features of stem infections by *P. infestans*. A second goal was to determine the levels of disease control against stem lesions provided by several commercial fungicides including Tanos[®] 50DF and Curzate[®] M68 from DuPont.

Materials and methods

For greenhouse bioassays, nine-week old potato plants (cv. Bintje) grown from meristem culture were inoculated in the third leaf axil with a 10- μ l droplet of a sporangial suspension containing 10^4 sporangia/ml. The *P. infestans* isolate used in these studies was from the highly virulent US-8 clonal lineage. Immediately after inoculation, plants were placed in an 18° C, 100% relative humidity (RH) dew chamber for 18 hours. After this incubation period, plants were moved to growth chambers with constant temperatures in the range of 17-27° C, depending on the objective of the study.

Fungicide treatments were first applied 24-72 hours after inoculation followed by a second application seven days later. Fourteen days after inoculation, plants were returned to the 18° C, 100% RH dew chamber for 24 hours to induce sporulation. Stem lesion length was determined by direct measurement. Sporangial production was determined by cutting the infected length of stem into 2-cm sections, placing these sections into a large glass culture tube containing 10 ml water, then agitating the tube in a Vortex mixer to dislodge sporangia. Sporangial density was determined with a Fuchs-Rosenthal counting chamber. After disease evaluation, stem sections were placed in FAA (10% formalin: 5% acetic acid: 50% ethanol: 35% water) fixative for 24 hours, then hand sectioned for microscopic analysis.

In a field test conducted in the summer, 2001, in Nambesheim France, field plots of cultivar Bintje potatoes were 2 rows x 5 meters. Following field irrigation, a total of 20 sprouts per plot (10 plants x 2 sprouts/plant) were inoculated at a leaf axil near the base of the sprout with a 10- μ l droplet of sporangial suspension (10^4 sporangia/ml). Each sprout was enclosed in a polyethylene bag overnight.

Two fungicide spray programs were evaluated in this test. The first program included a single application of Tanos® 50DF at 0.5 kg/ha, followed by two applications of Tanos® 50DF at 0.7 kg/ha, followed by two applications of Curzate® M68 at 2.0 kg/ha. The second program included a single application of Shirlan® at 0.3 liters/ha, followed by four applications of Acrobat® MZ at 1.5 kg/ha. Plots received the first of several fungicide applications on the day after inoculation. Five fungicides applications were made on a 6-8 day spray interval. Fungicides were applied in 300 liters/ha spray volume using a horizontal boom sprayer equipped with hydraulic flat-fan nozzles.

First stem lesions were observed 7 days after inoculation. The number of stem lesions was

recorded 25 days after inoculation and lesion length measured 13, 18 and 25 days after inoculation. Secondary stem lesions were first observed approximately 3 weeks after inoculation and their number recorded 27 days after inoculation.

Results and Discussion

Biological features. Stem lesions generally grow more slowly but sporulate longer than foliar lesions (Figure 1).

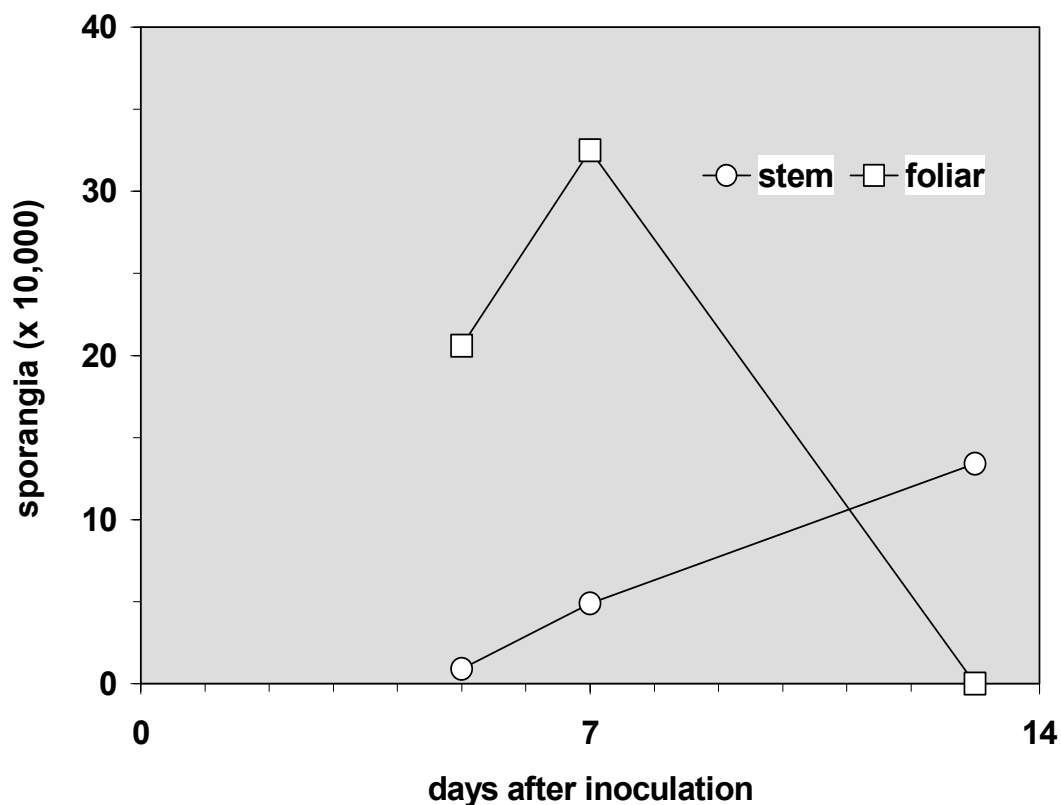


Figure 1. Spore production of stem and foliar lesions of *P. infestans* on potato at 18° C.

Stem lesion development also is affected by environmental factors, especially temperature (Shepherd and Geddens, 2001). At typical daytime temperatures for mid-season (24° C) in potato production regions of the USA, individual stem lesions expand rapidly, sporulate abundantly for approximately one week and then become quiescent. The fungus, however, may survive prolonged periods of high temperature in stem lesions but not foliar lesions (Kable & MacKenzie, 1980). The situation changes dramatically, however, for cool temperatures characteristic of the early weeks after planting. At 17° C, stem lesions develop

more slowly, but continue to produce spores over a longer period compared to higher temperatures (Figure 2).

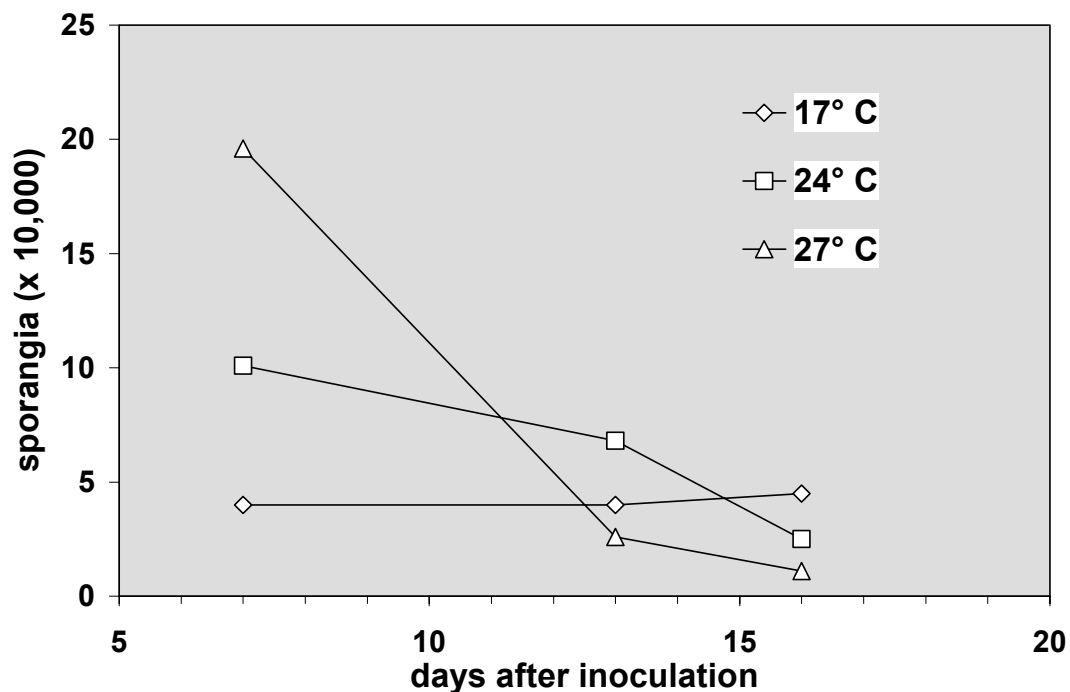


Figure 2. Effects of temperature on sporulation of stem lesions of *P. infestans*. Note that low temperatures also favor indirect germination of sporangia to produce zoospores.

In bioassays at cool temperatures, stem lesions are very deceptive and even when sporulating can be very difficult to detect in their early stages of development (Figure 3). Infected plants appeared healthy with no visible sign or symptom of infection until a week or more after inoculation. Based on these observations, we believe that many primary stem lesions appearing very early in the growing season probably are missed because of their deceptive appearance.

The difficulty of detection and prolonged sporulation associated with stem lesions at cool temperatures create a dangerous situation for potato growers because initial foci of infection may become established and abundant secondary inoculum produced before control measures are begun.

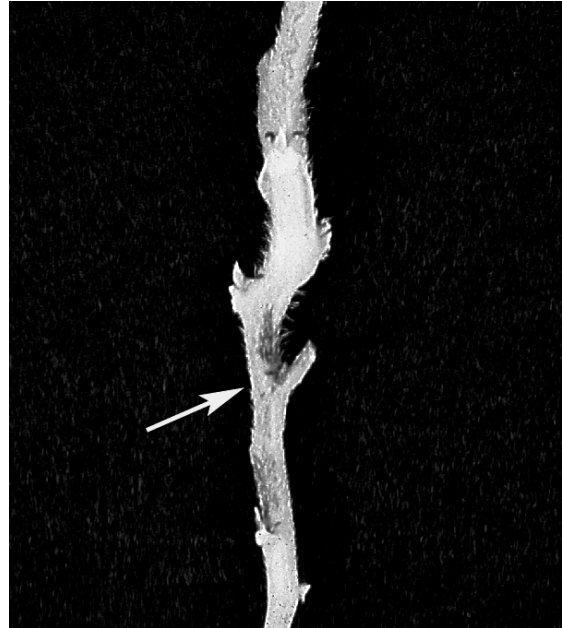


Figure 3. Stem lesions are difficult to detect in their early stages of development. Plants maintained at 18° C and observed 7 days after inoculation. Arrows indicate point of inoculation. Stem on right was soaked in FAA fixative to remove natural pigments.



Figure 4. Stem lesions may lead to foliar lesions. Arrows indicate point of inoculation in leaf axil and initial sporulation on leaflets. Plants maintained at 18° C and observed 7 days after inoculation.

After infection of the stem, the pathogen also easily grows from stem to the leaves. We saw several examples where the pathogen grew from an established stem lesion out through the leaf petiole and into the leaf, often beginning to sporulate as the new foliar lesion expanded (Figure 4). Based on visual symptoms, anyone observing these plants may conclude that the

pathogen initially infected the leaf and grew from the leaf down into the stem.

Microscopic examination of infected stem sections revealed that the pathogen initially colonizes the superficial epidermal, hypodermal and cortical tissues outside the vascular cylinder (Figure 5). The fungus also favored areas directly adjacent to the three major vascular bundles. Examination of the exterior of the infected stem showed that lesions expanded longitudinally along the stem ridges that are adjacent to the major vascular bundles on the exterior of the stem.

There may be several advantages for the fungus to favor these regions of the stem for colonization. They contain the nutrient-rich phloem and xylem tissues. By restricting initial growth to those areas outside the vascular cylinder, the integrity of the stem is not compromised by destruction of the structural tissues of the pith, thus ensuring host and pathogen survival for an extended period. Finally, the porous sieve tubes and tracheids of the vascular bundles may serve as conduits for rapid growth of the fungus up and down the stem into uninfected areas.

Fungicidal control. A key objective of this work was to determine whether DuPont's Curzate[®] M68 and the recently introduced late blight product, Tanos[®] 50DF, controlled stem lesions. In a series of curative, postinfection laboratory bioassays, Curzate[®] M68 and Tanos[®] 50DF significantly reduced both lesion length and sporulation compared with an untreated control and commercial standard (Figure 6).

Field data also demonstrated that a program including an initial application of Tanos[®] 50DF at rosette stage, followed by 2 applications of Tanos[®] 50DF plus 2 applications of Curzate[®] M68 in the rapid growth phase of canopy development gave complete control of both primary and secondary stem lesions (Figure 7).

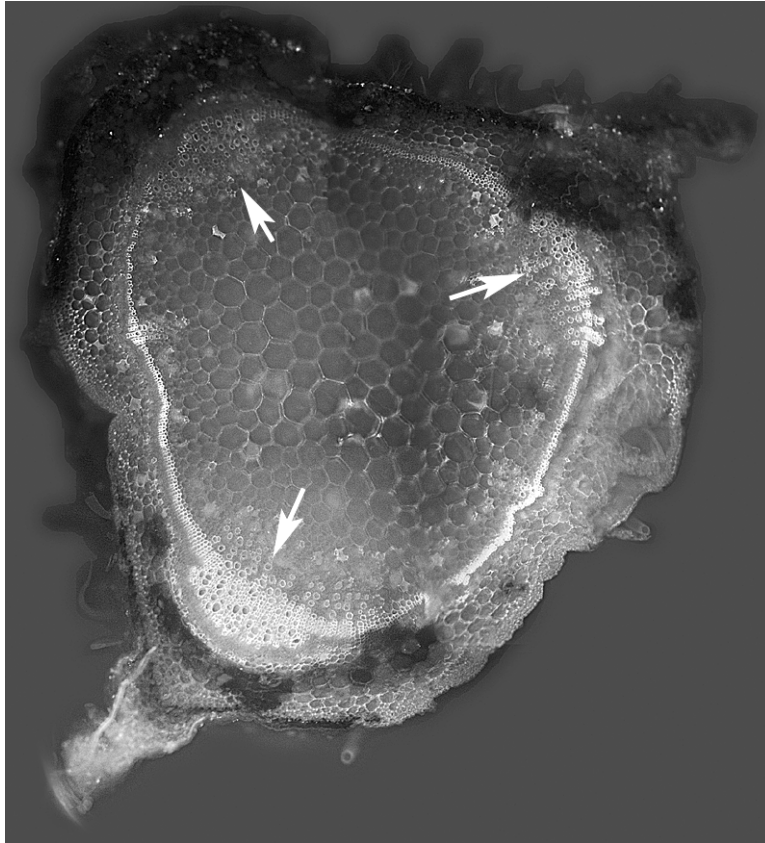


Figure 5. Cross section of potato stem infected with *P. infestans*. Dark areas in epidermis, hypodermis and cortex tissues outside the central vascular cylinder indicate areas of infection. Arrows indicate major vascular bundles.

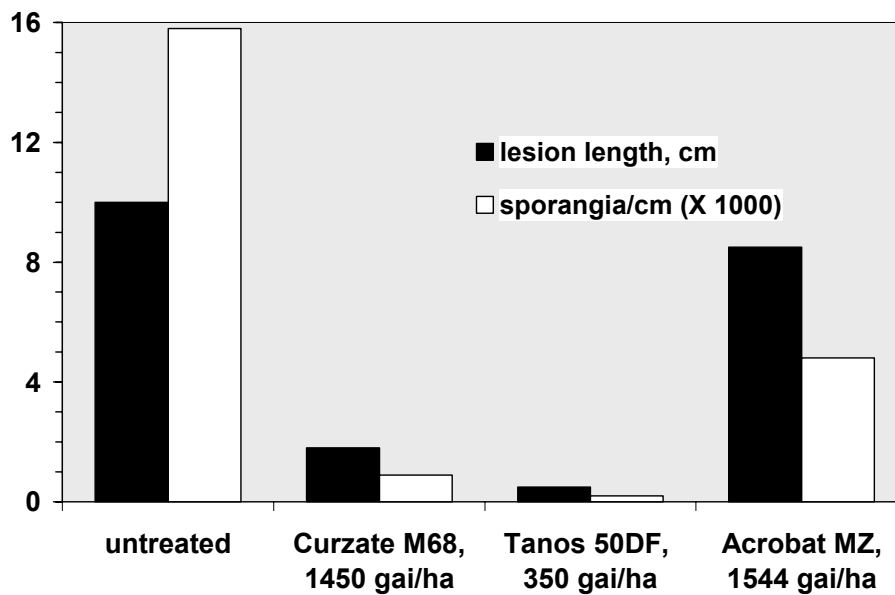


Figure 6. Fungicide inhibition of stem lesion size and sporulation. Fungicides were applied twice on a 7-day interval with first application 1-3 days after inoculation. Data represent average of 4 tests, each with 4 replications. Plants were rated 14 days after inoculation.

Spray Program	Average no. of stem lesions per plot	Average Lesion size (cm)			No. of secondary stem lesions
	25-Jun	13-Jun	18-Jun	25-Jun	27-Jun
1 x Tanos 0.5kg 2 x Tanos 0.7kg 2 x Curzate M 2 kg	0	0	0	0	0
1 x Shirlan 0.3l 4 x Acrobat MZ 1.5 kg	11.3	3.8	7	9.3	0
Untreated	12.8	4.2	7.7	10.5	17

Figure 7. Effects of fungicide programs on stem lesions of late blight in the field. First curative fungicide application was made one day after artificial inoculation of the stems.

These data are confirmed by recent research from Washington State University (USA) that demonstrated that a mixture of Curzate[®] 60DF plus mancozeb, very similar to Curzate[®] M68, effectively reduced stem lesion length and sporangia production (Johnson et al, 2000).

Although both Curzate[®] M68 and Tanos[®] 50DF were highly active, Tanos[®] 50DF consistently gave better control of both stem lesion size and sporulation. The higher concentration of cymoxanil at the recommended field use rate of Tanos[®] 50DF probably was the most important factor accounting for its superior curative performance in these tests. But we believe that famoxadone, the other active ingredient in Tanos[®] 50DF, also contributes to the control of stem lesions in the field by providing extended protection of the stem from both primary and secondary infections.

Late blight management programs must be designed to effectively control both foliar and stem lesions before crop canopy closure. Applications of products containing cymoxanil, in combination with an appropriate protectant fungicide like mancozeb (Curzate[®] M68) or famoxadone (Tanos[®] 50DF) are effective, flexible and affordable early-season late blight management tools.

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**Supervised protection of potatoes in a network of fields of the group Pom'
Alliance conducted by the SRPV and the FREDEC**

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Summary

The potatoes require a supervised control against late blight and aphids: indeed, those can cause significant damage. A systematic fight is very effective, but it consumes a large amount of pesticides and is not very respectful to the environment. Eager to adopt a step of supervised production with its growers, the group Pom'Alliance approached the Regional Plant Protection Services (SRPV) and the Regional Federations of Defense against the Enemies of Cultures (FREDEC) to develop a warning system against late blight and aphids. Since 1997, this follow-up is set up in Nord/Pas-de-Calais, Picardy, Centre, and Champagne Ardenne. The results obtained are very encouraging and show that it is possible to decrease the number of sprays by maintaining the quality of the final product.

Key words: Late blight, model, supervised control, integrated control, Pom'Alliance.

Introduction

The new market trends of the fruit and vegetables push many producers and traders to change their practices and to direct themselves either only towards one objective of quantity

but also quality. " To produce clean " becomes a current expression in this sector, and one of the surest means to arrive there and to find new methods of fight allowing to reduce the quantities of chemicals applied to the productions intended for consumption. The objective is to maintain the quality of the final product while adopting a supervised (integrated) control, respectful of the environment. To meet these aims, the group Pom' Alliance, producing potatoes for human consumption for the fresh market in several areas of France, turned to the SRPV and the FREDEC to set up follow-ups in its producers.

Objectives

- ⇒ To set up a "supervised" integrated control on potatoes for human consumption.
- ⇒ To reduce the number of the fungicide and insecticide sprays on the potato crops.
- ⇒ To ensure the quality of the product.
- ⇒ To extend the follow-up of the fields to a greater number of farmers

Material and methods

The Plant Protection Services and the FREDEC have great experience in the fight against late blight and aphids. Since many years, Agricultural Warnings are diffused to the growers. These messages inform the producers about the levels of risk by micro area. For the Group Pom' Alliance, these messages are not sufficient. The group is eager to bring a more significant help to its producers to supervise the protection of potatoes. In order to answer waitings of the various partners, an operation of advice for each field is set up.

This follow-up of fields extends in several areas:

Nord/Pas-de-Calais

Picardy

Champagne Ardenne

Center

In each area a follow-up of about twenty fields is set up. Complete recommendations of treatment are carried out there.

In order to work out the most effective possible recommendations, i.e. allowing to minimize the number of fungicidal treatments and insecticides while avoiding the entry of the late

blight in the field and an important population of aphids. Informations coming at the same time from the field, the producer and the models are necessary.

❶ *Field follow-up (feedback of the fields):*

Groups of one to three fields of reference are formed.

The fields of reference will preferably be gathered by three (even variety or even group of varietal sensitivity to the late blight).

It is significant to define fields of reference by variety and geographical sector.

These fields are observed twice per week:

an observation is carried out by the technicians of the SRPV / FREDEC

an observation is carried out either by the grower, or by the technician of the group Pom' Alliance

On these fields, observations of the pathogens are carried out. An assessment on the level of the diseases is also carried out (late blight, alternaria...), as well as a counting of the aphids on 20 to 30 plants. That makes it possible to define a mean level of population. Moreover, some samples of aphids are taken to determine the dominant species.

❷ *Study of the data*

In addition to the field observations, the SRPV has other elements to do an effective integrated control:

At each rain or irrigation, the farmers send a fax to the SRPV indicating the duration and the quantity of fallen water.

At the time of the visits on the fields, samples are brought back to the laboratory in order to know the cause of a symptom. These informations influence the decision of treatment, or not-treatment.

The observation of the growth is also a significant point.

The attentive observation of the environment of the field is also necessary to apprehend the risk of development of an epidemic, or an invasion of aphids. Thus the presence of a garden contaminated by the late blight near a field can explain the contamination of this one in spite of a strategy of powerful fight.

The epidemic models of the late blight bring very significant information on the evolution of the epidemic. The Plant Protection Services use the models Guntz-Divoux and Milsol with the data of the weather stations. It is significant to work with reliable climatic data. This is why a daily remote maintenance of the weather stations is made. Information of risk resulting from the models Milsol and Guntz-Divoux will make it possible to know the periods of contamination and sporulation of the late blight.

③ *Diagnosis:*

All these data allow to have a realistic diagnosis of the fields followed for this integrated control. All these elements will be daily consulted in order to establish strategy of the fungicide and insecticide sprays.

It is possible to anticipate the risks (late blight, aphids...) and thus to carry out the treatment appropriate to the convenient period. On the level of the late blight, the treatments are modulated according to the sensitivity of potatoes to the disease. Protection will be done before the periods of release of spores envisaged by the Milsol model. The choice of the product is a function of weather forecasting (precipitations), and of the irrigation.

On the level of the aphids, a treatment will be recommended when the populations reach 10 aphids on average by leaf. The choice of insecticide depends on the dominant species.

Two types of message are carried out:

For the farmers followed field by field (where observations are carried out) a personalized message is sent. They receive several times per week an assessment on the sanitary state of their fields. They know if they have to spray, and what product they have to choose. The transmission of information is done by fax. The farmer will indicate by return of fax if it could follow the recommendations.

For the farmers who have potato fields located around the reference fields, a message of information on the parasitic pressure is sent.

The message gives an assessment on the level of late blight (presence in the fields and risks by the level of the models) and on the populations of aphids by variety and sector. On these messages, it is also indicated the periods when it is necessary to have a field under fungicidal protection and the most adapted products for the period. The farmer will decide.

For the farmers who follow the supervised control, a permanent telephone service can be contacted twice per week. Meetings on fields with the growers are organised.

Results

The areas where the follow-ups are carried out are rather different:

For Nord/Pas-de-Calais, the climate is rather oceanic, rather favourable to the disease. The fields are of small size. Many waste piles and contaminated gardens increase the risks of primary contamination. The area has a long tradition of production of potatoes.

In Picardy, the risks are similar to the Nord/Pas-de-Calais Area, but the structures are larger.

In Champagne Ardenne, the climate is less favourable to the disease. The fields are large and are generally irrigated. The production of potatoes for human consumption is rather recent.

In Center the continental climate is less favourable to the disease. The crops are under irrigation. This area belongs to the new zones of production of potatoes.

The first year of follow-up, in 1997, is regarded as experimental. The conditions of development of the disease are favourable at the beginning of season. In August, the climate is less favourable but it strongly increases at the end of the season. This first year of follow-up is very interesting because no problem of late blight is observed in the crops. A low saving of fungicidal sprays is realised, but the producers and Pom' Alliance are very satisfied with the operation. It is on the level of the insecticide recommendations that the economies are most significant : 50 % of the fields did not receive treatment. The participation of the producers in the level of the operations is good.

The follow-up is renewed in 1998, 1999, 2000 and 2001. We will show here some examples of the integrated control conducted in 1999 in Picardy (cf table I), in 2000 out of Ardenne Champagne (cf table II) and in 2001 in the Nord/Pas-de-Calais Area (cf table III).

1999 in Picardy:

The risks are significant in June with late blight on waste pile. In July, the storms wash the products, but the return of the sun in August decreases the risks. The control of the disease is good during all the season, with a significant use of products containing cymoxanil. On the harvest there is no late blight on tubers. On the supervised fields, savings in treatment are relatively low (1 or 2). For aphids, 85 % of the followed fields did not receive insecticide.

Results 2000

In 2000, in Champagne Ardenne, the risks of late blight were very high in June with symptoms on many fields. But in the supervised fields, control was good (very few symptoms on leaves, and no disease on tubers) and they are 4 treatments less than the farmer practice.

On aphids, the cancelled treatments are about 50 %.

Results 2001

In 2001, the risks were moderate in June, and very high on July with many symptoms in the fields and on tubers. In the supervised fields, about 2 to 3 fungicidal treatments depending on the varieties are cancelled in June, the control of the disease was very good on leaves and tubers when many symptoms are observed in the farm of the growers who have a routine practice. No treatment was sprayed on aphids.

Conclusion

This planning with Pom'Alliance trader shows the interest to implement a true policy of supervised (integrated) control of the crops enemies. It is possible to decrease the number of fungicides especially on less sensitive varieties. The growers are satisfied because the late blight and the aphids are correctly controlled.

But this approach is very expensive and to satisfy a greater number of growers, evolutions of the advice and tools are envisaged.

Table 1. Picardy 1999

Variety	Number of fields by variety	Average number of treatments	Duration of the vegetation in weeks
Agata	1	12	10
Amandine	2	10.5	8
Charlotte	4	10	8
Chérie	2	12	9
Franceline	4	11	12
Innova	2	13	11
Maritiéma	1	15	14
Nicola	4	13	12
Ratte	2	14	10
Samba	2	12.5	10
Turbo	1	No data	14

Table 2. Champagne Ardenne 2000

Variety	Number of fields by variety	Average number of treatments	Duration of the vegetation in weeks
Agata	3	10	11
Charlotte	3	9	10
Chérie	2	9	9
Innovator	1	14	15
Monalisa	2	13	14

Table 3. Nord/Pas-de-Calais 2001

Variety	Number of fields by variety	Average number of treatments
Agata	1	15
Charlotte	1	10
Innova	3	14
Maritiéma	1	13
Nicola	2	13
Victoria	1	16

Influence of irrigation on the wash-off of fungicides in field grown potato

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Summary

Fungicides possess variation in rain-fastness which influence the length of interval between sprays in rainy periods and in connection to irrigation. It is therefore important to know which fungicides can be used before a high risk period involving rain and before irrigation without the need for a renewed spray afterwards. In this study, we have tried to establish a system under field conditions involving irrigation and artificial inoculation with a mixture of sporangia and zoospores to simulate natural infection. This field trial showed that it is possible to study the effect of irrigation on the wash-off of fungicides and the following influence on the control of late blight under field conditions. At a low disease pressure, there was no difference on six fungicides in efficacy up to 20 days after inoculation

Introduction

Research on rain-fastness of fungicide deposits on potato leaves has primarily been carried out on leaves from potted potato plants or detached field grown leaves in bioassays carried out under controlled conditions (Bruggen *et al.*, 1986; Kudsk *et al.*, 1991; Schepers 1996). In this study, we have tried to establish a system under field conditions involving irrigation and artificial inoculation with a mixture of sporangia and zoospores to simulate natural infection. In the control of late blight in potato caused by *Phytophthora infestans*, a decision support system (DSS) is an important tool for a precise timing of the fungicide application. In most DSSs, the weather prognosis has become one of the key components because the reliability

of these prognosis models have improved and because late blight needs to be controlled preventively. Fungicides possess variation in rain-fastness which influence the length of interval between sprays in rainy periods and in connection to irrigation. In Denmark, it is a normal procedure that potato growers perform a renewed spray of most fungicides after a rainy period or after irrigation. The major aim of our research is a reduction in fungicide use in potato. To achieve this goal, it is important to avoid the unnecessary sprays and then make the preventive sprays according to needs. It is therefore important to know which fungicides can be used before a high risk period and before irrigation without the need for a renewed spray afterwards.

The objective of this study was to investigate the influence of irrigation on fungicide deposits in field grown potato.

Material and methods

In 2001, a small plot (two rows, 1.5 x 5 m) field trial was established at the Research Centre Flakkebjerg. Six fungicides (Dithane NT, Shirlan, Sereno, Acrobat WG, Ranman) were tested for the rain-fastness on potato leaves (Table 1).

Table 1. Fungicides tested for the influence of irrigation on the efficacy toward late blight in potato in field trials.

Fungicide	Dose per ha	Active ingredients
Dithane NT	2,0 kg /ha	Mancozeb
Shirlan	0,4 l/ha	Fluazinam
Sereno	1,25 kg/ha	Mancozeb + fenamidone
Acrobat WG	2,0 kg/ha	Mancozeb + dimethomorph
Ranman	0,35 l/ha	IBE 3878
Electis	1,8 kg/ha	Zoxamide + mancozeb

The fungicides were applied the 26th of June. Each plot was only treated with fungicide once. The sprayer was mounted with Hardi flat nozles (ISO) 03 3.75 Bar and a speed of 4 km/hr. All treatments were arranged with four replicates in a split-plot design with a non-treated plot for each fungicide. The field trial was heavily irrigated before the fungicides treatment to assure the soil to be saturated with water. Next day (27th of June), different plots were irrigated with 0, 15 and 50 mm water within a period of approximately ten minutes.

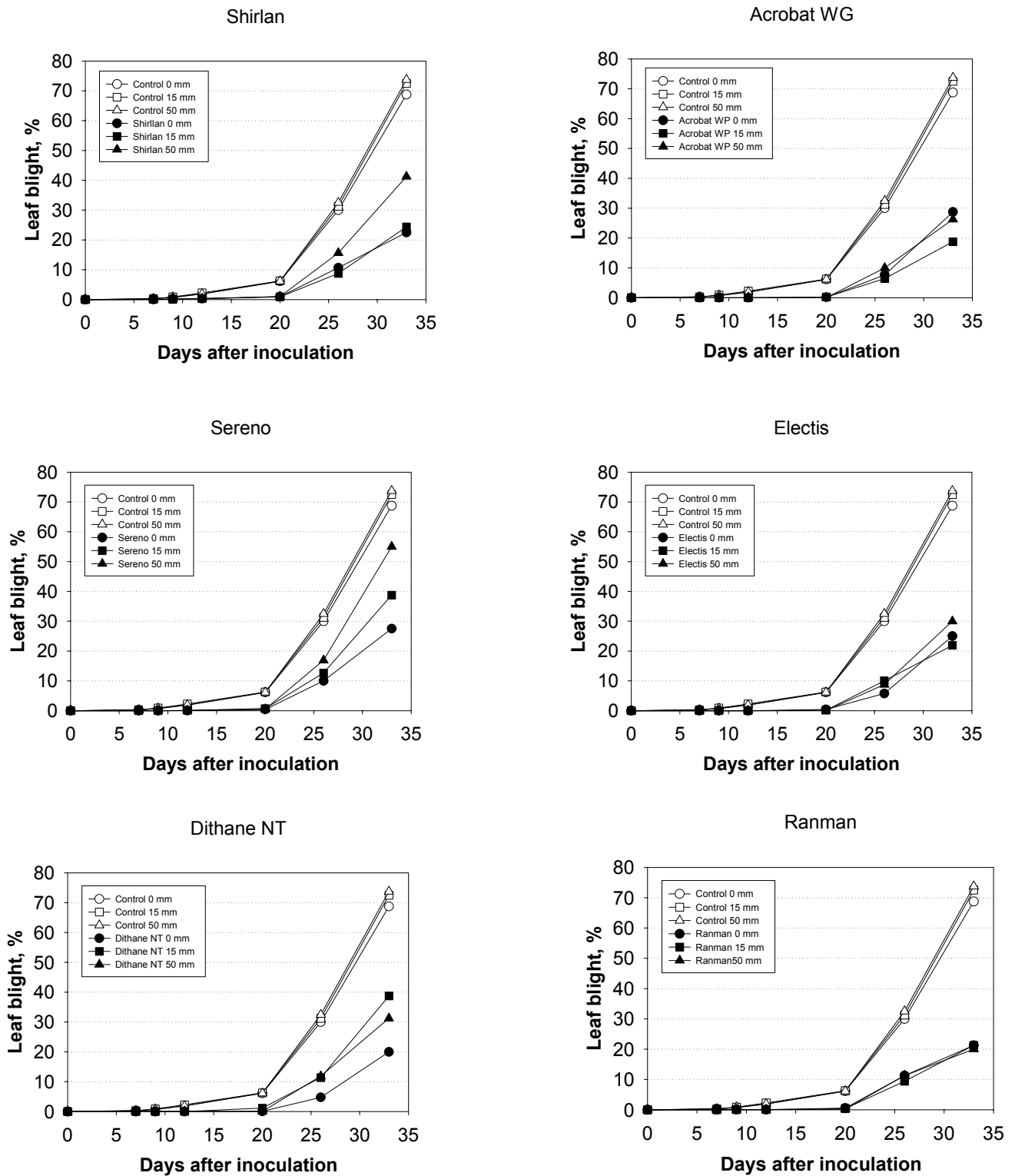


Figure 1. Percent potato late blight on leaves after treatment with six different fungicides, followed by 0, 15 and 50 mm irrigation and artificial inoculation with *Phytophthora infestans*.

In the evening, all plots were inoculated with a diluted sporangiasuspension (500 sporangia/ml) of a mixture of six different isolates of *P. infestans* (all A1) isolated in Denmark in 2000. After inoculation, all plots were covered with a fibre cloth to keep high moisture content and favourable conditions for infection during the night. The plots were inoculated at a time where blight was only registered in Jylland (Western part of Denmark) (Pl@nteInfo) and not at the Research Station at Sjælland (Eastern part).

Results and discussion

This trial shows that it is possible to study the effect of irrigation on the wash-off of fungicides and the following influence on the control of late blight under field conditions. The disease progress in this field trial was not as fast as seen in other trials using the same inoculation technique (Bødker and Nielsen 2001, Nielsen and Bødker 2002). At this low disease pressure there was no difference on the six fungicides in efficacy up to 20 days after inoculation (Fig 1). All combinations of fungicide and irrigation were significant lower than irrigated controls without fungicide treatments. After 33 days, only Sereno treated with 50 mm water showed a significant higher level of leaf blight compared to the other fungicides. However, a 33 day long interval is not relevant under practical conditions but is measured to see possible long-term effect of fungicide wash-off. Ranman seems not to be influenced by irrigation.

The field trial will be repeated in the growing season 2002 supplemented with a study of detached leaves from the field trial in a rain simulator.

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BlightWatch - A Spatially Interpolated System for the Calculation of Smith-Periods in the UK.

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Keywords: *Phytophthora infestans*, potato blight, forecasting systems, BlightWatch

Introduction

A late blight forecasting scheme for England and Wales, begun in 1950 (Large, 1959), was based on the Beaumont Period (Beaumont, 1947). The validity of the Beaumont Period was evaluated at the time using the Meteorological Office's network of some 40 synoptic stations. The Smith Period (Smith, 1956) replaced Beaumont in 1975 and, although developed empirically, remains the most widely used system in the UK. A full Smith Period has occurred if, on each of two consecutive days from 0900h GMT:

- the minimum air temperature was at least 10°C, and
- there were at least 11 hours with a relative humidity of at least 90%

Within the calculation there is a provision for a 'Near Miss'. This occurs when the temperature criterion has been satisfied but the number of hours with a high relative humidity totalled only 10 on one or both days (Croxall and Smith, 1976).

In the UK, routine fungicide spray programmes are still perceived to be the most effective means of controlling blight. They are invariably applied as prophylactic treatments at regular intervals either from a specific growth stage or according to local risk of blight but usually, well before the disease becomes established in the crop. There is a reluctance by growers to rely on forecasting blight as a means of targeting individual fungicide sprays for a number of

reasons, not least the perceived robustness of the forecasting models(s) currently available (Bradshaw *et al.*, 1998). Blight forecasting based on data collected from synoptic meteorological stations may have limitations due to the coarse grain nature of data capture. The availability of portable weather stations has recently raised considerable interest in using meteorological data captured by ‘in-field’. Comparisons have been made using blight forecasting models specifically developed for the purpose, with existing schemes such as Smith (Hims *et al.*, 1995). However, the accuracy of blight forecasting using ‘in-field’ monitors will depend on where they are situated in relation to field topography, potential problems with sensor drift and also the forecasting model being used (Bradshaw *et al.*, 1998; Hardwick *et al.*, 2000a & 2000b; Taylor *et al.*, 1998).

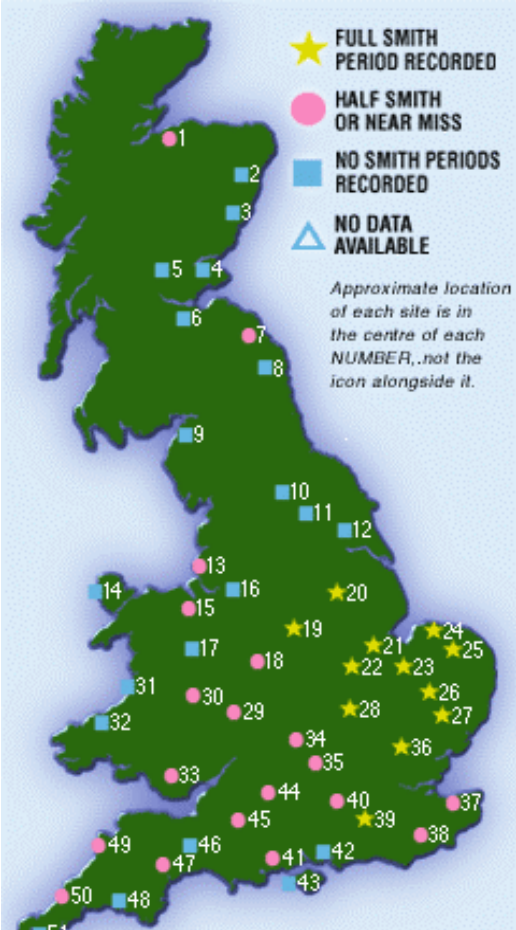


Figure 1. Example of Weekly Smith Period Map

The UK Met Office maintains and operates a network of over 200 weather stations that report information on a real-time basis. These stations are a mixture of manual and automatic sites, some of which report every hour, while others report at less regular intervals (3 or 6 hourly). The traditional method of calculating Smith Periods relies upon the network of stations taking hourly readings of which there are some 140 in the UK. However, a significant proportion of these are situated in areas where potatoes are not usually grown. This leaves a network of around 75 stations for which Smith Periods can be calculated. In essence this network produces spot values and makes no attempt to estimate conditions between each location (Figure 1: Source Syngenta web site).

In this paper, we compare the occurrence of Smith Periods calculated at weather stations with interpolated values calculated by the BlightWatch system and delivered through the internet via the web site 'potatocrop.com'.

An example of the calculated BlightWatch output is given in Figure 2. The daily values, covering the previous two weeks, show whether the location had no Smith Periods (Nil), a Near Miss (NM) or if the criteria were satisfied on that day (P).

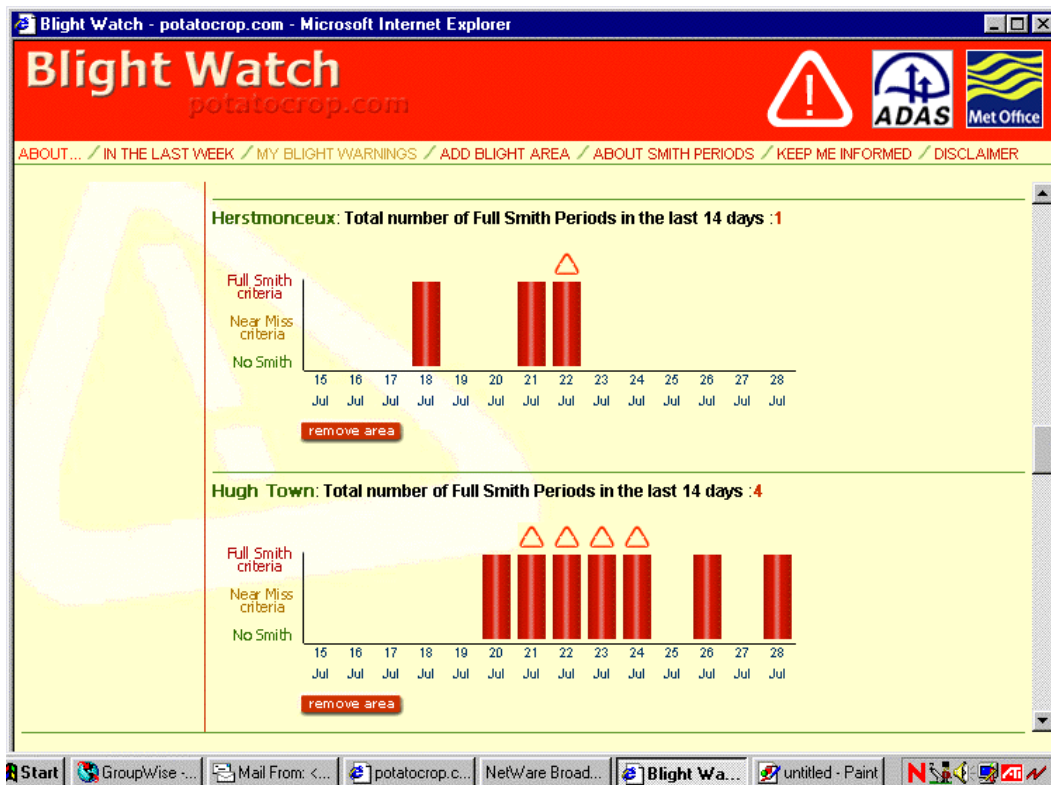


Figure 2. Illustration of BlightWatch Web Page : 15 - 28 July 2001

Materials and methods

Meteorological Records

During the summer of 2000, the opportunity arose to adapt, for agricultural applications, existing Met Office interpolation routines using daily temperature and wind speed values. These same interpolation routines were applied to the available hourly records from the whole Met Office network of over 200 stations. It was considered more robust to interpolate dew point temperatures, rather than relative humidity (RH) values, with RH subsequently calculated from the values of dry bulb and dew point temperatures. Details of the interpolation routines are given at Annex 1.

The existing Met Office grid of points for which interpolations are performed (numbering

653 over the whole of the UK) was adopted directly for the BlightWatch project. This gives a ratio of roughly three BlightWatch polygons to every recording station, thus avoiding over-interpolation of the original data.

No part of the UK was excluded from the system resulting in coverage from the Isles of Scilly off the southwest coast of England, to the Channel Islands through the mainland up to the north west of Scotland. Once registered, users could select up to ten areas using either postal towns or postcode areas. BlightWatch was formally launched in May 2001 on the web site "potatocrop.com". The web site also contains supporting information from ADAS plant pathologists and agronomists regarding, for example, recommended spray intervals.

In order to validate the system, the database of Smith Periods held within BlightWatch was used in a series of comparisons against station-based records. Several Met Office sites were selected for this part of the study.

Records from the Channel Islands were chosen because of the maritime climate and as there are only two Met Office reporting stations - one each at Jersey and Guernsey airports. Interpolated Smith Period data were also compared with data from a network of automatic weather stations maintained on Jersey by the Department of Agriculture & Fisheries (Rosemary Collier, pers. comm.).

During the course of the study, relative humidity sensor calibration and its' effect on the frequency of Smith Periods was investigated. Two RH recording systems are in common use - calculations which are based upon wet and dry bulb temperatures, and electronic sensors of which there are many designs and manufacturers. Using hourly weather records from a Met Office site in Northern Ireland, the sensitivity of Smith Periods to RH probe calibration was tested by increasing and decreasing the RH value by set amounts and recalculating the number of days satisfying the Smith Period criteria.

Statistical analysis

There are some general problems with interpreting measures of agreement as percentages (or using chi-square tests) but one recommended indicator of observed agreement is the kappa statistic (Cohen, 1960). However, the data in most of the tables have a high number of sparse data cells making the basis of tests of agreement somewhat invalid. It was therefore decided to let the data stand by themselves, as the agreements are self-evident.

Results

BlightWatch compared to Met Office Station Values

The first test examined the internal consistency of the BlightWatch system by comparing the occurrence of Smith Periods at one of the Met Office sites. Jersey Airport met. station was chosen because each of the main Channel Islands forms a unique polygon within the BlightWatch system. The results from this comparison are shown in Table 1. These are **not** the number of full Smith Periods, as in this comparison, the criteria are collated on the basis of individual days, not consecutive days.

Table 1. Number of Days Satisfying the Smith Criteria recorded at Jersey Airport and compared with BlightWatch Polygon Values for Jersey (1 May to 31 July 2001).

BlightWatch Area	Jersey Airport Met Station		
	Nil	NM	P
Nil	64	1	4
NM	0	2	1
P	0	0	20

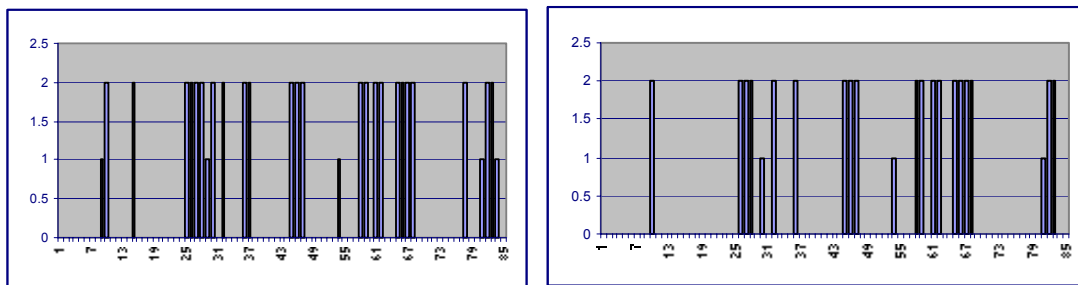
Smith Period criteria and Near Misses were recorded on 25 and 3 days respectively at Jersey Airport. There was agreement between BlightWatch and Jersey Airport for Smith criteria on 20 days and on two of the three occasions when Near Misses were recorded. There was complete agreement between Jersey Airport and BlightWatch for the 64 days when neither Smith Period criteria nor Near Misses were recorded. On one of the 4 days when Smith criteria were satisfied at Jersey Airport but not in the BlightWatch polygon, the number of high RH hours at the neighbouring Guernsey station reduced the Jersey Airport total to below 10 hours, i.e. below the imposed limit of 11 hours. On the other days, missing data within Met Office internal network resulted in undue weight being given to more distant stations where either temperatures or RH values were lower (Figure 3).

Evaluation for Jersey

Comparisons were also made against the records collected from the private network of automatic weather stations covering 'Jersey West' and 'Jersey East' operated by the Department of Agriculture and Fisheries. These data were subjected to the same analysis as described above. (Tables 2 and 3).

a. Jersey Airport

b. BlightWatch Polygon



Y Axis Notation - 1 = Near Miss criteria 2= Smith Period criteria

Figure 3. Number of Days Satisfying Smith Criteria (May-July 2001) - Jersey

Table 2. Number of Days Satisfying the Smith Period Criteria for Jersey East and BlightWatch (1 May –31 July 2001).

BlightWatch Area	Jersey East Site		
	Nil	NM	P
Nil	61	2	6
NM	3	0	0
P	2	2	16

Table 3. Number of Days Satisfying the Smith Period Criteria for Jersey West and BlightWatch (1 May - 31 July 2001).

BlightWatch Area	Jersey West Site		
	Nil	NM	P
Nil	64	1	4
NM	0	2	1
P	0	0	20

The comparison between Jersey (East) and the BlightWatch polygon shows a good level of agreement with 77 of the 92 observations recording the same daily value. Smith Period criteria were recorded on 22 days at the Jersey (East) site and on 20 days by BlightWatch. Neither Smith Period criteria nor Near Misses were recorded at Jersey (East) on 66 days compared with 69 days using the BlightWatch polygon values.

The comparison between Jersey (West) and the BlightWatch polygon shows less scatter with agreement between the two systems on 86 of the 92 daily comparisons. Smith Period criteria

were recorded on 25 days at the Jersey (West) site compared with 20 occasions by BlightWatch. There was complete agreement between the two systems for the 64 days when neither Smith Period criteria/Near Misses were recorded.

As a final comparison, the met records from Jersey (East) and Jersey (West) were compared both with each other and the BlightWatch polygon values. The results are expressed as a percentage of available daily observations. The three categories are when there was a direct match, or when the systems differed by one, or more than one, category (e.g. a 'P' and a 'NM' is considered 1 category different). The results are given in Table 4.

Table 4. Analysis of Correlation between Results - expressed as percentage of days.

	B'Watch:Jersey (E)	B'Watch:Jersey (W)	Jersey (E):Jersey(W)
Direct Match	84	93	75
+/- 1 Category	8	2	16
> 1 Category	9	4	9

The level of agreement is greatest between the BlightWatch polygon and Jersey (West) values followed by BlightWatch and Jersey (East) and between Jersey East and West.

National Distribution of Smith Periods

The number of full Smith Periods was calculated for the period 1 May - 15 August for the whole of the UK. The results, shown in Figure 4, reveal a clear spatial trend with the lowest number of full Smith Periods in the east and south east of England and the highest number in the south west. In what was a low blight year, BlightWatch calculated two or less Smith Periods for a large area covering East Anglia, the East Midlands and into Yorkshire. In contrast, over twenty Smith Periods were recorded in Cornwall and south west Wales. The important seed producing areas on the east coast of Scotland recorded between five and ten periods. Both the Channel Islands and most of Northern Ireland recorded between ten and fifteen periods.

Smith Period Sensitivity Analysis

To demonstrate the importance of accurate RH sensor calibration, modifications were made to the hourly weather records recorded by the Met. Office site at Ballykelly in Northern Ireland. The relative humidity was either increased (by 2, 4 or 6 %) or decreased (by 2 or 4 %)

over the period 1 May - 30 September 2001. The effect of this on the date of the first Smith Period and the number of full Smith Periods is shown in Table 5.

As the RH values increase, the date of the first Smith Period was earlier and the number of full Smith Periods was greater. Conversely, reducing the RH value delayed the date of the first Smith Period and reduced the number recorded.

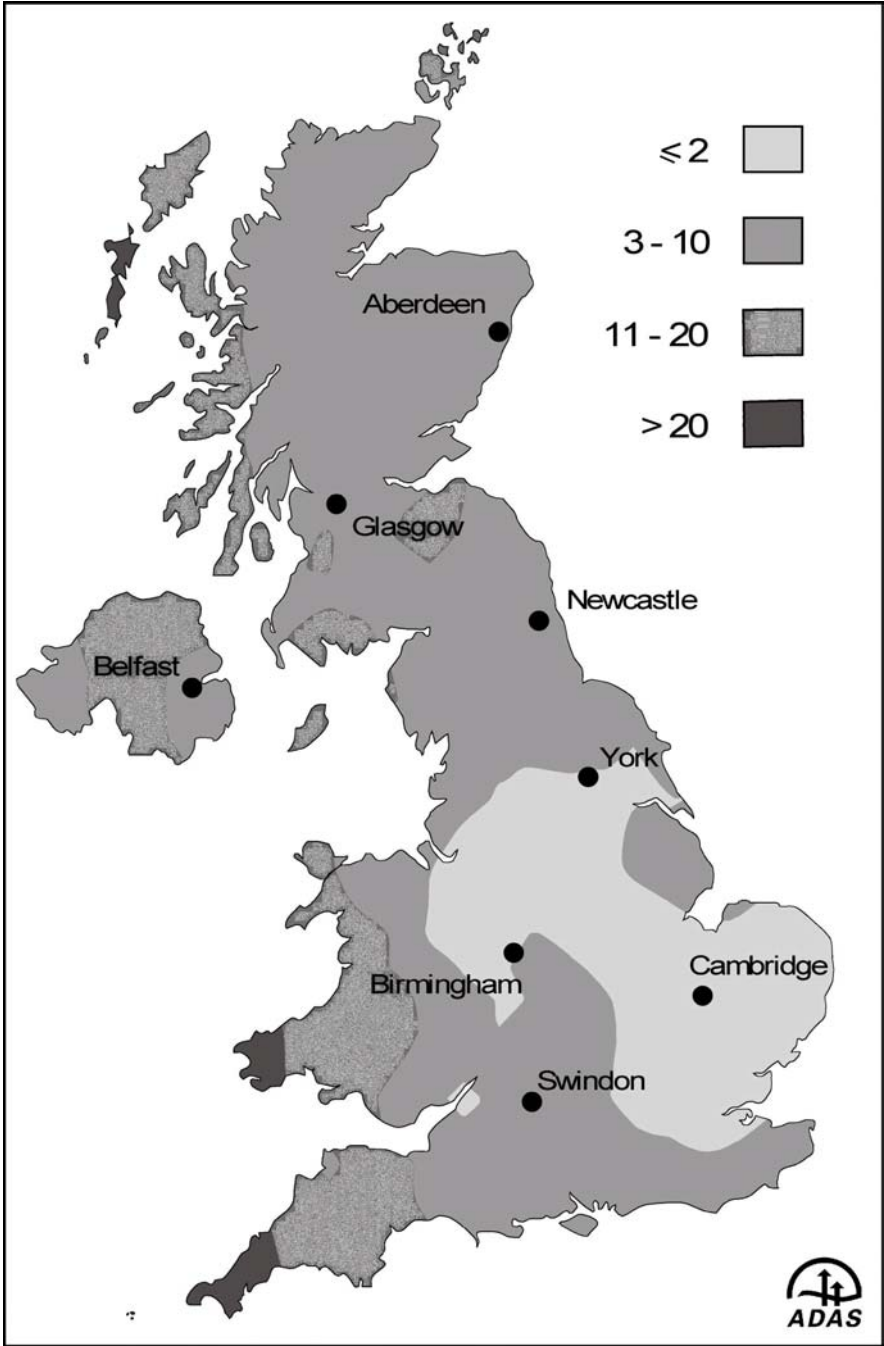


Figure 4. Number of Full Smith Periods : 1 May - 15 Aug 2001

Table 5. Effect of Altering % RH Values on the Timing and Number of Smith Periods

	Change in Hourly RH Value (%)					
	-4	-2	0	+2	+4	+6
Date of First Smith Period	05 Jul	28 Jun	28 Jun	27 Jun	20 Jun	20 Jun
Number of Smith Periods	1	10	15	18	27	34

Discussion

We consider that BlightWatch has a number of advantages when compared with the existing system of providing Smith Period data. Not least is the ready availability of a greater volume of primary recordings from the official Met. Office network of synoptic stations covering the whole of the UK ie >200 stations compared with 75. Further benefits arise from the use of Met. Office interpolation routines, as when these are periodically upgraded, any refinements will be automatically incorporated into the BlightWatch system. Finally, BlightWatch information is distributed via the internet which gives users direct and immediate access to the information.

In the validation exercise described here, a high degree of correlation was found between the Smith Period days calculated for the Met. Office station at Jersey Airport and the corresponding BlightWatch polygon. This indicates that the interpolation system is performing to its specification. Although lower, a good level of agreement was found between the number of Smith Period days from the independent network on Jersey and BlightWatch. Assuming that the Met. Office stations are accurate base-line reference sites, this also shows that the sensors on the independent network were accurately calibrated. In the case of Jersey (West), there were no occasions when BlightWatch calculated a Smith Period day without a corresponding day from the private weather station. There was slight over recording of Smith days from BlightWatch compared with Jersey (East). A more extensive analysis of BlightWatch output compared with other Met. Office stations (not reported here) showed both over and under recording. This suggests that BlightWatch is successful at levelling out local effects of exposure at individual sites, many of which may be considered to be spurious.

All Met. Office sites (automatic and manual) currently use wet and dry bulb thermometry. The maintenance programme allows for fortnightly inspections when the wet bulb wick and water reservoir are changed. Electronic sensors, as used by the majority of other automatic weather stations, require specialist calibration using, for example, saturated salt solutions. Different salt solutions (such as lithium chloride or sodium chloride) allow the sensors to be calibrated at a range of RH values. Typically, the accuracy of calibration lies within +/- 2 to 5%. Often, no calibration interval is recommended by the manufacturers, but in RH sensitive studies an interval of one month appears appropriate.

It was clear from the sensitivity analysis that small changes in RH values can have a dramatic impact on the calculated number and timing of Smith Periods. This highlights the importance of careful and regular checking of sensors, especially at high relative humidities. For applications where the sensitivity is to higher RH values it would be prudent to ensure that the emphasis should be on calibration accuracy at around the 90% RH values, and less emphasis at the lower end of the RH scale.

Conclusions

Given the complex multivariate interaction between the late blight pathogen and its' environment, a simple set of weather based criteria as used in Smith Periods may no longer be appropriate. This may be more relevant following the discovery of the A2 mating type and the displacement of blight populations both in the UK and Europe (Day & Shattock, 1997; Drenth *et al.*, 1994). The reaction of these new populations to temperature and humidity parameters marginally outside those used for the calculation of Smith Periods is not known.

Smith Periods are a respected and familiar measure of disease risk in the UK, however, it is important to note that the occurrence of a Smith Period is not intended to indicate the need to apply a fungicide spray to a crop. Smith Periods were originally developed as an indicator of general blight risk in a broad geographical area. There are also regulatory controls on blight fungicides which stipulate the minimum interval between applications of commercial products (Bradshaw *et al.*, 2000).

The BlightWatch system provides an increased resolution through interpolation (while not over interpreting the data), producing national coverage which is publicly accessible via the internet. BlightWatch also has the flexibility to incorporate more sophisticated blight forecasting criteria as they become available whilst taking advantage of a national system of data collection which is known to meet the quality standards in terms of temperature and humidity measurements.

Acknowledgements

The authors would like to formally thank Rosemary Collier of the Jersey Department of Agriculture for her co-operation and willingness to share information and ideas during the course of this project.

The authors, with respect, would also like acknowledge the works of L P Smith, who died on 11 October 2001. A formal obituary is being prepared for the scientific press and will appear in due course.

Figure 1 is provided courtesy of Syngenta.

Figure 2 is reproduced by courtesy of “potatocrop.com” and DBT Ltd.

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Annex 1

Interpolation of Weather Records

The data collection system picks up all available UK synoptic observations from the Met Office network. Currently there are around 220 stations which are available to the system. As a consequence of this procedure at main hours (00, 06, 12 and 1800 GMT) there will be a greater volume of information reported than at intermediate hours.

Within the interpolation routines there are default settings which govern the methods employed. Under normal conditions all data from meteorological stations within a radius of 65 km from each grid point are included in the interpolations. A simple linear interpolation routine is used with a weighting factor based upon the distance of the recording station from the given point.

An exception is made in the event of communications problems which result in missing values. In this instance the system will search areas outside the default 65km radius.

While this may result in poorer estimates on the day, it does ensure that the best available estimate **at that time** is calculated. The follow up message which repeats the calculation 4 days in arrears will pick up more data on these occasions and update the BlightWatch value in the database.

**www.phytopre.ch: the internet based decision support system (DSS)
PhytoPRE+2000 to control late blight on potatoes in Switzerland**

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Summary

From 1994 to 2000, Swiss potato growers were supported by the decision support system (DSS) PhytoPRE+95 to control potato late blight (PLB). Main elements of the decision process were information about the actual disease state and farm specific data like the PLB susceptibility of the planted variety and already applied fungicides. Based on this information the DSS recommended a next treatment shortly before a critical amount of rain was reached. The recommendation with the indication of a minimal and maximal spray interval and the critical rainfall was sent to the farmer by mail.

In epidemiological field studies in 1995/1996, weather conditions which are crucial for the development of *P.infestans* were determined (MISPs: Main Infection and Sporulation Periods). The MISP-model is the core of our new DSS PhytoPRE+2000. In field trials since 1996, the model proofed to be a reliable tool for the timing of PLB spray interventions and - depending on the weather conditions- a good means to spare fungicide treatments.

To integrate the MISP model in the DSS the information exchange had to be accelerated, which was achieved implementing PhytoPRE+2000 on the internet (www.phytopre.ch). With the new interactive PLB warning and information system, farmers, consultants and plant protection services can find information whenever they want: daily actualised maps/lists of the national and regional PLB-situation, actual and forecasted MISP-events and plot specific fungicide recommendations are offered. A first enquiry among 200 framers showed that they are satisfied with the new program and 90% of them would recommend the support of our new DSS to their colleagues.

Keywords: DSS, late blight, *Phytophthora infestans*, internet, warning system

Introduction

Since May 2001, Swiss potato growers are supported by an internet based decision support system (DSS) PhytoPRE+2000 to control potato late blight (PLB). The DSS is a plot specific PLB-recommendation system, and a national and regional information and warning system. The 'old' DSS PhytoPRE+95 (Forrer et al, 1993) was replaced by this new system, when our Main Infection and Sporulation Period (MISP)-rule was implemented into the system (Steenblock and Forrer, 2001). The MISP-model indicates single weather events (MISPs), which are crucial for the outbreak and the development of late blight epidemics. Therefore, the mode of information exchange had to be accelerated, what we achieved by a fully interactive Internet application, namely: PhytoPRE+2000.

Material and methods

In 1999, in co-operation with Swiss potato growers, the cantonal plant protection services and sponsors of the PhytoPRE-project the main features of the new DSS were determined. In 2000 a first internet program generating MISP-graphs was used to test the model and the possibilities to implement it in the new DSS. In the same year the characteristics of the entire PhytoPRE+2000 DSS were specified.

Half of the project-costs were financed by swisspatat (Swiss potato growers association), the cantonal plant protection services and the participants of PhytoPRE, the other half of the costs are financed by our Research Station FAL.

The programming was done in close collaboration with the Swiss company MSI Dr. Wälti AG Buchs. The program was installed on a public internet server to facilitate easy access for all users. To connect and run PhytoPRE+2000, a PC with the Internet Explorer 5.0, Netscape Navigator 4.5 or a higher version is needed (www.phytopre.ch).

Results and discussion

Main components of PhytoPRE+2000

The key components of a plant pathogen-epidemic are: the pathogen, the host-plant and the environment. That means, a reliable DSS should be based on information of all three components. Similar to PhytoPRE+95, in PhytoPRE+2000 the main components are a late

blight monitoring system, knowledge to the PLB-susceptibility of the varieties and the interpretation of weather data. With the integration of the MISP model in our new DSS, weather data play a much more decisive role in PhytoPRE+2000 than in our old DSS.

Weather data

Hourly weather data from 72 MeteoSwiss stations and private stations, measured and forecasted (48 hours), are transferred to our server via ftp. Here, the data are automatically analysed according to the MISP-rule. The results are forwarded via ftp to and stored on the public server.

Late blight situation

Information about the late blight occurrence can be fed into the system in different ways: either the outbreaks of disease can be put in by the system-administrator (FAL) or they can be actualised by authorised people, for example the officers of the cantonal plant protection extension services (KZP). This PLB-information network between our research station, the KZP, the consultants and farmers exists now for 10 years and is well-established. With the internet PhytoPRE, plant protection services have the possibility to insert PLB-outbreaks and attacks directly, whenever they want. This procedure guarantees around the clock updated record of the late blight situation in Switzerland.

In addition a PLB-observation net and field trials to examine the PLB susceptibility of the varieties are an important information source to run the DSS. For the PLB-observation net we have about 70 untreated plots of the variety Bintje spread over the main potato growing region of the country. KZP and advisers take care of these plots and report to us the occurrence of PLB as soon as it is recognised in the field. With this information it is possible to analyse and compare LB-epidemics of different years.

The variety trials are managed by the KZP. In each trial all the registered varieties of Switzerland are planted. No fungicides are used in these trials and the disease progress is rated several times. The results of these trials are used to classify the varieties into three susceptibility groups.

Field data

Participants put their individual field data into the program without restrictions. There is a special procedure only for late blight attacks: attacks reported by farmers are in a first step only effective for their own fields. After checking the input, the attacks are 'given free' and are valid for all participants. This restriction was installed to reduce false information on the Internet.

Bulletins

Once a week a national PLB- bulletin is prepared and published by the FAL. The cantonal plant protection officers have also the possibility to write their individual reports for their own region. How often they actualise these comments depends on them.

Rules for treatment recommendations

Similar to PhytoPRE+95 no treatments are recommended with PhytoPRE+2000 before a first PLB-outbreak has been detected in our country: first recommendations for fungicide applications are only provided if a first PLB-attack is reported in the region and the growth stage of the plants is at least $GS \geq 10$ (plants emerged and first leaves have developed). The conditions for the first and the following treatments are summarised in the following table (Tab.1).

Data processing and recommendations for treatments

Meteo- and MISP-data are updated once a day. Disease observations and individual field data are updated permanently, respectively each time when new data are stored to the system. To generate individual recommendations the local and regional MISP- and PLB-situation and individual field data (e.g. location, cultivar and last fungicide treatment) are processed by the rule based PhytoPRE software.

Table 1. PhytoPRE+2000 – conditions for the first and the following treatments

<u>Conditions for the first application:</u>			
Growth stage (GS)	MISP	Distance to the LB-attack	Recommendation
GS <10			no application before GS>10
GS > 10	n.r.	0 km (attack in the field)	'emergency treatment'
	n.r.	0-5 km	LS/S
	+	5-20 km	P/LS/S (except SG/VD)
GS> 20	+	20-50 km	P/LS/S
	+	50-80 km	P/LS
	+	>80 km	no application
<u>Conditions for the following treatments:</u>			
GS > 10	+	< 80 km	P/LS/S* *if fungicide protection is over

n.r.= not relevant; P= protective, LS= locally systemic, S= systemic fungicide; emergency treatment: immediately an application with a locally systemic fungicide, after 3-4 days a treatment with a protective fungicide

Main features and outputs of PhytoPRE+2000

At the beginning of the season participants log in at the Internet address www.phytopre.ch and register (Fig.1). There are three different possibilities to use the program:

- Information site: free access for consultation of the actual late blight situation, the fungicide and variety list
- Subscription 1: 30.- SFr/ season (220 €), consultation of the actual late blight situation (map/ list/reports), the national and regional weather situation (MISP), the fungicide and variety list
- Subscription 2: 50.- SFr/ season (350 €), in addition to Subscription 1 allows to generate plot specific fungicide recommendations.

Registration

With this first registration, participants have to put in various data depending on how they want to use the program. For 'Subscription 1' input data like name, address and the name of the nearest or most representative weather station (proposed by the program) are requested.

For ‘Subscription 2’ individual data have to be recorded and in addition, plot specific data, for example the planted variety and the location of the field, must be inserted. Having completed the requested queries, the participant gets a username and must choose a password. As soon as the fee is paid, participants obtain free access to the subscribed parts of the DSS.



Figure 1. Homepage of the warning and forecast system PhytoPRE+2000 (www.phytopre.ch). The functions of icons marked with a star, can only be accessed after registration. Other functions can be accessed freely.

Late blight situation

On the screen a map of Switzerland highlights all late blight attacks registered into the system by authorised people. New PLB-foci are displayed as red dots, foci, older than fourteen days, are blue (Fig.2). This figure offers the participants a clear overview about the geographical late blight situation.

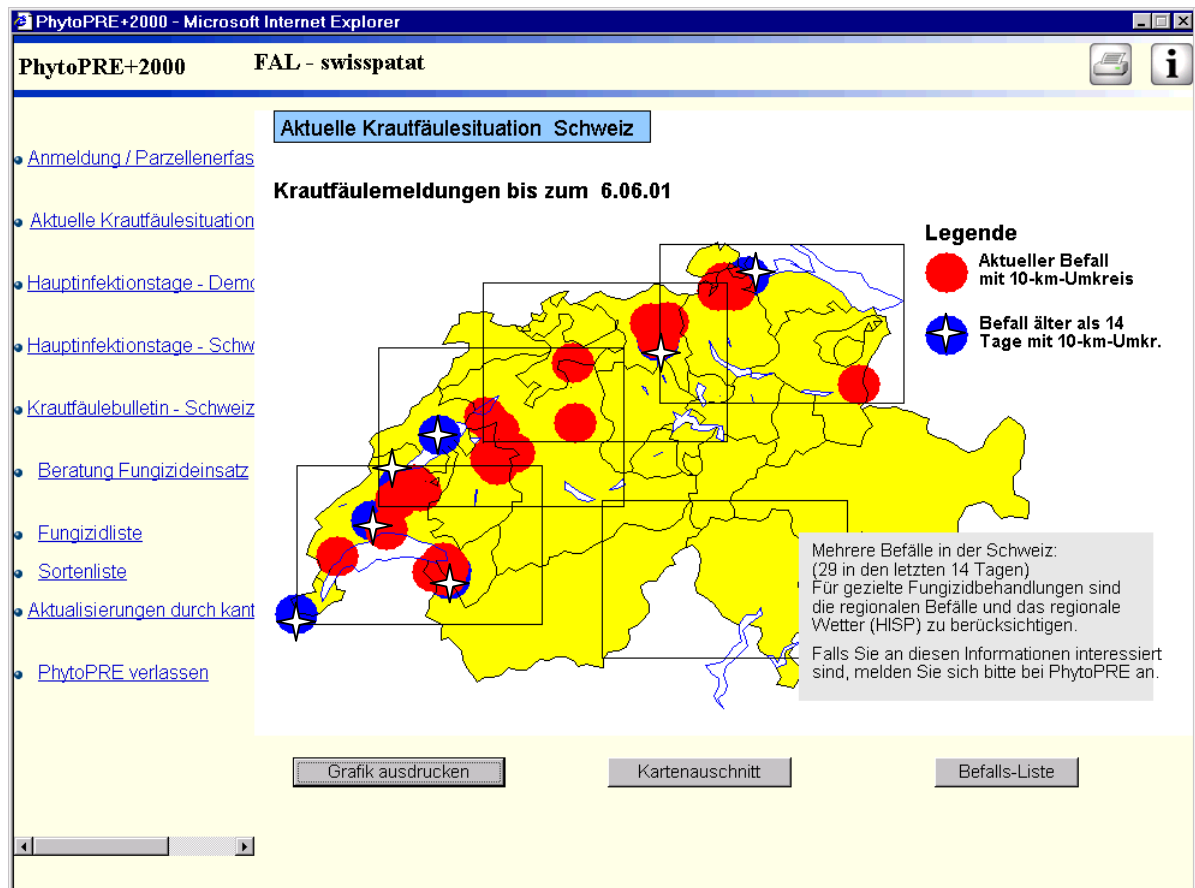


Figure 2. Actual PLB-situation of Switzerland. Red dots (●) indicate the location of actual PLB-attacks, blue dots with plus whit star indicate the location of PLB-observations older than fourteen days.

For more detailed information, a table of the late blight attacks with the date of registration, the location, and the variety can be seen. In addition the distance of the next and newest attacks to a specific field is given.

MISP situation

To show the actual and forecasted main infection and sporulation periods (MISPs), we decided to use the well-understandable mode of a traffic light: red dots mean high, yellow dots medium and green dots no risk for epidemiologically critical late blight events. Grey dots are shown if weather data are missing (Fig. 3). The definition of the MISP-rule is described in the PAV report No.1 (Cao et al, 1997).

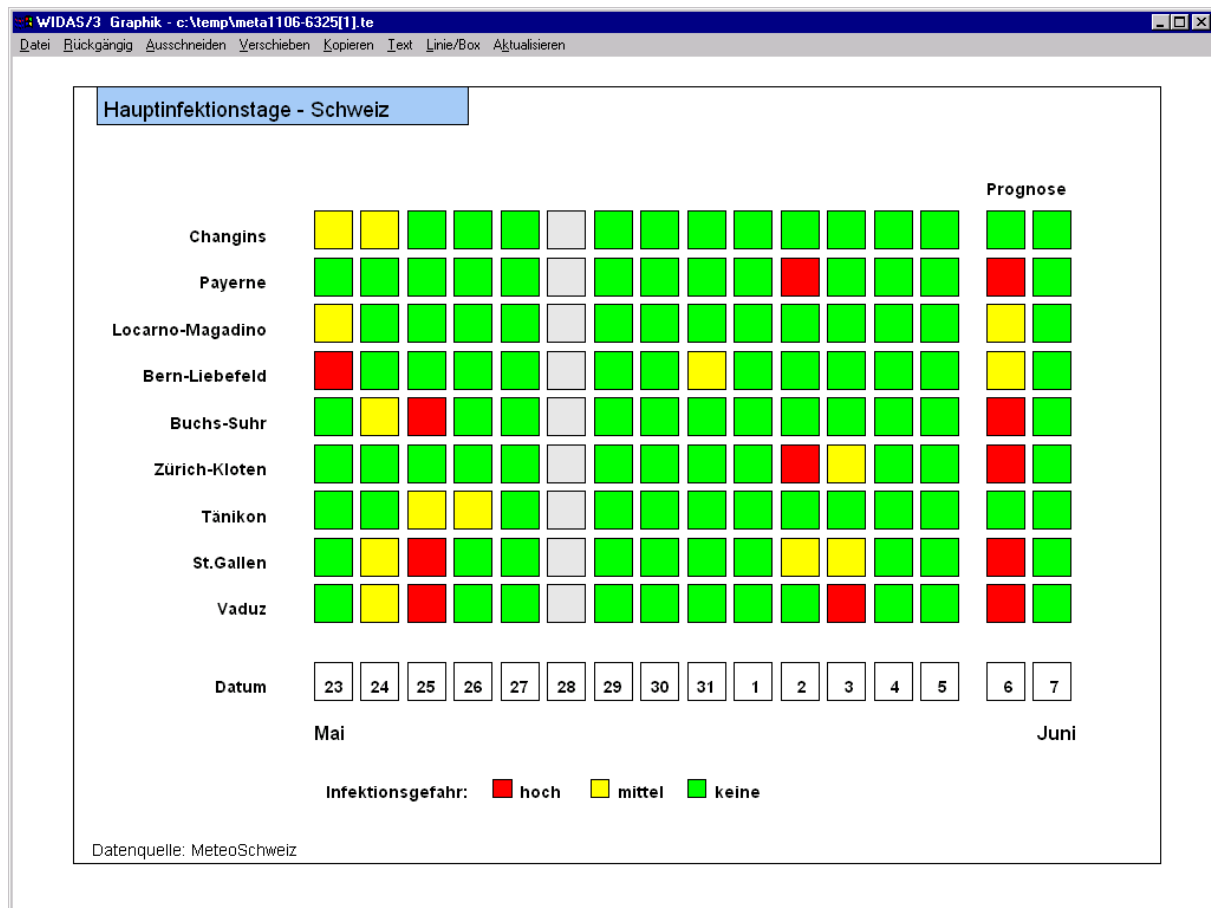


Figure 3. MISP situation for nine MeteoSwiss weather stations for a first overview of weather situation. ■ high, ■ middle and ■ no risk for MISP events. If weather data are missing, grey dots are shown (in this example May 28, 2001).

First, PhytoPRE presents the MISP data of nine stations, spread over Switzerland from the western to the eastern part. In a further step, farmers can click on their own region to get information about MISP-data of their regional weather stations. In a third step, they can choose a set of individual weather stations which are representative for their own field. On all pages weather data of the last 14 and two forecasted days are presented, which inform participants about the past and actual MISP-situation.

Fungicide recommendation

PhytoPRE+2000 users decide on their own, whether they want to have plot specific recommendations or conduct their treatments based on the two information tools mentioned above.

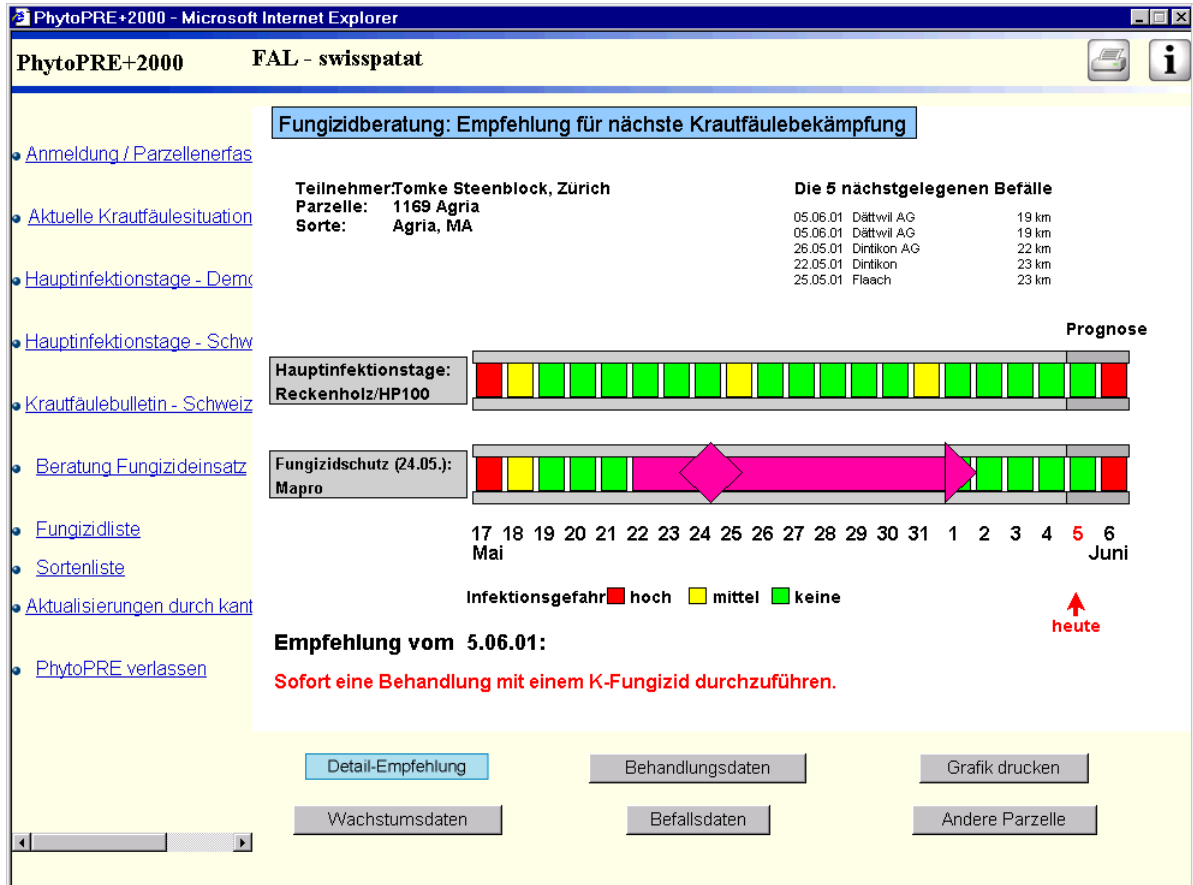


Figure 4. Example for a treatment recommendation of PhytoPRE+2000: Based on the weather forecast a MISP event is expected the next day (June 6). The DSS recommends an immediate treatment with a protective fungicide. In the graph the MISP-situation for the farm related weather station is given. The arrow indicates the protection duration of the last applied fungicide.

In case a farmer requires fungicide recommendations, a mouse-click on this menu leads him to his plot specific recommendation. In the upper part of this Internet page the address of the farmer and 5 PLB-attacks, nearest to his plot, are listed. In the graph, the actual fungicide protection level is shown by a purple arrow. A red coloured short message summarises the recommendation, a more detailed recommendation is at disposal on the left hand side of the bottom. In addition, farmers are led from this page to the masks where they can put in their individual field data: the growth stage of the plants, the amount of rain after the last application, fungicide data and PLB-observation data (Fig.4). The new system calculates the period of protection for each applied fungicide. The length of this protection period depends on the fungicide, on the susceptibility of the planted variety, the amount of rain after the last spray and the growth stage of the crop. Therefore, the period may become shorter after heavy rainfalls. That's why farmers are requested to contact the program before the fungicide protection expires.

Acceptance

In 2001, 200 participants have registered. At the end of the season, a questionnaire was sent to 159 participants in order to identify in which points the PhytoPRE+2000 DSS should be improved. 63% of the questionnaires were returned. 78% of the participants used the program as a full DSS ('Subscription 2'), 14% as an information and warning system ('Subscription 1') and 8% used the free access. 81,5% of the recommended fungicide treatments were classified as well suited. 80% of the participants confirmed to use PhytoPRE+2000 again next year and 90% would recommend the program to their colleagues. Based on these arguments we are convinced that, with a more intensive advertisement and the offer of some Internet-courses for farmers, the number of participants could be increased.

Acknowledgement

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**Impact of new populations of *Phytophthora infestans* on integrated late
blight management**

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Summary

A recent migration of a variable population of *P. infestans* has largely displaced the clonal A1 population in Western Europe. Sexual reproduction in European late blight populations is now possible and has been reported. The increased levels of aggressiveness form an important epidemiological feature of this new blight population. The impact of 'new blight' on crop protection strategies based on late blight resistant cultivars and fungicides is discussed.

Introduction

The oomycete *Phytophthora infestans* (Mont.) de Bary, the cause of late blight in potatoes and tomatoes, is considered to be among the most important pathogens of potato crops worldwide (Hooker, 1981). The pathogen is feared by farmers around the globe due to its ability to quickly destroy entire fields of potatoes and tomatoes. The pathogen affects foliage and stems, reducing the photosynthetic capacity of the crop and therefore leading to tuber yield reduction. In addition, *P. infestans* can infect fruits and tubers, which adds to total losses in marketable yield. These days, crop losses due to late blight have been estimated to account for 10 to 15 percent of the total global annual potato production (Anonymous, 1996). The economic value of the crop lost, plus the costs of crop protection amount to 3 billion US \$ annually (Duncan, 1999).

In the developed world, control of potato late blight is heavily dependent on the use of fungicides. Despite frequent fungicide use, late blight epidemics have proven to be increasingly more difficult to control (Turkensteen *et al.*, 1997; Schepers, 2000).

Resurgence of the late blight pathogen

The increased problem with controlling potato late blight coincides with the displacement of the US-1 clonal lineage by a new, more variable *P. infestans* population in many parts of the world (Spielman *et al.*, 1991). New populations are marked by more aggressive genotypes of the pathogen (Day & Shattock, 1997; Lambert & Currier, 1997, Turkensteen *et al.*, 1997). In regions where both mating types have been found, evidence is accumulating that sexual reproduction takes place (Drenth *et al.*, 1994; Andersson *et al.*, 1998). In sexual populations, both sexual (oospores) and asexual (i.e. mycelium in infected tubers) propagules serve as inoculum sources, whereas asexual populations are totally dependent on asexually produced inoculum. Prior to the 1980s, a single A1 clonal lineage of *P. infestans*, designated US-1, was spread throughout the world, whilst the occurrence of the A2 mating type was confined to an area of the highlands of central Mexico (Niederhauser, 1956). Oospores in field crops (Gallegly & Galindo, 1958) were first reported from the Toluca Valley of central Mexico, and evidence indicates that the highlands of central Mexico are indeed the centre of origin of *P. infestans* (Fry & Spielman, 1991; Goodwin *et al.*, 1992). Populations of *P. infestans* outside central Mexico were restricted to asexual reproduction and survived during crop free periods by existing as mycelium inside potato tubers. During the 1980s, potato late blight became more difficult to control in Europe and resistance to the fungicide metalaxyl developed rapidly. (Davidse *et al.*, 1981). It is plausible to suggest that the displacement of the US 1 population by 'new' isolates may have been accelerated by the concomitant introduction of phenylamides in Europe as tolerance to phenylamides (including metalaxyl) is more common amongst 'new' isolates.

The presence of A2 mating type strains in Europe was first reported in Switzerland (Hohl & Iselin, 1984), and was soon followed by a UK report on the presence of A2 mating type strains in imported ware potatoes from Egypt (Shaw *et al.*, 1985). These observations led to a revival of late blight research in Western Europe. Population genetic studies using allozymes (Spielman *et al.*, 1991) and DNA fingerprinting revealed the presence of a new, genetically

variable population of *P. infestans* in Western Europe. In the United Kingdom, it appeared that a genotypically diverse population had displaced the old clonal population of *P. infestans* during the 1970s and early 1980s (Shattock *et al.*, 1990; Cooke *et al.*, 1995). In contrast to reports from other European countries, the A1 mating type remained the predominant type among samples of *P. infestans* obtained from potato and tomato collected in England, Wales and Northern Ireland. The A2 mating type was identified in 3-10% of the samples collected, and no evidence for an overall increase in the frequency of the A2 mating type over this period was observed. As a consequence, dumps and infected seed still act as principal infection sources for late blight, caused by the A1 mating type, possibly supplemented by oospores, which may act as an additional infection source in both commercial potato fields and home gardens. The relative contribution of oospores to initial inoculum appears to be limited by the low frequencies of A2 mating type strains observed. In a recent survey during the 1995-1997 growing seasons, Cooke and co-workers (in prep.) reported a mixture of A1 and A2 mating type strains in 8.4% (Scottish farm sites) and 35.3% (home gardens) of the locations sampled. Like the present situation in the UK, tuber related inoculum sources appear to be important for initiating early late blight epidemics in the Netherlands (Table 1), even when high frequencies of A2 isolates are present in field crops and volunteer plants (Turkensteen, unpublished).

Table 1. Sources of early outbreaks of *Phytophthora infestans* in three different potato growing areas in the Netherlands, June 2000

Region	Source				
	Infected mother tuber	Dump	Distant source	Volunteer potatoes	Unknown (incl. oospores)
North-East (starch potato area)	8	2	0	0	0
South-East (ware potatoes)	2	0	5	2	1
South-West (seed & ware potatoes)	3	0	4	0	0
Total	13	2	9	2	1

The results in Table 1 show that thirteen out of twenty seven (48%) early late blight epidemics recorded in the Netherlands in 2000, were caused by infected seed. Dumps did

not appear to have a strong role in causing epidemics in 2000, which can be attributed to an active campaign for elimination of potato dumps by the Dutch farmers association.

Impact of 'new' populations

Farmers' experience of controlling late blight suggests that blight epidemics tend to start earlier in the growing season and the onset appears less predictable than in the past. It was found that 'new' isolates are more aggressive than 'old' isolates when infection frequency, latent period, sporulation and tuber infection were measured under controlled conditions (Day & Shattock, 1997; Flier *et al.*, 1998; Flier & Turkensteen, 1999). It is conceivable that the presence of aggressive strains will lead to shorter infection cycles and a more rapid epidemic development of the disease. In monocyclic tests, the difference between the individual components for aggressiveness in the old and the new population are strikingly in favour of the new population. The combined effect of the components of increased aggressiveness on polycyclic late blight epidemics is dramatic. Comparison of infection efficiencies and sporulation capacity of isolates representing the old and the new population of *P. infestans* in the Netherlands shows that isolates of the newly established population are able to infect potatoes at temperatures ranging from 3 to 27 °C while old population isolates caused infections from 8 to 23 °C (Flier *et al.*, unpublished). Recent results (Flier *et al.*, in preparation) show that isolates of the new population are marked by more rapid spore germination and host penetration, leading to shorter critical leaf wetness-periods. Under normal field conditions, isolates need only a few hours of leaf wetness (approx. 4 hours at 15 °C) to penetrate potato leaves instead of the 8 hours that was widely considered to be the minimum time needed for germination and infection. In 1999, we successfully inoculated a field crop under extremely high temperatures (max/min: 34°C/27°C) and observed a latent period of approximately 2.5 days under field conditions. In 2000 and 2001, comparable latent periods were observed (Flier, unpublished). Whether observations like this should be regarded as rare incidents or to represent the current performance of *P. infestans* is still under debate, yet evidence supporting the hypothesis of increased levels of pathogenic fitness is accumulating.

The increased chance of infection at sub-optimal temperatures, in combination with shorter leaf wetness periods will increase the number of critical infection periods during the growing season, whilst shorter latent periods boost the speed of the epidemic. The window of

opportunity for action by the potato grower is narrowing and it has become extremely difficult to achieve a proper fungicide application timings. This grim view of the negative impact of 'new blight' on late blight control is supported by recent figures on fungicide use in the Netherlands. To date, the number of fungicide applications to control late blight in potatoes range from an average of 7 to more than 20 applications per season (Scheepers, 2000), which is approximately 40% higher than fungicide use in the late 1970s.

Stability of late blight resistance

With the growing public demand for environmentally acceptable crop protection methods, breeding for durable resistance against late blight has been a focus for most modern potato breeding programmes (Colon *et al.*, 1995; Inglis *et al.*, 1996; Peters *et al.*, 1999). Incorporation of host resistance in integrated late blight disease management could result in significant reductions in fungicide use, whilst maintaining present yield and quality standards (Inglis *et al.*, 1996). The importance of minimising yield losses due to potato late blight by exploiting host resistance has been recognized for more than a century. In the early days of breeding for late blight resistance, complete resistance of potatoes to late blight was highly valued and the first complete resistant potato cultivars appeared in the 1930s (Müller & Black, 1952). During the 1950s and 1960s, breeding efforts to select for more durable forms of late blight resistance were initiated (Toxopeus, 1964; Hermsen & Ramanna 1973). These forms of resistance, often referred to as partial resistance, field resistance or quantitative resistance (Turkensteen, 1993; Colon *et al.*, 1995) are thought to be polygenic, non-race-specific and therefore effective against all *P. infestans* genotypes by reducing the rate of the epidemic (van der Plank 1968; Parlevliet & Zadoks, 1977). Partial resistance is thought to provide long-lasting protection against late blight (Turkensteen, 1993). The need for potato cultivars with high levels of stable late blight resistance was highlighted with the increase of organic potato production during the 1990s and the presence of a more aggressive sexual reproducing *P. infestans* population.

Recent work (Flier *et al.*, 2001) has shown differential interactions in tuber blight attack between potato cultivars and *P. infestans* isolates, manifested by changed resistance ranking of cultivars after exposure to several different *P. infestans* strains. Unpublished data support evidence for substantial differences in expression of foliar blight resistance depending on the

strain of the pathogen. The observed levels of partial resistance in foliage and tubers did not correlate well with foliar and tuber blight resistance ratings as presented in the Dutch national list of recommended potato varieties (Flier, 2001). It is concluded that cultivar-by-isolate interactions are important in determining the outcome of interactions between partially resistant potato cultivars and *P. infestans* strains. The presence of specificity in interactions between *P. infestans* and partially resistant potato cultivars may affect the stability and the durability of partial resistance against late blight in potatoes.

The road ahead

Late blight management has become more complicated following the introduction of ‘new blight’ in Europe. The pathogen has become more aggressive, and epidemics can start early in the season, even at crop emergence. In the past, missing one or two critical periods for late blight development did not lead to a severe blight situation, but such risks can no longer be taken. In response to this situation, an integrated approach to late blight management is advocated in which cultivars with stable forms of resistance, effective fungicides that combine low levels of active ingredient with superior persistence on leaves, and accurate timing of fungicide applications are implemented in late blight decision support systems (DSS). These integrated late blight management tools will enable potato growers to choose and apply the most effective fungicide at a suitable timing, whilst at the same time complying with the current impetus to optimise fungicide inputs. In addition, decision support systems offer the opportunity to safely explore the use of reduced fungicide rates in combination with more resistant cultivars (Fry, 1975; Clayton & Shattock, 1995).

In conclusion, potato growers, breeders and plant pathologists alike are facing a pathogen that is becoming more adaptable, more variable and more aggressive. Late blight has also become less predictable for the farmer. An integrated strategy for late blight control based on sophisticated decision support systems will enable potato growers to exploit stable forms of host resistance, dynamic fungicide use and cultural practices in an effort to protect their crops whilst minimising fungicide inputs for late blight control.

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***P. infestans* oospores in the Netherlands: occurrence and effects of cultivars
and fungicides**

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Introduction

In the Netherlands, a genotypically diverse, sexually reproducing *P. infestans* population has displaced the old, clonally reproducing, population during the 1980s and early 1990s (Drenth *et al.*, 1993). A1 and A2 mating types were detected in infected potato crops (Frinking *et al.*, 1987) and new complex races and virulence factors were found (Drenth *et al.*, 1994). Functional oospores were found in naturally infected commercial potato and tomato crops and in home gardens (Turkensteen *et al.*, 1996). Oospores are able to survive Dutch winter conditions (Drenth *et al.*, 1995) and are thought to be common in the Netherlands. Specific measures to control or prevent oospore formation are not available.

This paper describes a survey for the occurrence of oospores in the four major potato-producing regions in the Netherlands and experiments on the effects of fungicides and potato cultivars on oospore formation.

Materials and methods

Oospore survey

A survey was conducted in the north-eastern (NE), central (CE), south-eastern (SE) and south-western (SW) potato production areas in the Netherlands. Sandy soils dominate the

NE and SE production areas whereas clay soils dominate the CE and SW production areas. In each of these four areas, five unsprayed (volunteer) potato crops were sampled by collecting 25 *P. infestans* infected leaflets with two or more lesions. These leaflets were incubated in water agar petri dishes at 15°C for three weeks. Following incubation the leaves were microscopically examined for the presence or absence of oospores. The density of oospores per leaf was estimated using a 0 – 9 density index (0 = no oospores, 9 = high densities of oospores throughout the entire leaflet). Thus the potential for oospore formation is measured. This was done to avoid the influence of local (micro) climate on oospore formation (Cohen *et al.*, 1997; 2000).

Effect of cultivars on oospore formation

Potato plants, representing 11 cultivars, were grown in the field and inoculated with *P. infestans* A1 and A2. When disease severity reached 40%, 20 leaflets, with 2 lesions or more, were sampled per cultivar and incubated in water agar petri dishes at 10°C for three weeks. Following incubation, oospores were extracted from the leaves and quantified.

Effect of fungicides on oospore formation

Oospore formation in the presence of fungicides was studied *in vitro* and *in vivo*. For the *in vitro* experiments A1 x A2 crosses were carried out in Rye A agar in the presence of sub-lethal concentrations of a range of modern fungicides. Fungicide concentrations were chosen such that the radial growth rate of *P. infestans* colonies on Rye A agar was reduced by 75% as determined in a preliminary experiment. Four weeks after the A1 x A2 cross was initiated, oospores were quantified in the contact zone of the A1 and A2 colonies. Oospores were then extracted from the agar and viability was determined using tetrazolium bromide (Jiang & Erwin, 1990).

For the *in vivo* experiments potato plants, cv Bintje, were inoculated with *P. infestans* A1 and A2 and incubated at 10°C and high RH. Eight days after inoculation the foliage was sprayed with fungicides at the recommended concentrations. Five replicate plants were included for each of seven fungicides. Fourteen days after inoculation, 10 leaflets, with two lesions or more, were collected per plant and incubated in water agar petri dishes at 10°C for three weeks after which oospores were extracted and quantified.

Results

Oospore survey

Oospores were found in 78% of the leaflets from the NE production region and in 50%, 30% and 15% of the leaflets from the SE, CE and SW regions respectively. The average number of lesions on the sampled leaves was 6, 14, 2.5 and 2.5 for the NE, SE, CE and SW areas. A2 isolates constituted 62%, 17%, 9% and 6% of the isolates collected in each of the regions respectively. When oospores were found the oospore density was usually high. Average densities for the NE and SE areas was 7 on a 0 – 9 scale. Oospore density in leaflets from the CE and SW production areas was not determined.

Effect of cultivars on oospore formation

Average oospore densities in the 20 leaflets from field inoculated plants are given in Table 1. Considerable differences between cultivars are evident. The large standard deviations demonstrate however that considerable differences between replicate leaflets exist. This indicates that, apart from cultivar effects, factors related to the success of the inoculation and climatological factors are major influences on oospore formation.

Table 1. Influence of cultivar on oospore formation. Oospore density in leaflets of potato plants grown and inoculated in the field with *P. infestans* A1 + A2. Prior to quantification of oospores, leaflets were incubated in water agar petri dishes at 10°C for three weeks. Averages \pm standard deviation based on 20 leaflets per cultivar.

Cultivar	Oospores/cm ² leaf area	
Agria	22	\pm 34
Aziza	87	\pm 63
Bintje	274	\pm 374
Doré	5	\pm 9
Eigenheimer	22	\pm 19
Escort	405	\pm 442
Innovator	719	\pm 449
Pimpernel	0	\pm 0
Remarka	5	\pm 10
Santé	411	\pm 209
Troll	0	\pm 0

Effect of fungicides on oospore formation

Results of the *in vitro* experiment are summarised in Figure 1. Most of the protectant fungicides (except fluazinam) do not have specific activity against oospore formation.

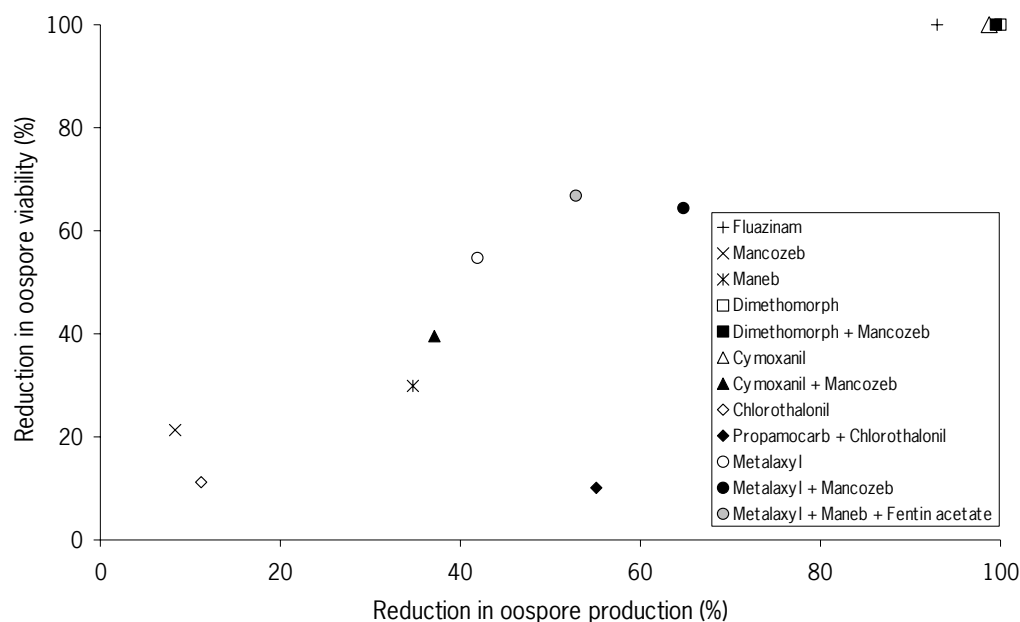


Figure 1. Results from the *in vitro* experiment on the effect of fungicides on oospore formation. Crosses between *P. infestans* A1 & A2 were carried out in Rye A agar in the presence of sub-lethal concentrations of fungicides. Concentrations were chosen such that the radial growth rate of the colonies was reduced by 75%.

Modern (semi) systemic or translaminar active ingredients and fluazinam have excellent activity against oospore formation. With these compounds oospore formation is inhibited more than proportional as compared to mycelial growth which was inhibited by 75%. Fungicides with two or more compounds seem to be less active against oospore formation. The total amount of a.i. in these fungicides is however dominated by the less active protectant a.i.'s. which leaves the concentration of the (semi)systemic or translaminar ingredient too low for a sufficient effect.

Results of the *in vivo* experiment are summarised in Table 2. Oospore formation is very significantly inhibited by all fungicide applications, despite the fact that fungicides were only applied eight days after inoculation, when symptoms were well developed. Differences between fungicides are small when compared to the overall difference between the control treatment and the fungicide applications. Viability of the oospores formed was not determined. Surprisingly, there is no clear separation between non-systemic and (semi)

systemic or translaminar fungicides. Absorption of all fungicides, including contact fungicides, by necrotic tissue may be responsible for this effect. Oospores are only formed after contact between *P. infestans* “A1 and A2 lesions”. Oospore formation itself is a relatively slow process. Thus, fungicides absorbed by necrotic tissue in the lesion may not prevent infection of the plant but they may still inhibit the mycelium inside the necrotic tissue and prevent oospore formation.

Table 2. Influence of fungicides on oospore formation. Oospore density in leaves of potato plants cv Bintje after inoculation with *P. infestans* A1 + A2. Fungicides were applied eight days after inoculation. Prior to quantification of oospores, leaflets were incubated in water agar petri dishes at 10°C for three weeks. Average oospore densities followed by a common letter do not differ significantly according to analysis of variance followed by a LSD test at $P = 0.05$.

Fungicide	Active ingredients	dose rate	oospores / cm ² leaf area
Untreated	none	-	171.6 d
Acrobat	Dimethomorph + Mancozeb	2.0 kg/ha	0.4 a
Tattoo C	Propamocarb + Chlorothalonil	2.7 l/ha	0.4 a
Daconil 500	Chlorothalonil	3.5 l/ha	0.6 a
Penncozeb	Mancozeb	4.0 kg/ha	1.1 ab
Shirlan	Fluazinam	0.4 l/ha	5.8 abc
Ridomil Gold	Metalaxyl + Mancozeb	2.5 kg/ha	9.9 bc
Curzate M	Cymoxanil + Mancozeb	2.5 kg/ha	26.6 c

Conclusions and discussion

From the oospore survey it can be concluded that the potential for oospore formation in infected crops in each of the surveyed regions is high. Whether or not this potential is realised under practical conditions depends on tolerated disease levels and climatological conditions. Differences between regions, and especially between the (NE + SE) and (CE + SW) regions, are most likely caused by reported differences in A1:A2 ratio's in combination with differences in the average number of lesions on sampled leaflets. Differences in cultivated cultivars, soil types and crop management practises, such as crop rotation, also have an impact on oospore formation.

The cultivars tested seem to differentially support oospore formation. More experiments, and especially experiments under controlled conditions with compatible isolates, should be

conducted to verify the results presented here. In a field experiment as conducted there is no possibility to check whether both isolates have successfully infected and are colonising the plants.

Most fungicides have excellent activity against oospore formation. At concentrations well below the recommended concentrations all fungicides tested *in vitro* reduced oospore formation significantly. The modern systemic or translaminar compounds and fluazinam have a specific activity against oospores since oospore formation is inhibited at concentrations that are only sub-lethal for mycelial growth. From the *in vivo* test it can be concluded that fungicides can prevent oospore formation despite the fact that an epidemic is well underway. Absorption by necrotic tissue seems to be more important to the activity of the fungicides than specific systemic characteristics. Overall however all fungicides tested had excellent activity against oospore formation *in planta*.

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Field Experiments with preventive and curative control of potato late blight

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Summary

The results from the field trials 2000 and 2001 with artificial inoculation of potato late blight showed that almost 100 % control was obtained when sprayed just before spore infection. If sprayed later in the latency period there was some control with the curative fungicides but the control level was significantly lower. Especially if spraying was performed in the last part of the latency period or after symptoms were visible, a very low control level was obtained even with the curative fungicides. The results emphasises the importance of a preventive spray even with systemic fungicides.

Keywords: Late blight, *Phytophthora infestans*, control, curative control, fungicides

Introduction

The timing of fungicide application according to the infection process is very important for the effect of the spraying. The best effect of the fungicides is normally obtained when they are applied preventively i.e. before spore infection. After infection only fungicides with systemic action are potentially able to control the growing lesions but the effect depends very much upon the activity of the specific fungicides. In practice it can be difficult to apply the spraying preventively just before the infection period and often spraying is done after infection or even on established lesions.

Most often trials with preventive and curative effects of fungicides are carried out under controlled conditions. Experiments with artificial inoculation in the field are more

problematic especially because of influx of spores from the surrounding areas. It is crucial that the experiment is carried out at the right stage just before the natural occurrence of spores. In Denmark, a registration net for the occurrences of late blight is established (www.Planteinfo.dk) and has made it possible to inoculate field plots in the narrow time gap between blight occurrences in the Eastern and Western part of the country.

Only little is known on the effect of the fungicides when they are applied at different times in the latency period. This information is very important for targeting the right fungicides at the right time in the spray programme or DDS and the aim of this paper is to describe the preventive and curative effect of fungicides against potato late blight under field condition.

Material and methods

In 2000 (Bødker and Nielsen, 2001) and 2001, field trials with small plots (two rows, 1.5 x 5 m) of the susceptible cultivar Bintje was established at the Research Centre Flakkebjerg. Six (2000) to eight (2001) fungicides with contact, translaminar and systemic compounds, respectively were tested for the preventive or curative effect (Table 1). All plots were inoculated with a diluted sporangiasuspension (100 sporangia/ml in 2000 and 500 sporangia/ml in 2001) of a mixture of six different isolates of *P. infestans* (all A1) isolated in Denmark in 1999 or 2000 respectively. The plots were inoculated the 5th of July 2000 and 27th of June 2001 at a time where blight was only registered in Jylland (registration data in www.Planteinfo.dk) and not at the Research Station. The fungicides were applied 12 hours before inoculation, 12 hours after inoculation and then at different time after inoculation up to 84 hours after inoculation in 2000 and 138 hours after inoculation in 2001. All treatments were arranged with four replicates in a split-plot design with a non-treated plot for each fungicide. The field trial was heavily irrigated four hours before the first spray. After inoculation, all plots were covered with a fibre cloth to keep high moisture content.

Each plot was only treated with fungicide once. The sprayer was mounted with Hardi flat nosles (ISO) 03, 3.75 Bar and a speed of 4 km/hr.

Table 1. Fungicides, type and doses used in field trials to study preventive/curative effect of fungicides against potato late blight.

Fungicide ^a	Normal dosage	Active ingredients		
		Contact	Translaminar	Systemic
Shirlan *	0,4 l/ha	fluazinam	-	
Dithane DG *	2,0 kg /ha	mancozeb	-	
Tattoo *	4,0 l/ha	mancozeb	-	propamocarb
Ridomil MZ	2,5 kg/ha	mancozeb	-	metalaxyl
Acrobat WG *	2,0 kg/ha	mancozeb	dimethomorph	
Tanos	0,7 kg/ha	famoxate	cymoxanil	
Sereno ^{a)}	1,25 kg/ha	mancozeb	fenamidone	
Electis ^{a)}	1,8 kg/ha	zoxamide / mancozeb		

**) Only the marked products are registered for the moment for control of potato late blight in Denmark.*

a) Only in the trial 2001.

Results

After inoculation 5th of July 2000 a very cold period occurred with temperatures at night just above 10 C (Bødker and Nielsen, 2001). In 2001 the temperature was higher after inoculation on 27th of July. This difference in temperature is clearly seen in the length of the latency period. In 2000 the first symptoms first appeared approximately 288 hours (12 days) after inoculation whereas in 2001 the first symptoms could be observed approximately 109 hours (4½ days) after inoculation. At this time, there was still no sign of blight in other non-inoculated plots in the field.

The results shows that contact fungicides like Dithane DG, Electis and Shirlan have a marked preventive effect whereas products with both systemic and translaminar components, like Acrobat WG, Tanos, Tattoo and Ridomil MZ, shows some curative properties. Our results with Sereno shows typically preventive action on the same level as the other contact fungicides although the active ingredient *fenamidone* is claimed to have translaminar action. The effect of all the products, however markedly declined when sprayed later in the latency period. In Fig. 1 is shown the relative length of the latency period and in the figure the time in the latency period is calculated when 50 % control is obtained. If a product like Dithane DG is sprayed 17 % within the latency period (18 hours in 2001) the efficacy is only 50 %. For Shirlan, Electis and Sereno the picture is the same. Only in the first fifth (20 %) of the latency period is 50 % control or more expected. With products that typical have curative

action (Ridomil MZ, Tattoo, Acrobat WG and Tanos) there is a longer time in the latency period where spraying would be expected to have good effect. For Tattoo, e.g. spraying in the first 2/3 the latency period (63 – 73 % of the period) would still give at least 50 % control.

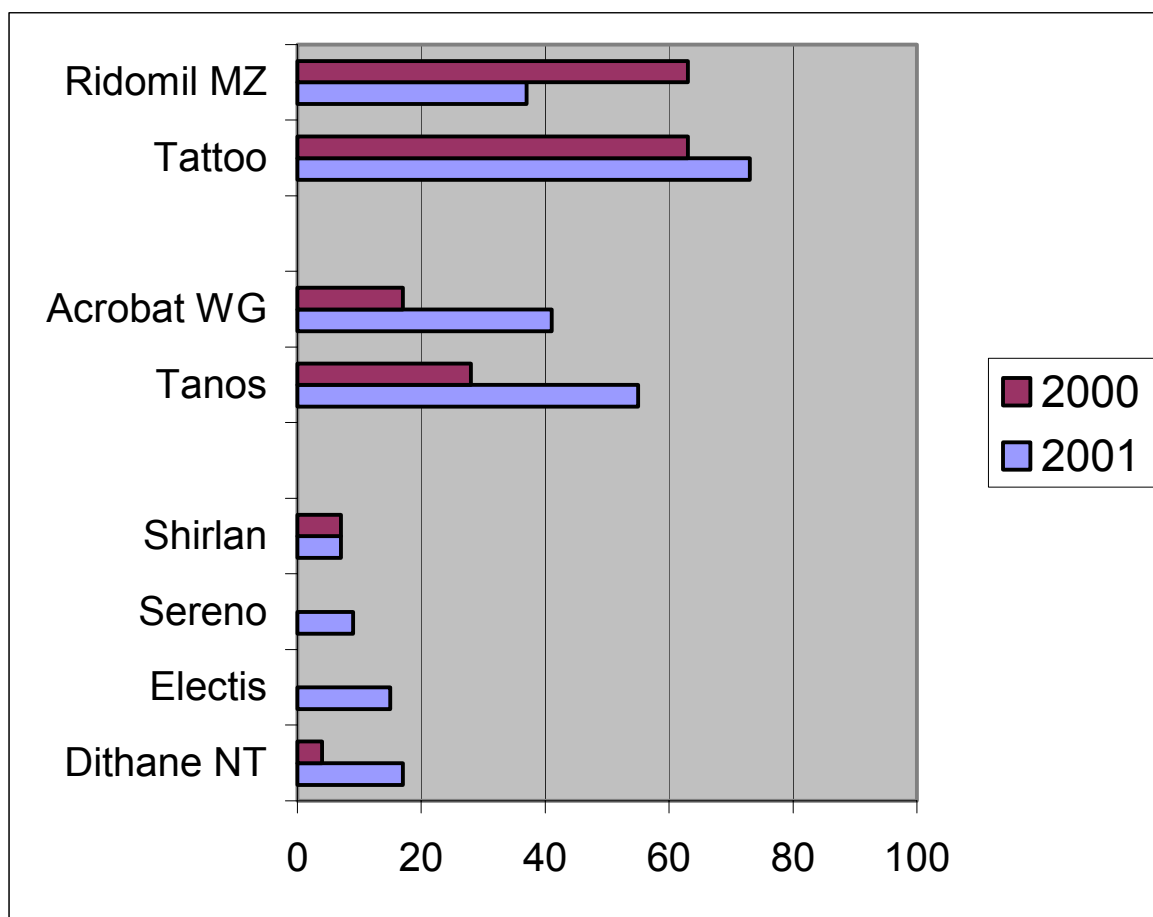


Figure 1. Relative latency period for potato late blight in field experiments 2000 and 2001 (100 = first symptoms visible) and the relative part of the period where at least 50 % control was obtained after spraying with the different products.

Discussion

When potatoes are treated preventively 12 hours before inoculation all the tested fungicides have 100 % effect on potato late blight. The effect declines, however very sharply if products like Dithane DG, Shirlan, Electis or Sereno is sprayed shortly after inoculation. If the spraying were done more than approximately 20 % within the latency period, the treatment would give less than 50 % control. The curative effect was better for Ridomil MZ, Tattoo, Acrobat WG and Tanos where at least 50 % control was achieved when sprayed up to 2/3 within the latency period. There was however a big variation between the products as seen in

Fig. 1. A relative better effect of fungicides when applied early in the latency period have also been observed with other pathogens, e.g. *Septoria tritici* in cereals (Jørgensen *et al.*, 1999)

In 2000 it was not possible to test the eradicated effect of the fungicides because all treatments were performed within the latency period. In 2001 where the latency period was much shorter the last spraying was performed approximately one day after symptoms was visible. All the tested fungicides (table 1) had very low eradicated effects under these circumstances.

The results from the two field trials emphasises the importance of the timing of the application close to the infection period. If sprayed late in the latency period some control can be obtained with curative fungicides but the level is lower than for fungicides applied preventively according to the results from our field trials. Other experiments in growth chambers with spraying on leaflets after inoculation showed also good effect of *propamocarb* + *chlorothalonil* and *cymoxanil* + *mancozeb* in the first part of the latency period (up till 48 hours after inoculation. There was, however no spraying late in the latency period). In these experiments there was less effect of *dimethomorph* + *mancozeb* (Johnson *et al.*, 2000). When sprayed on established stem lesions on green house grown potato plants, Johnson *et al.* (2000), however found some effects of curative fungicides (*dimethomorph* + *mancozeb* or *cymoxanil* + *mancozeb*).

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Protection of new growth against *Phytophthora infestans* in fungicide schedules with spray intervals of four and seven days

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Introduction

Potato plants are sprayed preventively with fungicides to protect them against *Phytophthora infestans*. Spray intervals depend on the intrinsic fungicidal properties of the products used, the weather conditions, infection pressure and the growth rate of the potato plants. The increased aggressiveness of the new blight population probably leads to shorter infection cycles and a more rapid epidemic development (Flier *et al.*, 2002). The narrower window of opportunity for application of fungicides results in an increased importance of the protection of the new growth. The objective of this research was to determine the protection of new growth after application of contact, translaminar and systemic fungicides. This research was a follow-up of the research carried out in 2000.

Material and methods

Planting tubers 35 cm apart on ridges in a sandy loam soil grew potato plants (cv. Bintje) meant for these field experiments. Fertilisation and weed control were conducted under good agricultural practice. Two experiments were set up. In one experiment, sprays were carried out every four days and in another experiment sprays were carried out every seven days (Table 1, 2 & 3). The design for each trial was a randomised block with four replications per treatment. The first fungicide application was carried out when plants were 20 cm high. Fungicides were applied in a solution of 250 l.ha⁻¹ using a tractor pulled trial-site sprayer with Teejet XR110.04 nozzles. Just before each scheduled fungicide application, 20 leaflets from four growing points were detached from each plot and inoculated with blight spores and incubated (RH 98% and 15°C) in the laboratory for five days.

Table 1. Diagram of trial procedure in the field experiment with a spray interval of seven days.

Date	20-6	27-6	4-7	12-7	18-7	
Day	0	7	14	22	28	
Fungicide application						Assessments
1	Spray	inoculation				Day 12 (2-7)
2		spray	inoculation			Day 19 (9-7)
3			spray	inoculation		Day 27 (17-7)
4				spray	inoculation	Day 33 (23-7)

Table 2. Diagram of trial procedure in the field experiment with a spray interval of four days.

Date	21-6	25-6	29-6	4-7	9-7	13-7	18-7	
Day	0	4	8	13	18	22	27	
Fungicide application								Assessments
1	spray	inoculation						day 9 (30-6)
2		spray	inocul.					day 14 (5-7)
3			spray	inocul.				day 18 (9-7)
4				spray	inocul.			day 25 (16-7)
5					spray	inocul.		day 27 (18-7)
6						spray	inocul.	day 32 (23-7)

Number, size and sporulation of the lesions was assessed five days after inoculation. Growth rate of plants between spraying and inoculation was determined by observation of growing points that were sprayed with red paint just before each fungicide application.

Table 3. Treatments in the experiments in which the efficacy of fungicides on new growth was tested.

Treatment	Active ingredient (s)	Mobility	Dose rate
A Untreated	-	-	-
B Curzate M	cymoxanil (4.5%) mancozeb (68%)	local-systemic contact	2.5 kg/ha ¹
C Acrobat	dimethomorph (7.5%) mancozeb (67%)	local-systemic contact	2.0 kg/ha
D Tattoo C	propamocarb-hydrochloride (375 g/l) chlorothalonil(375 g/l)	systemic contact	1.5 l/ha
E Ridomil Gold MZ	metalaxyl-M (4%) mancozeb (64%)	systemic contact	2.5 kg/ha
F Shirlan	fluazinam (500 g/l)	contact	0.4 l/ha
G Dithane DG	mancozeb (75%)	contact	4.0 kg/ha

¹⁾ Dose rate first application in field experiments was 2.0 kg/ha and second application 2.25 kg/ha

Results

Spray interval seven days

The number of new leaves between fungicide application and detaching leaflets in spray interval 1, 2, 3 and 4 was approximately 1,5; 1,5; 1 and <1 respectively.

Table 4. Percentage lesions, lesion size and sporulation of the lesion after 1, 2, 3 and 4 fungicide applications with a seven day spray interval in which the efficacy of fungicides on new growth was tested.

Treatment Application	Lesion ¹				Lesion size ²				Sporulation ³			
	1	2	3	4	1	2	3	4	1	2	3	4
A Untreated	100.0	98.8	100.0	45.0	75.0	72.5	85.0	30.0	75.0	88.6	95.0	61.5
B Curzate M	93.8	78.8	58.8	3.8	55.0	62.5	67.5	2.5	92.0	86.4	84.2	0.0
C Acrobat	87.5	77.5	71.3	2.5	55.0	67.5	52.5	20.0	83.9	91.7	71.2	25.0
D Tattoo C	97.5	95.0	78.8	5.0	75.0	62.5	57.5	5.0	89.6	95.0	68.0	50.0
E Ridomil Gold MZ	72.5	73.8	16.3	0.0	37.5	21.3	6.3	- ⁴	39.4	45.2	0.0	-
F Shirlan	97.5	88.8	73.8	7.5	67.5	65.0	72.3	15.0	84.7	92.3	80.1	41.7
G Dithane DG	87.5	53.8	41.3	0.0	65.0	32.5	43.7	-	87.3	83.0	76.0	-
LSD ($\alpha=0.05$)	21.8				24.0				35.3			

1) Lesions

Percentage leaflets with a lesion

2) Lesion size

Lesion size of the lesion expressed in percentage of the leaflets covered by the lesion

3) Sporulation

Percentage lesions with sporulation

4) -

Since no lesions were observed, lesion size and sporulation could not be assessed.

After one fungicide application, only Ridomil Gold MZ resulted in significantly fewer and smaller lesions than untreated. After two applications Ridomil Gold MZ and Dithane DG showed significantly fewer and smaller lesions than untreated. When three fungicide applications were applied, all fungicides, except Tattoo C, resulted in significantly fewer lesions than untreated. Ridomil Gold MZ resulted in significantly fewer lesions than all other fungicides. The infection level after four fungicide applications was low. After four applications all fungicides resulted in significantly fewer lesions than untreated.

In general, the number of lesions decreased with increasing number of fungicide applications. The differences between the first and second application were only significant for Dithane DG. Besides fewer lesions, Dithane DG also resulted in significantly smaller lesions.

When fungicides were applied three times, all fungicides, except Acrobat and Tattoo C, resulted in significantly fewer lesions than after one application. Only Ridomil Gold MZ

resulted in significantly smaller and less sporulating lesions. After four applications, all fungicides resulted in significantly fewer and smaller lesions than after one application. Curzate M, Acrobat, Tattoo C and Shirlan also resulted in significantly fewer sporulating lesions.

Spray interval four days

The number of new leaves between fungicide application and detaching leaflets in spray interval 1, 2, 3, 4, 5 and 6 was approximately 1; 1; 1; 1; 0.5 and <0.5, respectively. After one, two or three fungicide applications, all fungicides resulted in significantly fewer lesions than untreated (Table 5, 6 & 7). Ridomil Gold MZ resulted in the fewest and smallest lesions. After four applications, Ridomil Gold MZ, Tattoo C and Dithane DG resulted in significantly fewer lesions than untreated. After five or six applications, all fungicides resulted in 100 % protection of the growing point. A cumulative effect of several fungicide applications was not clearly demonstrated. After the second fungicide application, a decrease in number of lesions and lesion size was observed. This decrease was significant for Shirlan and Dithane DG. Tattoo C, Shirlan and Dithane resulted in smaller lesions after two fungicide applications than after one application.

All fungicides resulted in more and larger lesions when fungicides were applied three times compared to two times.

Table 5. Percentage lesions after 1, 2, 3, 4, 5 and 6 fungicide applications with a four day spray interval in which the efficacy of fungicides on new growth was tested.

Fungicide applications	1	2	3	4	5	6
Treatment						
A Untreated	96.3	85.0	100.0	98.8	85.0	40.0
B Curzate M	43.8	41.3	46.3	90.0	0.0	0.0
C Acrobat	50.0	32.5	41.3	86.3	0.0	0.0
D Tattoo C	57.5	46.3	50.0	51.3	0.0	0.0
E Ridomil Gold MZ	11.3	10.0	25.0	13.8	0.0	0.0
F Shirlan	60.0	30.0	61.3	86.3	0.0	0.0
G Dithane DG	47.5	23.8	26.3	75.0	0.0	0.0
LSD ($\alpha=0.05$)				22.0		

Curzate M, Acrobat, Shirlan and Dithane DG resulted in significantly more lesions when fungicides were applied four times compared to one application. All fungicides resulted in complete protection of the growing point when fungicides were applied five or six times.

Table 6. Size of the lesions after 1, 2, 3, 4, 5 and 6 fungicide applications with a four day spray interval in which the efficacy of fungicides on new growth was tested.

Fungicide applications	1	2	3	4	5	6
Treatment						
A Untreated	57.5	62.5	72.5	80.0	35.0	35.0
B Curzate M	50.0	41.3	47.5	67.5	- ¹	-
C Acrobat	40.0	33.8	43.8	67.5	-	-
D Tattoo C	47.5	21.3	35.0	55.0	-	-
E Ridomil Gold MZ	3.8	3.8	17.5	8.8	-	-
F Shirlan	50.0	23.8	46.3	80.0	-	-
G Dithane DG	50.0	25.0	32.5	70.0	-	-
LSD ($\alpha=0.05$)				24.3		

1) - *Since no lesions were observed, lesion size could not be assessed.*

Table 7. Percentage of lesions with sporulation after 1, 2, 3, 4, 5 and 6 fungicide applications with a four day spray interval in which the efficacy of fungicides on new growth was tested.

Fungicide applications	1	2	3	4	5	6
Treatment						
A Untreated	100.0	80.0	100.0	100.0	86.8	70
B Curzate M	75.6	67.7	87.1	73.3	- ¹	-
C Acrobat	74.1	64.4	63.9	92.5	-	-
D Tattoo C	90.3	63.9	84.8	79.1	-	-
E Ridomil Gold MZ	5.7	2.1	37.5	25.0	-	-
F Shirlan	83.4	70.8	80.5	84.3	-	-
G Dithane DG	84.1	77.9	89.3	77.1	-	-
LSD ($\alpha=0.05$)				33.8		

1) - *Since no lesions were observed, sporulation on lesions could not be assessed.*

Discussion

Spray interval seven days

After one application, only Ridomil Gold MZ resulted in significantly fewer lesions compared to untreated. The protection of new growth increased when more applications were applied. Curzate M, Ridomil Gold MZ, Shirlan and Dithane DG resulted in significantly fewer lesions when three applications were carried out compared to one. Ridomil Gold MZ demonstrated the best protection of new growth after three fungicide applications. After four fungicide applications, all fungicides demonstrated a high level of protection of new growth. Protection of new growth by fungicides was also demonstrated by Spits & Schepers (2001) in field trials in 2000.

Spray interval four days

The protection of new growth against *P. infestans* of fungicides in a schedule with a four day spray interval was better compared to a seven day spray interval. Ridomil Gold MZ resulted in the best protection of new growth. Protection of new growth increased after two fungicide applications. After three fungicide applications a slight decrease in protection was observed. The longer period (5 days) between fungicide application and inoculation (more new growth) compared to the first two periods (4 days), might explain this lower protection. After four applications a large decrease in protection was observed. Probably several factors caused this decrease:

- Inoculation was carried out five days after spraying;
- An observed longer incubation time was caused by presumably lower vitality of the inoculum;
- Disease assessments were carried out seven days after inoculation instead of five days because of the longer incubation time;
- Beside the above factors inoculum contained more than the usual 5-6 thousand sporangia per ml.

After five fungicide applications, all fungicides resulted in significantly fewer lesions than untreated.

Conclusions

It has to be mentioned that in these experiments a high (artificially applied) disease pressure was used. This research provides more specific (basic) information about the efficacy of fungicides to protect new growth. Results cannot directly be translated into practical spraying strategies.

The efficacy of fungicides to protect new growth against *P. infestans* has been tested in experiments with four and seven day spray intervals. In the first 14 days of the experiments the protection of new growth was clearly better in the trial with four day spray intervals compared to the trial with seven day spray intervals. Shorter time between spraying and inoculation results in a better (re)distribution of (contact) fungicides on the new growth resulting in a better protection.

In the beginning of the growing season protection of new growth was not effective with all fungicides. This is most clearly demonstrated after the first two fungicide applications. Ridomil Gold MZ, with a systemic component metalaxyl, resulted in the best protection of new growth. In both strategies, the level of protection increased later in the season with lower growth rates. Based on the results of these trials it can not be concluded whether the better protection is caused by the cumulative effect of more fungicide applications or by the lower growth rate.

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Ranman, the new marathon fungicide

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Summary

RANMAN „Twin Pack“ a new broad spectrum fungicide, discovered by ISK, developed by BASF, exhibits a high level of activity against *Oomycetes* diseases. The new active ingredient cyazofamid is a strong and unique inhibitor of respiration at a low concentration: 80 g/ha. Used with RANMAN B, an organosilicone spreader, RANMAN shows superior foliar and tuber protection against *Phytophthora infestans* in potatoes. Good coverage of the leaf surface, longer residual activity and effective rainfastness provide consistent protectant performance.

Keywords: late blight, fungicide, cyazofamid, tuber protection, rainfastness.

Introduction

RANMAN „Twin Pack“ contains the active ingredient cyazofamid, which belongs to a new chemical class of fungicides: cyano-imidazoles. Discovered and synthesised by ISK, RANMAN has been exclusively developed by BASF. Cyazofamid has strongly lipophilic properties allowing it to adhere to the leaf surface. RANMAN Twin Pack, the combination of 80 g cyazofamid and an organosilicone superspreader, provides a high level of protection against *Phytophthora infestans*.

Chemical and physical properties

Common name: Cyazofamid

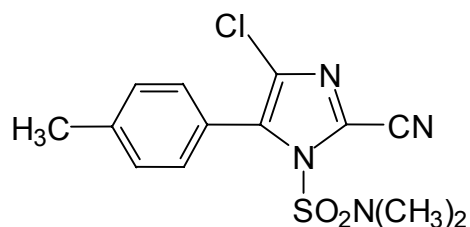
BASF code number: BAS 545F

Chemical name: 4-chloro-2-cyano-N, N-dimethyl-5-(4-methylphenyl)-1H-imidazole-1-sulfonamide

Molecular formula: $C_{13}H_{13}ClN_4O_2S$

Molecular mass: 324.8

Structural formula:



Formulation: 400 g/l SC + organosilicone super-spreader (Twin Pack)

Appearance: white powder

Melting point: 152.7°C

Solubility at pH7: 0.108 mg/l (20°C)

Vapour pressure: 1.33×10^{-5} Pa at 25°C

Mode of action:

Mitochondrial inner membrane

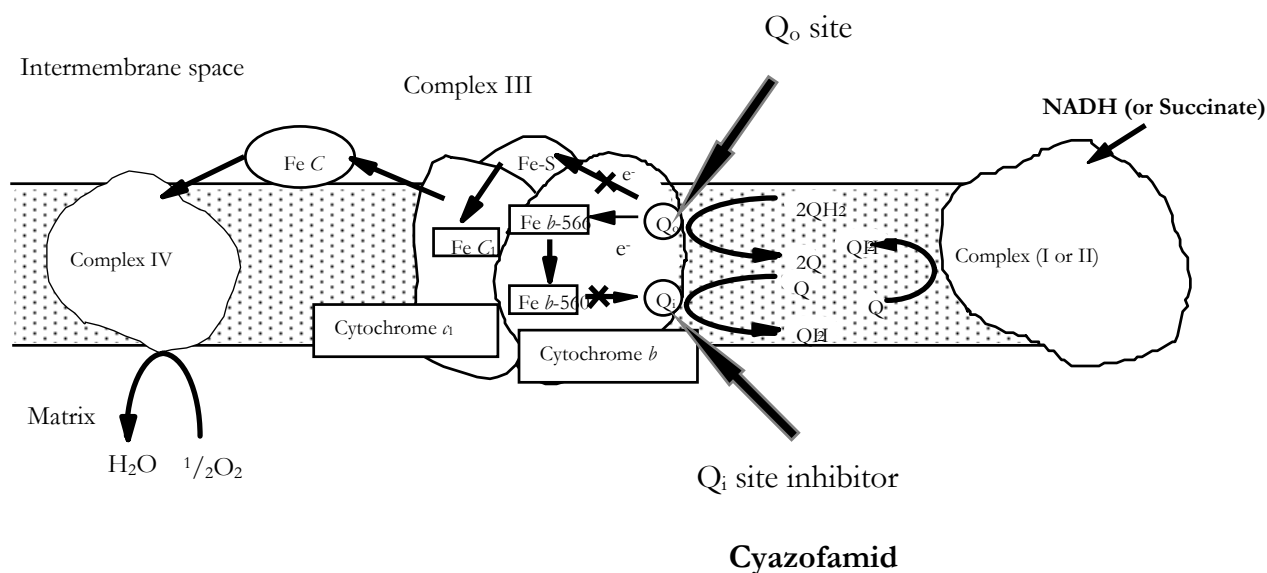


Figure 1. Mode of action of RANMAN.

The active ingredient in RANMAN, cyazofamid, blocks the cellular energy centres that are vital to the fungus. It breaks the mitochondrial electron transport chain at Complex III (ubihydroquinone-cytochrome C reductase), located in the inner mitochondrial membrane. Cyazofamid binds to the Qi site within Complex III, different from the Qo site where strobilurines, famoxadone and fenamidone bind (Figure 1). Fungi resistant to Qo inhibitors are not cross-resistant to cyazofamid.

RANMAN has been tested *in vitro* and found to be active against different steps in the *Phytophthora* life-cycle. RANMAN inhibits both the direct and indirect germination of sporangia. RANMAN prevents zoospores from being released. Zoospores burst on contact with the fungicide and sporulation is minimized. In reducing the germination, the number and the mobility of spores, RANMAN provides a reliable leaf and tuber protection.

Material and methods

The field experiments were conducted by BASF over 2 years in Germany, United Kingdom, Netherlands, France, Belgium, Denmark and Poland. All trials were conducted following EPPO guidelines or the CEB method. Selected trials were inoculated where the risk of blight development was perceived as low.

Tested products were:

RANMAN (0,2 + 0,15 l/ha),	ACROBAT M (2 kg/ha),
SHIRLAN (0,4 l/ha),	AVISO DF (2,5 kg/ha).

Interest of the Adjuvant

RANMAN develops its activity specifically on the surface of the plant. The adjuvant greatly improves uniform distribution on the plant surface. With little water volume RANMAN is adequately distributed to provide an allround protection (Table 1).

Table 1. Adjuvant effect in RANMAN.

Fungicide treatment	Phytophthora infection %	Potato Yield dt/ha
Untreated	100	238
RANMAN without adjuvant	24	402
RANMAN (0.2 + 0.15 l/ha)	16	474

Sources: 4 trials Germany, 1999-2000, 4-6 applications (spray interval 10-15 days), assessment 7-10 days after last application.

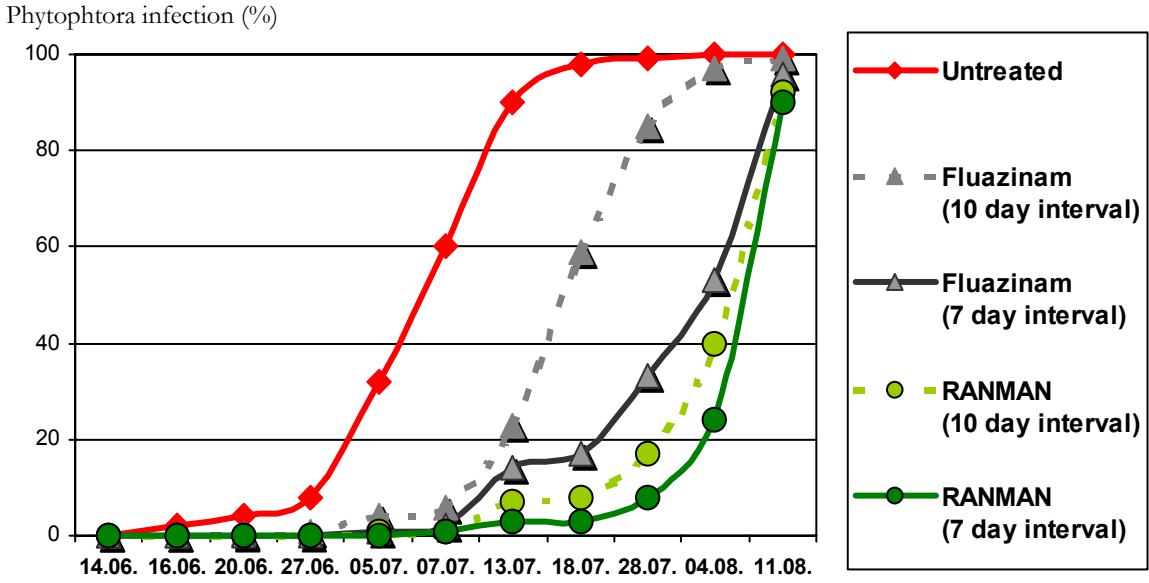
Outperformer at longer spray intervals

In a direct comparison with fluazinam, RANMAN shows superior control of *Phytophthora infestans* wether evaluated after 7, 10 or 14 day spray intervals. The performance decline seen with other contact fungicides is not observed with RANMAN (Table 2 and Figure 2), which means the farmer can have more security for the control of potato late blight

Table 2. *Phytophthora* infection % after fungicide application in different spray intervals.

Fungicide treatment	7 day interval	10 day interval	14 day interval
Untreated	77	87	89
RANMAN (0.2 + 0.15 l/ha)	8	18	21
Fluazinam (0.4 l/ha)	12	40	55

Sources: Summary of 9 to 18 BASF trials in Germany and Netherlands.



Sources: 1 BASF trial in Germany, 6-8 applications. Dose rates: RANMAN 0.2 + 0.15 l/ha, Shirlan 0.4 l/ha

Figure 2. Evolution of *Phytophthora* infection % under fungicides application at different spray intervals

Tuber blight control

Tuber blight can be reduced by limiting the development of foliar blight. In addition to the leaf protection, avoiding contact between zoospores and tuber is necessary. The good leaf protection combined and the high zoospores reduction with RANMAN leads to outstanding performance against tuber blight (Table 3)

Table 3. Efficacy of RANMAN against tuber blight. 6-16 applications, 5-10 day intervals, tuber assessment at harvest.

Fungicide treatment	Tuber infection %	Potato Yield (dt/ha)
RANMAN (0.2 + 0.15 l/ha)	2	449
DMM + Mz (2 kg/ha)	9	357
Fluazinam (0.4 l/ha)	6	422
Cymoxanil + Metiram (2.5 kg/ha)	12	385

Sources: 6 BASF trials from Netherland.

This high level of tuber protection from the use of RANMAN in a programme maximises the yield and the quality of the potatoes and increases the profit potential for the farmer.

Rainfastness

The lipophily of cyazofamid means RANMAN can bind strongly to the leaf surface. A minimum dry period of one hour is enough for RANMAN to be rainfast (Table 4). Once RANMAN is applied, the efficacy is guaranteed even under the worst humid weather conditions (Figure 3).

Table 4. *Phytophthora* infection under irrigation after different dry periods.

Fungicide treatment	Without irrigation	20 mm after 1 hour	20 mm after 2 hour
Untreated	42	45	45
RANMAN (0.2+0.15 l/ha)	2	2	2
Fluazinam (0.4 l/ha)	9	16	9

Sources: BASF Germany 2001, application, irrigation, inoculation. Assessment 14 days after application.

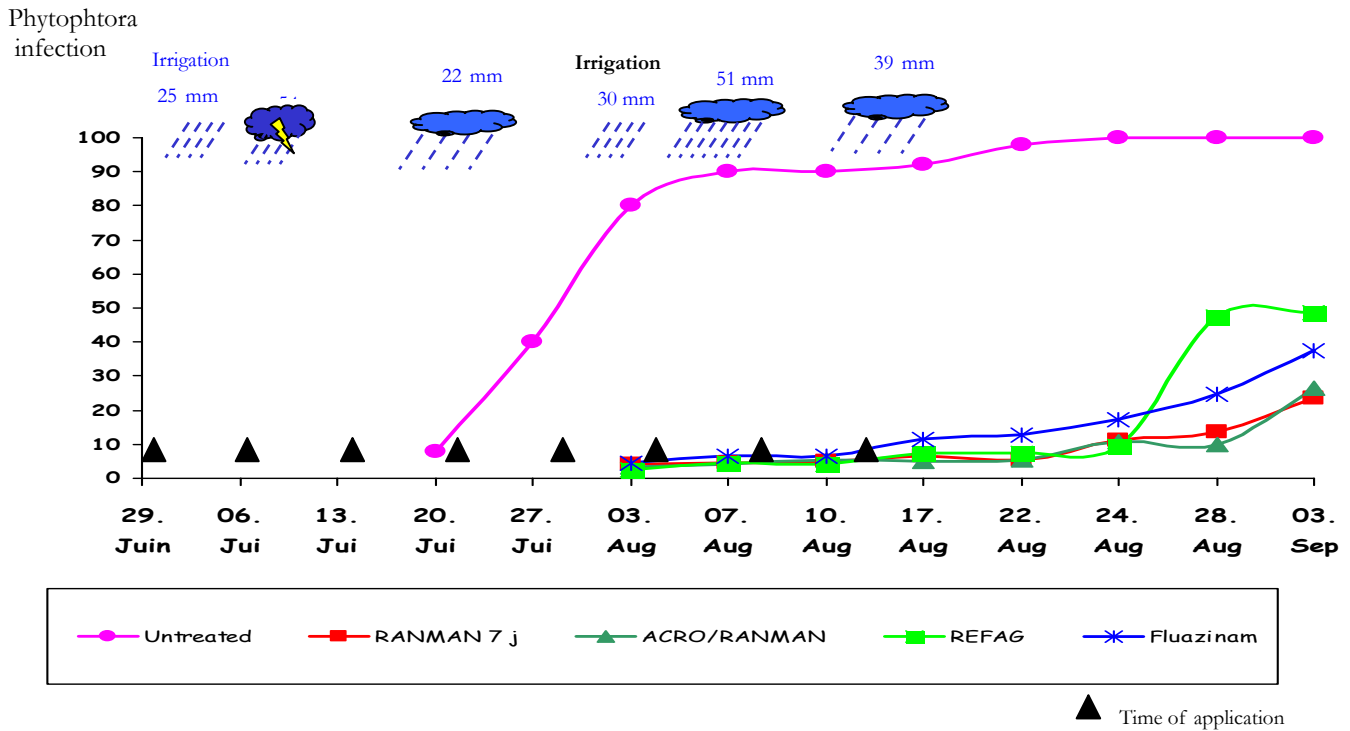


Figure 3. Evolution of the *Phytophthora* infection under different spray programmes in raining and irrigation conditions.

Sources: Trials in France, FREDEC Nord Pas-de-Calais with the scientific support of the SRPV Nord Pas-de-Calais.

Conclusion

RANMAN is a new contact fungicide against late blight . Cyazofamid in combination with an organosilicone spreader shows a long residual efficacy, good tuber protection and an outstanding rainfastness. These properties contribute to consistent *Phytophthora infestans* control.

RANMAN, with strong biological efficacy, crop safety and low rate per hectare, provides an excellent tool for control of potato late blight.

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Results of validation trials of *Phytophthora* DSSs in Europe, 2001

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Summary

Six different decision support systems for the control of late blight were tested in European validation trials in 2001: Simphyt, Plant-Plus, NegFry, ProPhy, Guntz-Divoux/Milsol and PhytoPre+2000. A total of eleven trials were carried out in seven countries. In each trial 2-4 different DSSs were validated, 29 DSS validations in total. The use of the DSSs reduced fungicide input by 8-62 % compared to routine treatments. The level of disease at the end of the season was the same or lower using a DSS compared to a routine treatment in 26 of 29 validations. Yield level was the same or higher for DSS strategies compared to routine

strategies. The DSS influence on tuber blight was not clear, but in most cases tuber blight level was at the same low level as for routine treatment (0-3%). No one single DSS always obtained a better control effect than other DSSs tested.

Key words: DSS, validation, late blight, Europe.

Introduction

In the frame of the EU concerted action, "European Network for Development of an Integrated Control Strategy of Potato Late blight", several late blight DSSs were tested in seven European countries in 2001. Similar validations were carried out in 1999 and 2000 (Kleinhenz & Jörg, 2000, Hansen, Kleinhenz & Jörg, 2001). This article reports the results of validation trials carried out in 2001.

Methods

Validation trials

Participants in the validation network and the DSSs tested are given in Table 1. In Holland three trials were carried out on three different locations - Lelystad, Vredepeel and Valthermond. In all other countries more than one trial in Table 1 refer to the fact that the same DSSs were tested in more than one variety, but at the same trial site. All participants followed a trial guideline agreed in 1999 (Jörg & Kleinhenz, 1999). In the Dutch trials, untreated and treated plots were desiccated when the disease level exceeded 1-2% to keep infection pressure at a low level (Wander & Spits, this proceeding). In all other trials untreated and treated plots were desiccated at the end of the season. Therefore, the treated plots were exposed to a high infection pressure from untreated plots, infection rows and sometimes other infected trials at the same trial site. Based on the EU policy on minimising the use of pesticides, the criteria of success for the DSS validation was defined as: *Use of a late blight DSS in the validation trials should have at least the same control effect as the use of a routine schedule and, at the same time, with less use of fungicide.*

Availability of fungicides strongly varies between the European countries, and not all active ingredients or products recommended by the DSSs could be used in the trials. In the validation trials fluazinam was used as contact fungicide in 10 out of 11 trials.

Table 1. Participants and DSSs included in the validation trials 2001.

Country	Institution	Number of trials	DSSs tested					
			Simphyt	NegFry	Plant Plus	ProPhy	Guntz- Divoux	PhytoPre +2000
CH	FAL, Zürich	2	X					X
BE	CRA, Gembloux	1	X		X		X	
NL	PPO, Lelystad	3		X	X	X		
IRL	Oak Park, Carlow	2	X	X	X	X		
AU	BFL, Vienna	2	X	X				
FR	SRPV L. en Gohelle	1	X	X		X	X	
DE	LPP, Mainz	2	X				X	

Weather conditions were measured by standard weather stations or by weather stations in the crop. If weather forecasts were implemented in the DSS and forecasted weather data were available they were used for decision-making.

Results

First appearance of late blight

Late blight was found in all the trials except in the two trials in Germany. No results from the German trials will be reported in this paper. Late blight attacks were recorded not only at the trial sites but also in the region in a 5-10 km circle around the trial site (Figure 1). The earliest attacks were recorded in Switzerland on June 11th (organic field in the region) and at Valthermond in Holland on June 12th (field in the region). Late blight was found much later at the specific trial sites, June 25th in Bintje in Switzerland and July 13th in Karakter at Valthermond. Late blight was found late in the season in Belgium: On July 25th at trial site and at the same time in ware potato fields in the region. Austria: On June 22nd in the region and June 28th at trial site, Bintje. France: On July 23rd in both region and trial site. Vredepeel in Holland: July 11th in the region (neighbouring organic field) and July 26th at the trial site and Ireland: On August 2nd in the region and August 10th at the trial site (King Edward and Rooster). Further information about the late blight situation in Europe in 2001 can be found in Schepers, 2002 (this proceeding). Final disease level in untreated plots ranged from 0.2 - 4.5% in Austria to 80 - 100% severity in Ireland, France, Belgium and Switzerland.

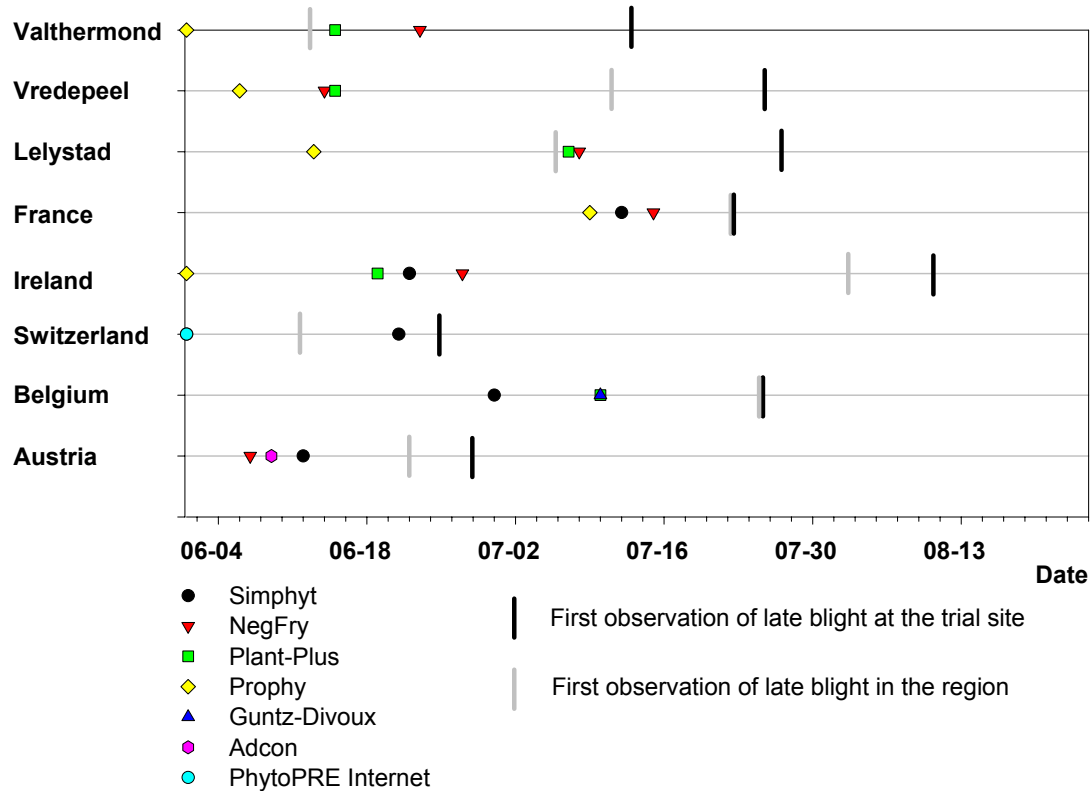


Figure 1. Late blight appearance at eight DSS validation trial sites in Europe (see Table 1). Dates of initial sprays recommended by several DSSs are compared with the dates when late blight was found in the region (5-10 km radius) and at the trial site.

DSS recommendation of first spray

Recommendations of first sprays by the DSSs compared to recordings of first attack are shown in Figure 1. In all the trials first attacks were recorded at 0.1 % or lower except in Ireland, when the first attack was recorded at 1% severity in two of four plots in King Edward on August 10. Under favourable weather conditions, the time from infection to appearance of symptoms is about 3-5 days. Therefore, the first preventive spray must be recommended 3-5 days before the first symptoms appear in the field (Figure 1). The early attack in the trial in Austria and the late attack in the trial in France were well predicted by all the DSSs tested. In Belgium, Plant-Plus and Guntz-Divoux recommended first spray on the same date (July 10th), 15 days before the first symptoms. In the same trial Simphyt recommended first spray on June 30th, 25 days before the first symptoms. In Switzerland PhytoPre+2000 recommended first spray 26 days and Simphyt 4 days before the first symptoms. In general, Prophy recommended first spray earlier than other DSSs tested (Figure 1)

In Ireland, Carlow, all DSSs recommended first spray very early compared to the day when blight was found in the trial: NegFry: 44, Simphyt: 49, Plant-Plus: 51 and Prophy: 73 days before first symptoms were recorded. At Carlow, the weather conditions in late June and early July were conducive to blight, and blight was recorded in many areas at that time, but not in Carlow. Probably, because Carlow is south of the main potato growing area of Eastern Ireland, there was no inoculum available at that time. The rest of July was very dry and not conducive to late blight development. Blight was first recorded in the area on August 7.

DSS use of fungicide and control effect

The fungicide use and the control effect by the different DSSs is given as consecutive fungicide applications, fungicide type, total number of applications, disease level end of season (% severity), yield (t/ha) and amount of tuber blight (%)(Table 2). Fungicide type is marked as C, T and S for contact, translaminar and systemic compound, respectively, or C/S for a mixture of a contact and a systemic ingredient. In all the trials fluazinam was used as contact fungicide, except in the Belgian trial, where mancozeb was used instead. Results are ranged according to total number of applications.

To show results according to the defined "criteria of success", the same results and some additional information are shown in graphics (Figures 2 to 4). **X and Y axes:** The DSS validation result is shown as "Reduction in number of fungicide applications (%)" compared to routine treatment" versus "Disease end of season, severity (%)". **Text upper left corner:** DSS tested and number of fungicide applications applied, country, variety used in the trial, the date on which the trial was ended, and disease severity in untreated plots at the end of the season.

Table 2. Type of fungicide used in the trials, number of applications, control effect as disease end of season, yield and tuber blight in eight European DSS validation trials. Values for Disease end of season, Yield and Tuber blight followed by a common letter are not statistically different ($P= 0.05$) as determined by Duncan's multiple range test

Trial name and variety	Consecutive fungicide applications according to DSS. C = Contact, T = Translaminar, S = Systemic	Total No app.	Disease end of season (%)	Yield t/ha	Tuber blight (%)	
Ireland (King Edward)	Routine	C,C,C,C,C,C,C,C,C,C,C,C	13	50 a	62.2 ab	0.15 a
	Prophy:	C,C,S,C,C,S,C,C,C,S,C	11	10 b	65.0 ab	0.03 b
	Plant Plus:	S,C,C,S,C,C,C,C,C,S	10	15 b	72.4 a	0.03 b
	Simphyt:	C,S,S,S,C/T,C/T	6	31 ab	61.1 b	0.08 ab
	NegFry:	C,C,C,C,C,C	6	15 b	62.2 ab	0.05 ab
Ireland (Rooster)	Routine	C,C,C,C,C,C,C,C,C,C,C,C	13	10 a	67.7	0.03 a
	Prophy:	C,C,S,C,C,C,C,C,C,C,S,C	12	15 a	71.7	0.00 a
	NegFry:	C,C,C,C,C,C	6	10 a	70.9	0.05 a
	Simphyt:	C,S,S,C/T,C/T	5	28 a	72.0	0.00 a
France (Ditta)	Routine:	C,C,C,C,C,C,C,C	8	0.49 bc	-	-
	Simphyt:	C,C,S,C/T,C/T,C	6	0.34 c	-	-
	Milsol:	C,S,C,C,S,S	6	0.44 c	-	-
	Prophy:	C,C,C,C,C	5	0.93 ab	-	-
	NegFry:	C,C,S,C	4	1.17 a	-	-
Belgium (Bintje)	Routine:	C,C,C,C,C,C,C,C,C,C,C	11	3.5 a	-	-
	Simphyt:	C,T,T,C,S,S,S,C,C,S	10	2.5 a	-	-
	Guntz-Di:	T,T,S,T,S,C,C,C	8	2.0 a	-	-
	Plant-Plus:	T,T,S,S,C,C,T	7	4.0 a	-	-
Austria (Bintje)	Routine:	C,C,C,C,C,C,C,C,C,C	10	0.000 a	40.4 a	-
	Simphyt:	C,C,C,C,C/T,C,C/T,C	8	0.050 a	41.5 a	-
	NegFry:	C,S,C,C,C/T,C,C	7	0.025 a	40.8 a	-
Austria (Saturna)	Routine:	C,C,C,C,C,C,C,C,C,C	10	0.0 a	33.2 b	-
	Simphyt:	C,C,C,C,C/T,C,C	7	0.0 a	38.3 a	-
	NegFry:	C,C,C,C,C,C	6	0.0 a	39.1 a	-
Switzerland (Bintje)	Routine:	C,C,T,C,C,T,C,C,T,C,C,C	12	8 a	36.7 a	0.00 b
	Simphyt:	C,S,S,S,S,C,T,C,T	9	13 a	36.4 a	0.68 a
	PhytoPre:	C,C,T,C,C,T,C,C	8	12 a	36.3 a	0.16 b
Switzerland (Agria)	Routine:	C,C,T,C,C,T,C,C,T,C,C,C	12	8 b	31.5 ab	2.55 a
	Simphyt:	C,S,S,S,C,S,T	7	16 b	33.3 a	1.33 ab
	PhytoPre:	C,T,T,C,C,T,C	7	25 a	30.0 b	0.42 b
Holland, Vredepeel (Asterix)	Routine:	C,C,C,C,C,C,C,C,C/T,C,C,C,C,C,C	16	0.17 b	70.7 a	0.2 b
	Plant-Plus:	C,C,C,C,C,C,C,C,C,C,C,C	13	0.08 b	70.6 a	0.2 b
	Prophy:	C,C,C,C,C,C,C,C,C,C,C	12	0.40 b	71.2 a	0.1 b
	NegFry:	C,C,T,C,T,C,C	7	1.80 a	67.5 a	1.1 a
Holland Valthermond (Karakter)	Routine:	C,C,C,C,C,C,C,C,C/T,C,C,C,C,C,C,C,C	16	0.86 a**	50.9 a	3.2 a
	Prophy:	C,C/S,C,C/T,C,C,C,C,C/C/T,C/T,C/T,C/C/T,C/T	15	0.50 a	58.2 a	1.8 a
	Plant-Plus:	C,C/T,C,C,C,C,C,C,C/C/T,C,C/T	12	0.80 a	55.1 a	3.0 a
	NegFry:	C,C/T,C,C,C*	5	>2.3*	-	-
Holland Lelystad (Bintje)	Routine:	C,C,C,C,C,C,C,C,C/S,C,C,C,C	13	0.23 ab	75.9 a	5.0 c
	Prophy:	C,C,C,C,C,C,C,S,S,C,C/S	12	0.17 b	76.0 a	19.4 b
	Plant-Plus:	C,C/T,C,C/T,C,C/T,C,C,C/T	9	0.45 a	73.5 a	33.2 a
	NegFry:	C/T,C,C/T,C*	4	>50.00*	-	-

* At Valthermond and at Lelystad all NegFry plots were dessicated before end of season because late blight attack exceeded 1-2% attack. Further fungicide applications were not carried out for NegFry. At Vredepeel two of four NegFry plots were dessicated 12 days before end of season. Fungicide applications continued in the remaining plots.

** At Valthermond one of four routine treated plots were dessicated because late blight attack was more than 1%.

Vertical reference line: The reference line for DSS reduction in fungicide use compared to routine treatment. **Horizontal reference line:** The reference line for DSS control effect (disease end of season, % severity). **The window of success:** is the window in the lower right corner of the graph: "The use of the DSS resulted in reduced fungicide use and, at the same time, a better control effect compared to a seven-day routine schedule". See also results on statistical analyses in table 2.

From results in Table 2 and Figures 2-4, some general conclusions can be drawn: In total, the DSSs were tested in 29 cases, excluding NegFry at Valthermond and Lelystad (dessicated) (Table 2). In 15 cases results were in the "window of success" (Figures 2-4). Taking into account the analysis of variance, only NegFry in France and at Vredepeel and Phytopre+2000 in Switzerland resulted in a significantly higher disease level end of season than the routine treatment. The DSSs reduced fungicide input as number of applications by 8-62% compared to a seven-day routine schedule. Lowest numbers of applications were recommended by the DSSs in France and in Austria and highest numbers of applications were recommended in the Dutch trials (Table 2). In general, NegFry recommended the lowest number of applications compared to other DSSs in the same trial, 30-54% fungicide reduction compared to routine treatments (Table 2 and Figures 2, 3, and 4). In Holland the use of NegFry was not successful. Probably, this system needs adaptation to humidity sensors used on local weather stations. The same sensors as those used in Holland were introduced on half the Danish meteorological stations in 2001 and the NegFry model needed adaptation to fit results from stations with old sensor types. No one specific DSS always recommended the highest number of applications. In Ireland, ProPhy and Plant-Plus recommended a relatively high number of applications compared to Simphyt and NegFry. In France and Belgium, Simphyt recommended more applications than Prophy and Plant-Plus (Table 2 and Figures 2, 3 and 4). In the Dutch trials even 12-15 DSS applications could not keep *Phytophthora infestans* at zero level.

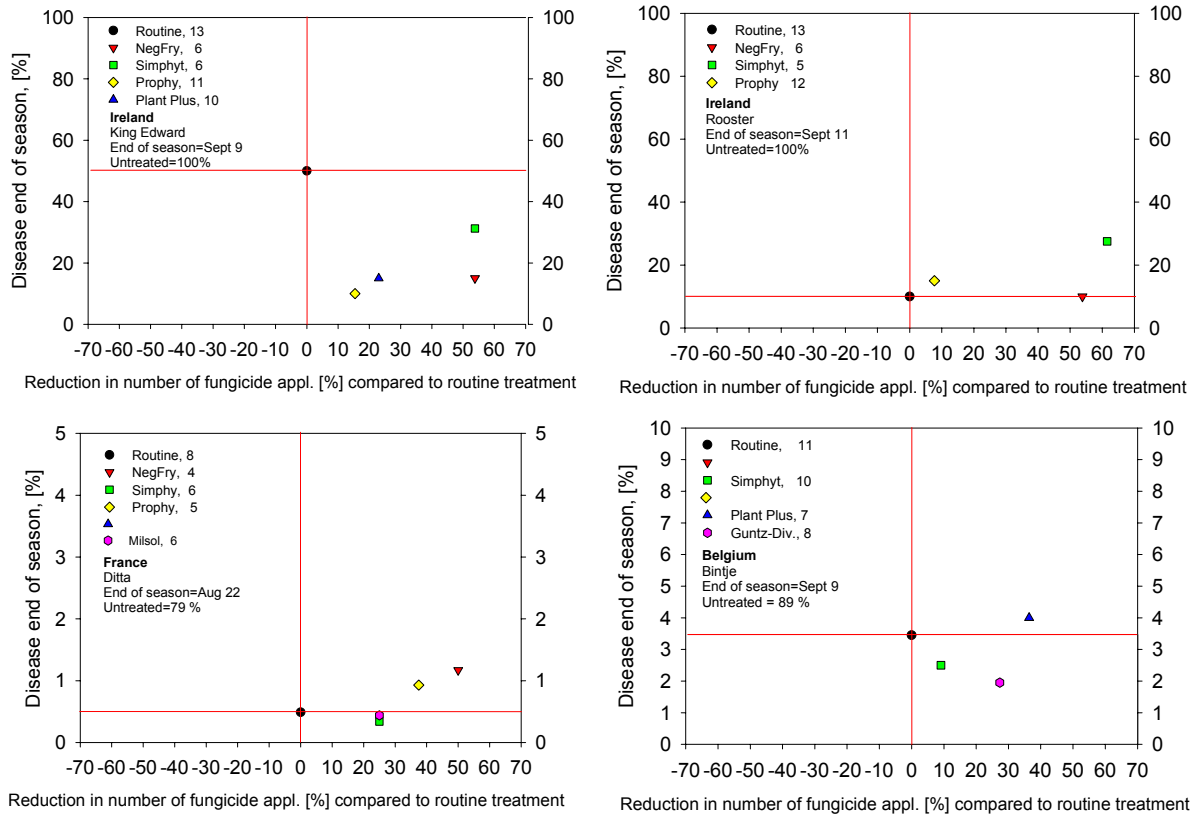


Figure 2. DSS validation results from Ireland, France and Belgium. See text for explanation.

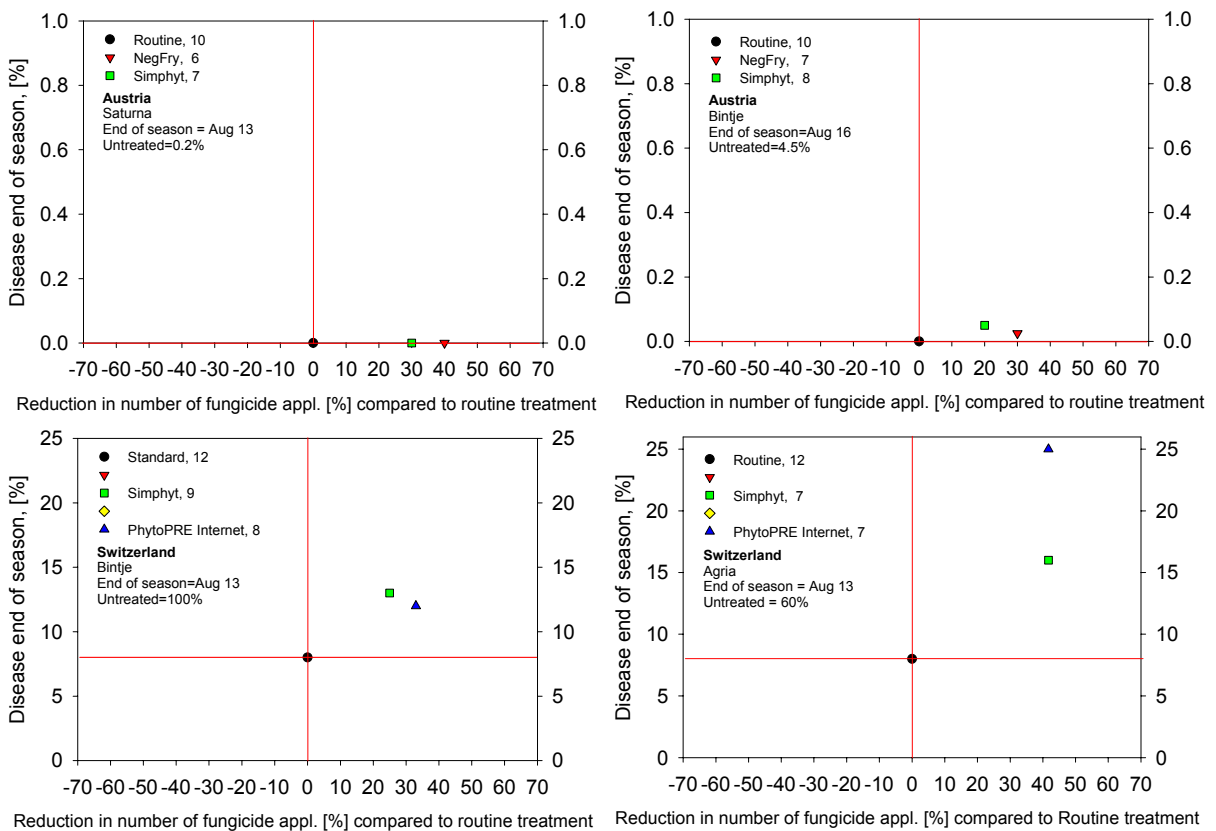


Figure 3. DSS validation results from Austria and Switzerland. See text for explanation.

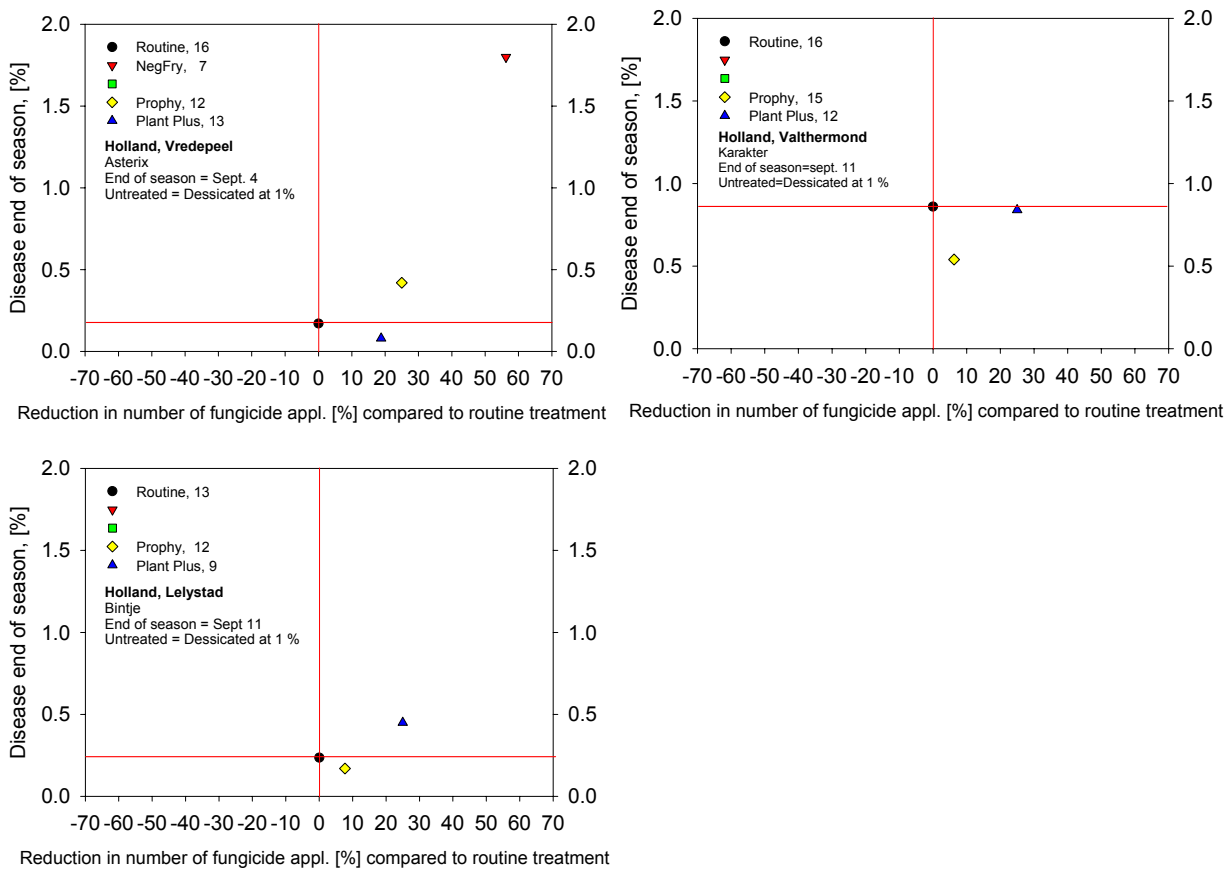


Figure 4. DSS validation results from three trials in Holland. See text for explanation.

Prophy and Plant-Plus kept late blight at the same level as routine treatments (<0.8%). There was no difference in disease level end of season between routine and the two Dutch systems. Comparing the two systems, the control effect was the same at Vredepeel and Valthermond. At Lelystad, the control effect was better using 12 applications according to Prophy than 9 applications according to Plant-Plus (Table 2). Simphyt recommended the highest share of systemic compounds. This fact may be due to a high amount of "emergency treatments" recommended by the programme. In all trials Simphyt obtained the same or better control effect than according to routine and, at the same time, reduced fungicide use by 9-62%. In France and Belgium, Guntz-Divoux and Milsol obtained a good control effect and at the same time with reduced input of fungicide. In Switzerland, although treatments according to Phytopre+2000 resulted in 12-25% disease end of season, yield was the same as for routine treatment and the level of tuber blight was relatively low.

It should be stressed that most DSS strategies included use of translaminar and systemic compounds and that control effects were compared to a seven-day routine strategy using contact fungicide only. Therefore, it is difficult to conclude whether differences in control effect were caused by a better timing of applications by the DSSs or by a difference in use of compounds compared to the reference treatment. From the results in Table 2, it is not clear if the use of translaminar and/or systemic compounds has a better control effect than the use of contact fungicide only.

Yield and tuber blight

Results for yield and tuber blight are available for some of the trials (Table 2). **Ireland:** For the trials with King Edward and Rooster, all DSS strategies resulted in the same yield level as the routine strategy. The level of tuber blight was low, even though the level of foliar disease at the end of the season was 10-50%. Use of NegFry and Simphyt resulted in the same level of tuber blight as for routine treatment. In King Edward, the level of tuber blight was significantly lower for Prophy and Plant-Plus than for other treatments. The season with active blight in the trial was relatively short - one month (Figure 1), which favoured a low risk of tuber infections. **Austria:** For Bintje, the yield level was the same for all treatments. For the trial with Saturna, Simphyt and NegFry obtained significantly higher yield than did the routine treatment. In August, *Alternaria solanum* damaged the crop severely and no assessment of *Phytophthora infestans* was possible. Late blight might have been a part of this damage, explaining the difference in yield. **Switzerland:** For the trial with Bintje yield was the same for all treatments. Treatment according to Simphyt resulted in a higher tuber blight level than did the routine treatment and Phytobre+2000. In the trial with Agria, treatment according to Simphyt and Phytobre+2000 resulted in the same yield as for routine. For PhytoPre+2000, the level of tuber blight was significantly lower than for routine treatment even though the disease level end of season was significantly higher (25% against 8%). **Holland:** Yield was the same for all treatments in three different trials. Tuber blight level was low at Vredepeel (0.2 - 1.1%), significantly higher for NegFry than for other treatments. This might be caused by a higher disease level end of season for NegFry than for other treatments. At Lelystad the level of tuber blight ranged from 5 - 33.2% and there was a significant difference between all three treatments (Table 2). See Wander and Spits, this proceeding, for discussion about tuber blight in the Dutch trials.

Discussion and conclusions

Use of late blight DSSs in eleven trials in seven different countries resulted in a 8-62% reduction in fungicide use compared to a seven-day routine schedule. Yield level was the same in 27 and higher in 2 of 29 cases for DSS strategies compared to routine strategies. The influence on tuber blight was not clear. In most cases, tuber blight level was at the same low level as for routine treatment (0-1%). In one trial in Holland the results indicate that higher input of fluazinam results in lower level of tuber blight. In the trial with Agria, Switzerland, the opposite was found. The risk of tuber blight is influenced by several factors e.g. the amount and the length of period of active foliar blight, tuber resistance, type of fungicide used, soil type, weather - especially rain and conditions during lifting. In the present results, there seems not to be a clear correlation between fungicide use, disease level and the level of tuber blight infections. Based on the validation results and the EU policy on minimising the pesticide use, zero level blight control cannot always be expected in conventional fields. Therefore, the understanding of the mechanisms and quantification of the risk of tuber blight should have a high priority regarding improvements of existing DSSs.

All the DSSs tested recommended the first spray before late blight was found at the trial site. But, first spray was often recommended much earlier than first observation at the trial sites and the recommendations differed considerably between the different DSSs tested (Figure 1). The importance of different inoculum sources for first outbreak is not well understood and DSS sub-models and methods need to be improved in this area. To take into account the uncertainty in predictions of early late blight attacks, several Internet based monitoring systems are now included in the Internet based versions of the DSSs tested.

In this study, the DSSs were compared to a seven-day routine schedule and often under a relatively high infection pressure. Compared to the reference treatment, all DSSs considerably reduced the number of applications and with good control effect. Weekly sprays with mostly contact fungicide throughout the season may be "standard" in many regions in Western Europe but not always and so, the capability of the DSS should not be overestimated. To document the potential of late blight DSSs, it will be important to carry out demonstration trials under "natural conditions" in farmers' fields, and compare DSS strategies with "conventional strategies". Further improvements of late blight DSSs must include validations

on sub-model level. Exploitation of crop resistance to late blight was not in focus in this study, because most varieties used were highly or medium susceptible to late blight. Further validations should include resistant varieties to document the potential of variety resistance in late blight control and to evaluate the way in which DSSs take resistance into account in sub-models.

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**Late blight populations in Wallonia in 2000: mating type, metalaxyl
resistance, pathotypes and aggressiveness.**

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Summary

90 isolates were collected in Wallonia in 2000 from potato fields, volunteers and waste piles.. Some of them were tested for mating type, metalaxyl resistance, pathotype and aggressiveness. We found A2 mating type in 20% of the sampled sites. 35% of the isolates were metalaxyl-resistant with 66% of those that were resistant to 100ppm metalaxyl. 23 different virulence profiles were found with 92% that were complex profiles. No isolate was found virulent on R9. 23% of the isolates show a latent period shorter than the one used in the epidemiological model.

29 cultivars were tested for the presence of efficient R-genes. 24 cultivars did not show any major efficient R-gene.

Introduction

The former populations of *Phytophthora infestans* have been replaced entirely in Europe during the years 1980's and 1990's by populations introduced from Mexico (Spielman *et al.*, 1991). The new populations are characterized by an important diversity of genotypes. They appear more aggressive (Flier *et al.*, 1999 & 2000) and present a high number of complex pathotypes (Schöber-Butin, 1999). The high diversity is also emphasized by the introduction of the mating type A2, which in presence of the A1 strains permits the achievement of the sexual cycle. Sexual reproduction produces oospores that could provoke a faster starting of the epidemics. The high genetic diversity within the pathogen population allows it to adapt to

every particular environment. They have a high potential of adaptation to protection strategies. They are able to overcome cultivars resistance or resist to fungicides.

In Belgium, the late blight warning systems are based on the Guntz & Divoux epidemiological model. This model is based on the characteristics of the old populations of *Phytophthora infestans* and calculated for the cultivar Bintje.

Changes in the epidemiological behavior of the population can lead to important changes in the prediction criteria used in the model. For that reason, the characterization of the present populations of *Phytophthora infestans* and the knowledge of their epidemiological behavior is necessary in order to adapt strategies of potato protection and to improve the warning systems.

The Guntz & Divoux model does not take into account the cultivar resistance factor, either. The cultivar resistance allows to decrease the number of fungicides treatments (Fry *et al.*, 1983; Hafskjold *et al.*, 2000; Michelante *et al.*, 1999). However, it is necessary to identify the kind of resistance shown by a cultivar. Given the high diversity in the pathotypes of the new populations, a vertical resistance based on a few R genes cannot last long. Horizontal resistance is partial but usually lasts for a long time. It is then important to know how partially resistant cultivars influence the pathogen cycle in order to adapt the model to different cultivars.

Materials and methods

90 isolates were sampled in 2000, mainly in Wallonia. They were collected in large potato fields, in cultivars trial plots, in organic farming cultures, refuse piles, volunteers and gardens. These isolates came from 16 districts (from which 2 in Luxembourg and 1 in Flandria), 25 different locations and 35 cultivars.

Mating types

In 2000, 85 isolates were tested for mating type. Mycelia plugs from each tested isolates were paired with references A1 and A2 isolates on separate plate with clarified V8-Agar. After incubation at 18°C for 15-25 days, the plates were examined for oospores production at the hyphal interfaces between the isolates.

Metalaxyl resistance.

In 2000, 36 isolates were tested for metalaxyl resistance. The testings were conducted in-vivo, using the floating leaf disk method with different metalaxyl concentrations (0, 0.01, 0.1, 1, 10 and 100 ppm). The isolates were classified according to the EC50 representing the concentration of metalaxyl assuring 50% of protection after 6 days of incubations (18°C):

- sensitive isolates: $EC_{50} < 0.01$ ppm
- intermediate sensitivity isolates: $0.01 \leq EC_{50} < 10$ ppm
- resistant isolates: $EC_{50} \geq 10$ ppm.

Pathotypes.

In 2000, 83 isolates were tested for pathotypes, on detached leaflets. The compatibility of the host-pathogen relationship was tested on a collection of differential R-gene clones carrying a resistant gene (R1 to R11). The relationship was judged compatible when there was formation of invasive sporulating lesions after 6 days of incubation at 18°C.

Aggressiveness

42 isolates were tested for aggressiveness.

The aggressiveness of an isolate can be divided in four components: the infection frequency (percentage of successful contaminations), the latent period (time between the infection and the sporulation), the growth speed of the lesions and the sporulation intensity.

The tests were conducted by inoculation of detached leaves of the cultivar Bintje with suspensions of sporangia ($2 \cdot 10^4$ sporangia/ml). The leaves were incubated at 18°C with a 16 hours photoperiod. The observations were carried out after 64, 72, 96, 120, 144 and 165 hours. FI, PL10, PS were determined. FI is the percentage of inoculation sites that develops lesions after 7 days of incubation. PL10 is the number of hours necessary after inoculation so that 10% of the contaminations sporulate. PS is the natural logarithm of the average number of sporangia by measured cm². A partial index of aggressiveness was calculated as follow:

$$IG = 1/PL10 \cdot FI \cdot PS.$$

Resistance of cultivars.

The behavior of 29 cultivars was tested. Detached leaflets of each cultivar were inoculated with suspensions of a set of differential pathotypes isolates of known virulence profiles. As in the pathotype testing, the relationship was judged compatible when there was formation of invasive sporulating lesions after 6 days of incubation at 18°C.

Results

Mating types

81.3% of the isolates were of mating type A1, and 15% were of mating type A2. 3.7% were unclassifiable (mixture of A1 and A2 or original self-fertiles).

The A2 isolates were found on 5 different sites in 4 districts (25 % of the districts). The first A2 isolate was found in June, on volunteers. One was found in July in another districts. The other A2 isolates were found in August.

Metalaxyl resistance

The frequency of metalaxyl-sensitive, metalaxyl-resistant and metalaxyl-intermediate isolates was 25%, 40% and 35% respectively in 2000. The first metalaxyl-resistant isolates appeared in the very beginning of the growing season and they were found all along the season. They were found on fields that had not been treated with systemic fungicides. Two third of them were resistant to the highest metalaxyl concentration used in the tests (100µg/ml).

Pathotypes

-Distribution of virulence factors

The majority of the isolates (99%) were virulent on R3 and R4. The virulence on R1, R7, R10 and R11 were also very frequent. More than 80% of the isolates were virulent on those factors. No isolates was found virulent on R9. The virulence on R2, R5, R6 and R8 were less common.

Isolates that were virulent on R2 were collected at the end of the season (from the 20th of August). The virulence on R2 was always associated with the virulence on R6 for the tested isolates. The isolates virulent on R8 were collected from the beginning of July. Those virulent on R5 from the beginning of August.

It has to be noted that some isolates collected on cultivars with known R-genes did not always express those genes in the virulence tests.

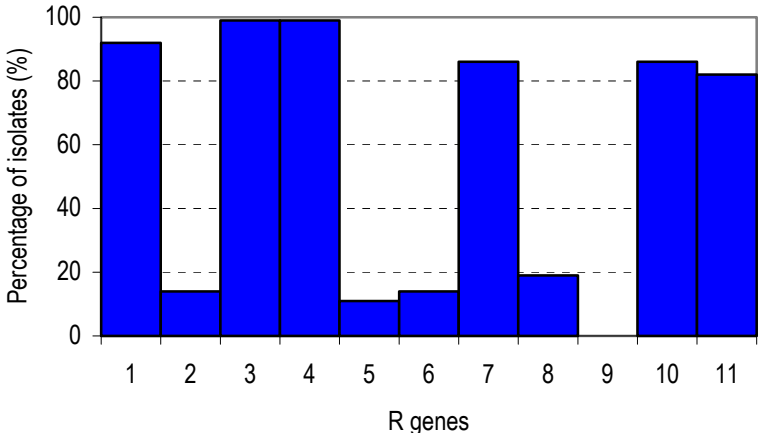


Figure 1 : Distribution of virulence factors

Distribution of the pathotypes.

The most frequent virulence profile was 1.3.4.7.10.11 (47%). These pathotypes appeared all along the season.

92% of the isolates had a complex profile (5 virulence genes or more). The profiles tend to diversify at the end of the season. They also became more complex at that time.

Table 1 : Distribution of virulence profiles

Pathotypes	%	Pathotypes	%
1.2.3.4.5.6.7.8.10.11	1	3.4.7.10.11	3,5
1.2.3.4.5.6.7.10.11	1	1.4.7.10.11	1
1.2.3.4.6.7.10.11	3,5	1.3.4.8.10	1
1.2.3.4.5.6.10.11	1	1.3.4.7.8	1
1.3.4.7.8.10.11	17	1.3.4.10.11	1
1.3.4.5.7.10.11	5	1.2.3.4.6	1
3.4.7.8.10.11	1	1.3.4.7	3,5
3.4.5.7.10.11	1	1.3.4.10	1
1.3.4.7.10.11	47	3.4.7	1
1.3.4.5.10.11	1	1.3.4	1
1.2.3.4.6.7	5	3	1
1.2.3.4.6.10	1		

Aggressiveness.

Although important differences were observed for a same component, it seemed difficult to determine big classes among these.

When all the components were compared for a same isolate, they seemed to have a tendency to accumulate.

The LP10 (latent period) measured for the tested isolates ran from 66h to 144h.

2 isolates presented a very short latent period of 66h at 18°C. In the original Guntz & Divoux model, the latent period at 18°C is 111h (Divoux, 1964). 80% of the tested isolates have a shorter latent period than in the model. In Libramont, the Guntz & Divoux model was adapted in 1994. The incubation unit at 18°C was changed from 1.5 to 2. Using those, the latent period at 18°C is 84h. Still 23% of the tested isolates had a shorter latent period at 18°C.

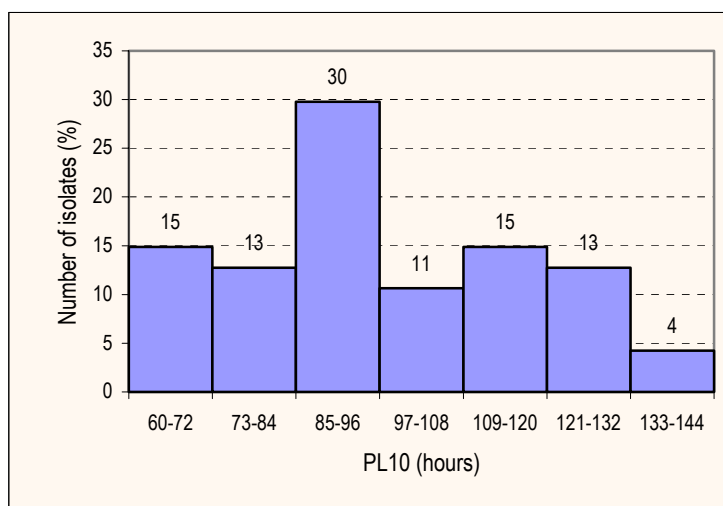
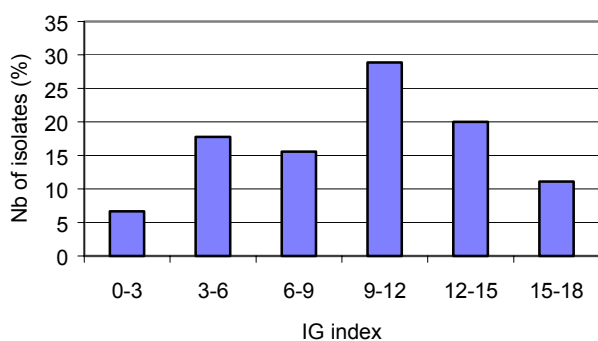


Figure 2 : distribution of latent period

59% of the isolates presented a Frequency of Infection greater than 90% (data not shown)

A large continuity was observed in the results of all aggressiveness components.

There was no correlation found between the aggressiveness components and the other criteria such as the mating type, the metalaxyl-resistance, the collection date or the districts of sampling.



: distribution of Index of Aggressiveness

Resistance of cultivars

The majority of the tested varieties didn't reveal any efficient vertical resistant gene (either the genes 2, 5, 6, 8 or 9). Many were infected by the classic profiles 1-3-4-7 or 1-3-4-7-10-11. In those tests, Gasore presented R2 and/or R6. However, 1 isolate collected in fields on Gasore show a virulence profile 1-3-4-5-7-10-11. Innovator wasn't infected by any of the tested isolates. 2 other varieties present efficient vertical resistance: Raja and Sante. In the test, Remarka presented the genes R5, R10 or R11. When looking at the isolates collected on Remarka in the fields, their virulence profiles were 1-3-4-7-10-11. It seems then that Remarka doesn't have any major vertical resistant gene.

able 2 : Major efficient R-genes in cultivars

Cultivars	Identified efficient R genes
AGRIA, ASTERIX, AZIZA, BINTJE, CARA, CHARLOTTE, CYCLOON, DESIREE, DITTA, EERSTELLING, EXEMPLA, EXQUISA, FRANCELINE, JULIETTE, MARFONA, MARKIES, MERIT, MONALISA, NICOLA, SATURNA, VICTORIA	No one
CRISPIN, FELSINA, MILVA	10/11
REMARKA	5/10/11
RAJA, GASORE	2/6
SANTE	2/6, 10/11
INNOVATOR	Unknown?

Discussion and conclusions

Those results confirm the presence of new populations in our regions.

There is a significant presence of A2 strains. This situation can lead to a bigger genetic diversity and the production of oospores.

The number of metalaxyl resistant isolates that have been found confirms the need of control strategies that limit the apparition of systemic fungicide resistance.

Given the presence of complex pathotypes and the large range of virulence genes that is present, varieties endowed with vertical resistance could rapidly lost their ability to resist to late blight. The use of cultivars with partial but long lasting resistant is fully justified.

The latent period at 18°C of 24% of the tested isolates was shorter than what is calculated in the Guntz & Divoux model with 16% shorter of 12 hours or more. In the future the isolates should be tested at other temperatures to adjust the model for those temperatures. A study of the behavior of the isolates at different relative humidity should also be undertaken in order to adapt the epidemiological parameters taken into account in the Guntz & Divoux model.

There is still some methodological problems with the determination of the presence of R-genes in the cultivars in the laboratory. Some results in the field and in the lab are slightly different. However, some cultivars with partial resistance seem promising and further tests should be conducted in order to include a cultivar unit in the model.

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Late blight resistance and vine killing

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Summary

Field trials with recommended and reduced doses of a vine desiccant in combination with mechanical vine destruction and cultivars with different level of foliar and tuber resistance were conducted in 1997, 1998 and 1999. In average over years the contamination potential of the vine remnants was significantly higher in the untreated vine than at any of the different vine killing methods. The contamination potential tended to increase in the treatments with reduced dose of vine killer, but full mechanical destruction gave as low contamination potential as application of full dose of chemical vine killer. The lack of difference between the different vine killing treatments in the amount of tuber blight observed after harvest indicates that the input of chemical vine killers can be reduced. The large difference between the cultivars in the amount of tuber blight observed after harvest indicates that tuber resistance should be an important part in integrated late blight disease management.

Key words: *Phytophthora infestans*, tuber blight, cultivar resistance, vine killing

Introduction

Potato vine killing in the fall crop is a common practice in Norway. One of the main reasons for vine killing is minimizing the inoculum source of *Phytophthora infestans*. In Norway the potato growing season is relatively short. Therefore fast acting vine killing methods are preferred. Commonly the vine is killed ten to fourteen days before harvest.

Due to the growing public concern about the negative side effects of pesticide use in agriculture the Norwegian government has decided to reduce the use of pesticides. Much pesticide is used to control late blight, both fungicides and herbicides to kill the vine. Research has shown that incorporation of host resistance in integrated late blight disease management could enable a significant reduction in fungicide application (Bus *et al.*, 1995; Duvauchelle & Dubois, 2000; Fry, 1975 and 1978; Fry *et al.* 1983; Gans *et al.*, 1995; Grünwald *et al.*, 2000; Nærstad, 2001; Shtienberg *et al.*, 1994; Wiik, 1996).

The objectives of this study were: 1) to evaluate the possibility of incorporating host resistance in integrated late blight disease management to enable reduction of chemical vine killers, 2) to compare the contamination potential of the vine of different varieties killed with different methods and 3) to investigate the direct effect of the chemical vine killer diquat and the fungicide fluazinam were conducted, to compare their effect on the *in vitro* growth of the pathogen.

Materials & Methods

Field trials with recommended and reduced doses of a vine desiccant in combination with mechanical vine destruction and cultivars with different level of foliage and tuber resistance were conducted in 1996, 1997, 1998 and 1999 at the Department of Horticulture and Crop Sciences at Agricultural University of Norway. There are no results from 1996, because the vine died of frost the night before it was planned to apply vine killing treatments. The trials were arranged as split plot with four replications each year. Two of the replications were given a higher foliage disease level than the two others. On the large plots there were eight different vine killing treatments: 300, 200 or 100 ml/ha Reglone (containing the active ingredient diquat 200 g a.i./litre), half cutting (with a rotary chopper, leaving 25 – 30 cm of vine) in combination with 150 ml/ha, 100ml/ha or 50 ml/ha Reglone, cutting (with a rotary chopper, leaving 1-5 cm of the vine) and untreated control. On the small plots within there were seven different cultivars/breeding lines: Kerrs Pink (foliage resistance level 6, tuber resistance level 3), Saturna (5,6), Beate (6,7), Danva (9,7), Troll (6,8), N-85-13-18 (9,9) and N-84-4-22 (9,9). The level of resistance in the foliage and tubers is determined by three or more years of testing at the Department of Horticulture and Crop Sciences (Bjor, 1989 and 1987). Between each small plot there were a boarder row of the resistant cultivar Danva.

The proportion of foliage affected by late blight was visually assessed four times. The last time was at the day of application of vine killing treatments. The vine killing treatments were applied in the end of August. The proportion of viable vine was visually assessed just before application of vine killing treatments and just before harvest eleven days later.

Nine days after application of vine killer ten tubers together with appertaining vine remnants were harvested per small plot. Tubers were placed in plastic boxes with a double layer of paper towel in the bottom. Five of the tubers were superficially wounded and placed with the wound uppermost. The superficial wounding was done by rolling the tubers over a group of 10 nail points, 2 mm high, 1 cm apart, pointing upwards from a wooden base. In addition ten “bait” tubers, freshly harvested superficially wounded tubers of a susceptible cultivar, Mandel in 1997 and Kerrs Pink in 1998 and 1999, were placed in each box. The appertaining vine remnants were distributed on the top and sprinkled with water. After incubation at 15°C for four weeks and storing at 4°C for 2-4 weeks, tubers were sliced and visually assessed for blight.

Eleven days after application of vine killing treatments the rest of the potatoes in each small plot were harvested. It was planed to irrigate a few days before harvest to make the harvesting conditions wet and difficult. Because of rain it was not necessary to irrigate before harvest. Tubers were stored at 15°C for four weeks and at 4°C for 2-4 weeks before they were washed and analysed. Tubers were sliced and visually assessed for late blight and soft rot. Tubers with symptoms of late blight were recorded as late blight even when they had some soft rot. Tubers with soft rot without clear symptoms of late blight were recorded as soft rot. Often tubers with soft rot were so putrid that it was impossible to determine if the rot had started as late blight.

An *in vitro* assay, in fungicide/vine killer-amended liquid growth media in 96-well microplates, was conducted to compare the toxicity of a vine killer and a fungicide. 100 µl liquid growth medium (pea broth with Ampicillin 0,2 mg/ml) with different concentrations of Reglone and Shirlan were inoculated with 100 µl of a spore suspension (10^4 sporangia/ml). The growth of *P. infestans* in the fungicide/vine killer –amended media was measured, after 5 day of incubation at 18°C in the dark, as the increase in optical density and compared to the growth in the control (non-amended media).

Results

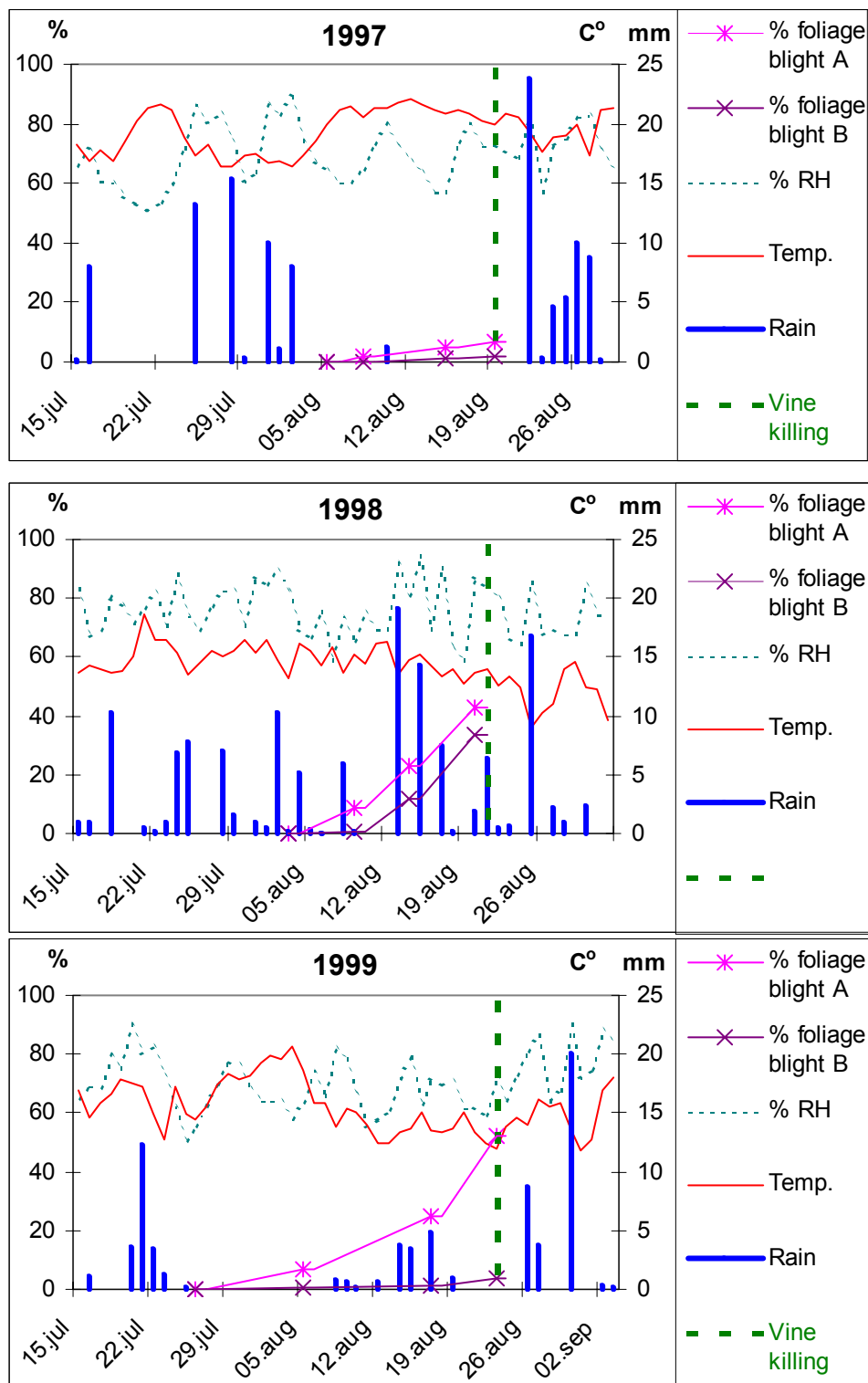


Figure 1 The average amount of foliage affected by *P. infestans* in all cultivars at the two different disease pressure levels A (high) and B (low) in 1997, 1998 and 1999. The weather conditions from the middle of July to harvest measured outside the field. Rain in mm per day and daily average of temperature in C° and % relative humidity at 2 m above ground. In 1998 it started to rain just after the vine killing treatments were applied.

The vine killing treatments were not as effective in 1997 as in 1998 and 1999 (Fig. 2). In 1997 it was very wet in the period after application of vine killing treatments and the vine desiccated slower and there was more regrowth. In average over years there was a small but significant increase in the amount of viable vine at harvest at reduced doses of chemical vine killer, both when the chemical vine killer was applied alone and when it was applied in combination with half cutting. Full cutting gave as good vine killing as application of full dose of chemical vine killer, 3.0 l/ha Reglone.

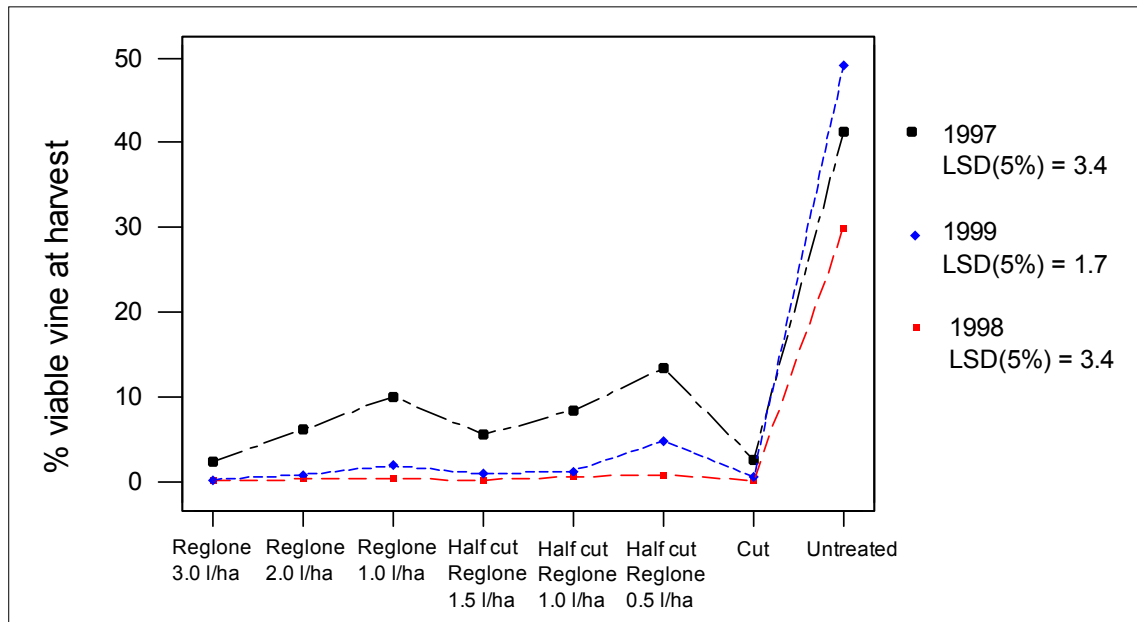


Figure 2 The average percent of viable vine in all the cultivars eleven days after different vine killing treatments in the field trails in 1997, 1998 and 1999. Least significant difference between treatments at the 5% level is shown for each year.

There was large variation between years in the number of bait tubers that were infected (Fig.3). In 1997 there were some infections at all treatment, but the vine remnants from the half cut with 0,5 l/ha Reglone and the untreated plots caused significant more infections. In 1998 there was much infection in the bait tubers and no significant differences between treatments. In 1999 there was very little infection in the bait tubers and there was no differences between the vine killing methods, but the vine from untreated plots caused significant more late blight infection. In average over years the contamination potential of the vine was significantly higher in the untreated vine than at any of the different vine killing methods. The contamination potential tended to increase in the treatments with reduced dose of vine killer, but full cutting gave as low contamination potential as application of full dose of chemical vine killer.

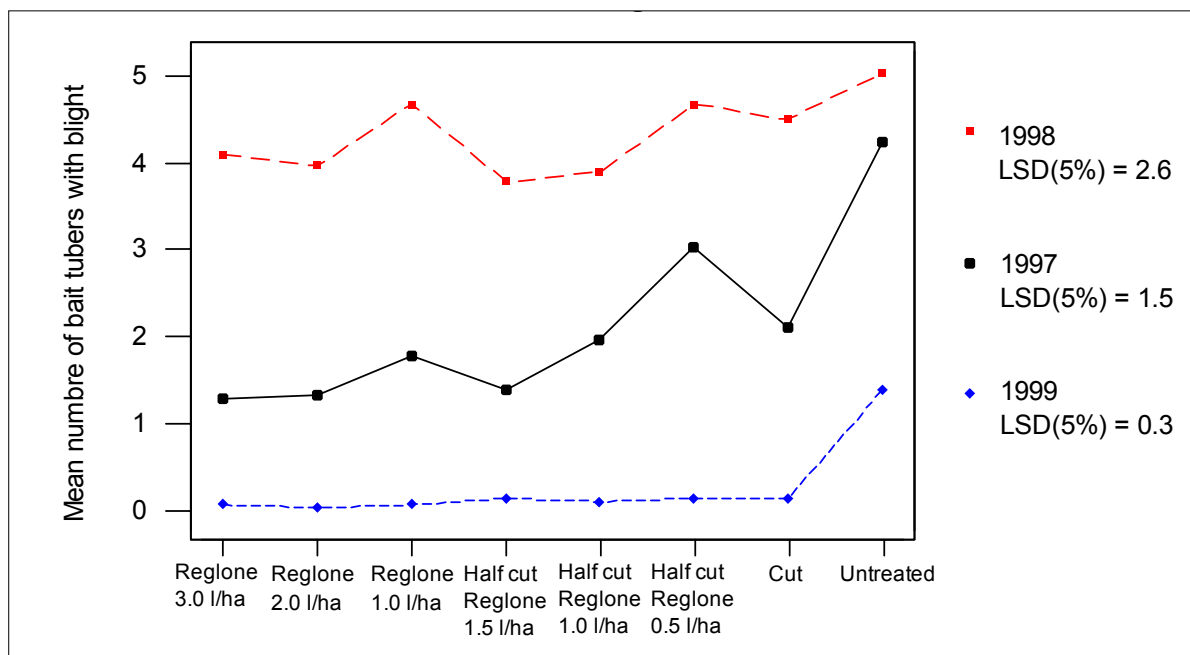


Figure 3 Contamination potential of the vine after different vine killing treatments in 1997, 1998 and 1999 averaged for all cultivars. Contamination potential is estimated by number of bait tuber that got blight. Least significant difference between treatments at the 5% level is shown for each year.

There were some differences between the contamination potential of the cultivars. The breeding clone N-84-4-22 had very little foliage blight all years (about two lesions pr ten plants) and the vine remnants caused very little tuber blight compared to all the other cultivars. In 1997 Saturna had very little viable vine at vine killing (because of stress induced premature senescence), and the vine remnants caused very little tuber blight this year.

At harvest we could see hardly any tubers with symptoms of soft rot. After storage there was significant correlation between weight percent of tubers with late blight and weight percent of tubers with soft rot (Pearson correlation coefficient was 0.397 and $P= 0.000$). This indicates that the soft rot probably mainly was secondary rot that had developed in late blight infected tubers during storage. The sum of soft rot and late blight infected tubers was therefore chosen as a measurement of tuber blight. The amount of tuber blight was mainly determined by year and cultivar. There were no significant differences between treatments, except for in 1999 when there was more tuber blight in the untreated control (Fig. 4).

1997 was a year with very little tuber blight, and there were no differences between cultivars. In 1998 there was very much tuber blight and much soft rot after storage, especially in the cultivars with much tuber blight. The proportion of infected tubers ranked the cultivars

according to their tuber resistance, except for Danva. In 1999 there was some tuber blight, and little soft rot and the proportion of infection tubers ranked the cultivar in a similar way as in 1998 (Fig. 5).

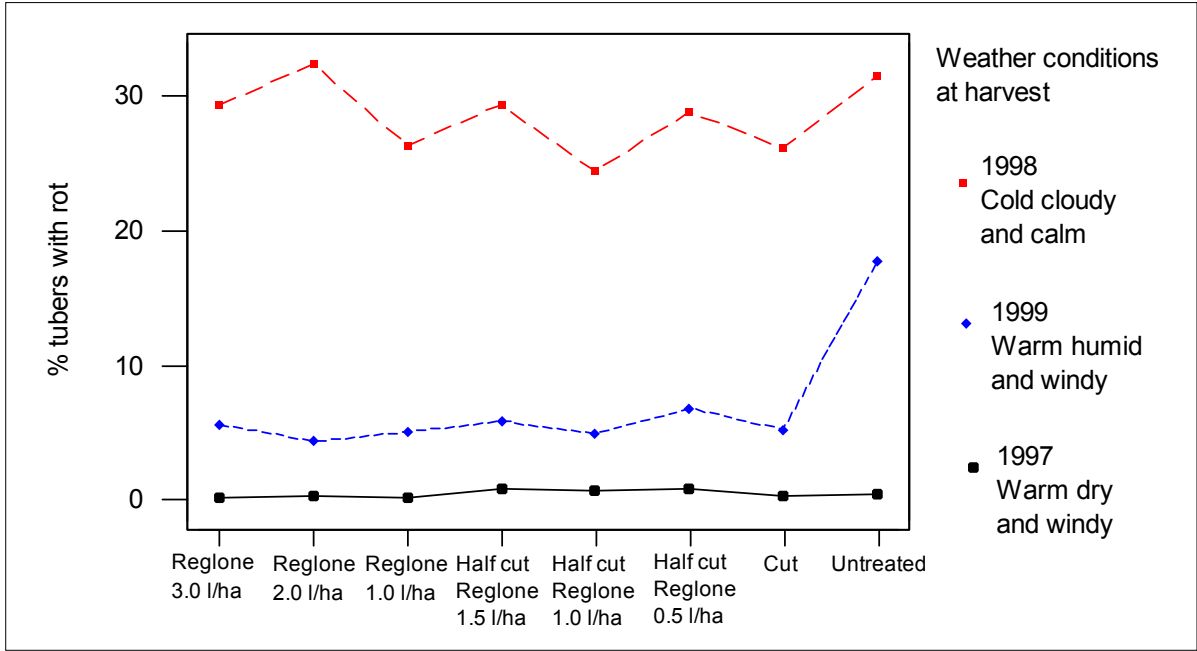


Figure 4. Weight % tubers with rot in average of all the cultivars at different vine killing treatments in field trials in 1997, 1998 and 1999.

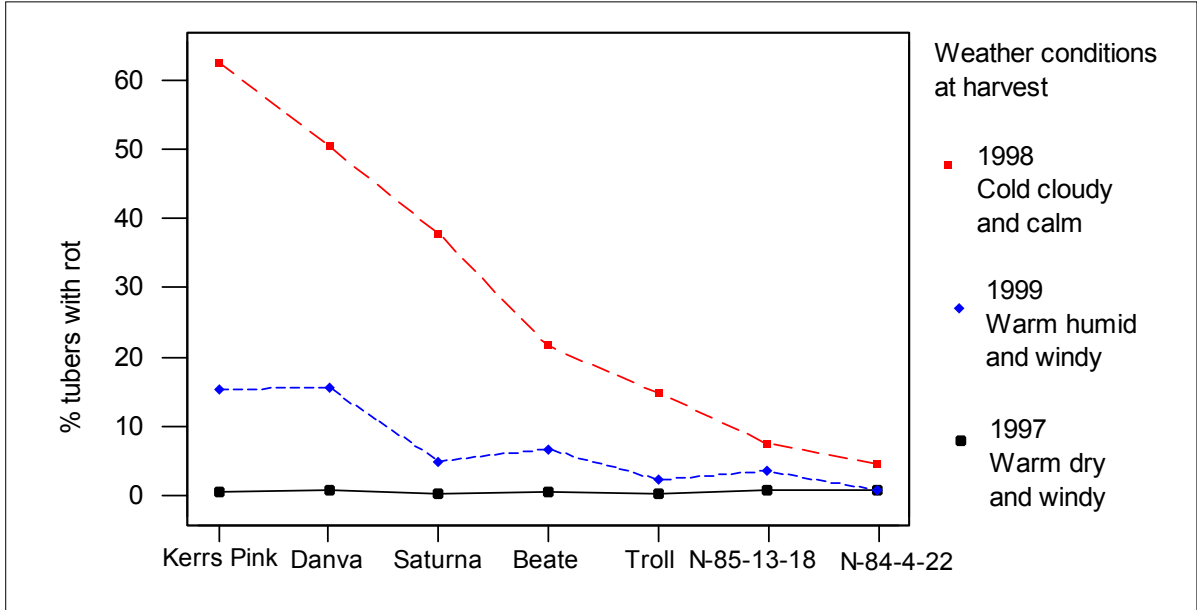


Figure 5. Weight percent tubers with rot, late blight and soft rot, in average of all treatments in the different cultivars and breeding clones in field trials in 1997, 1998 and 1999.

In the *in vitro* assay the vine killer Reglone were as toxic to the oomycete as the fungicide Shirlan and there was no extra effect of combining the vine killer and the fungicide (Fig. 6).

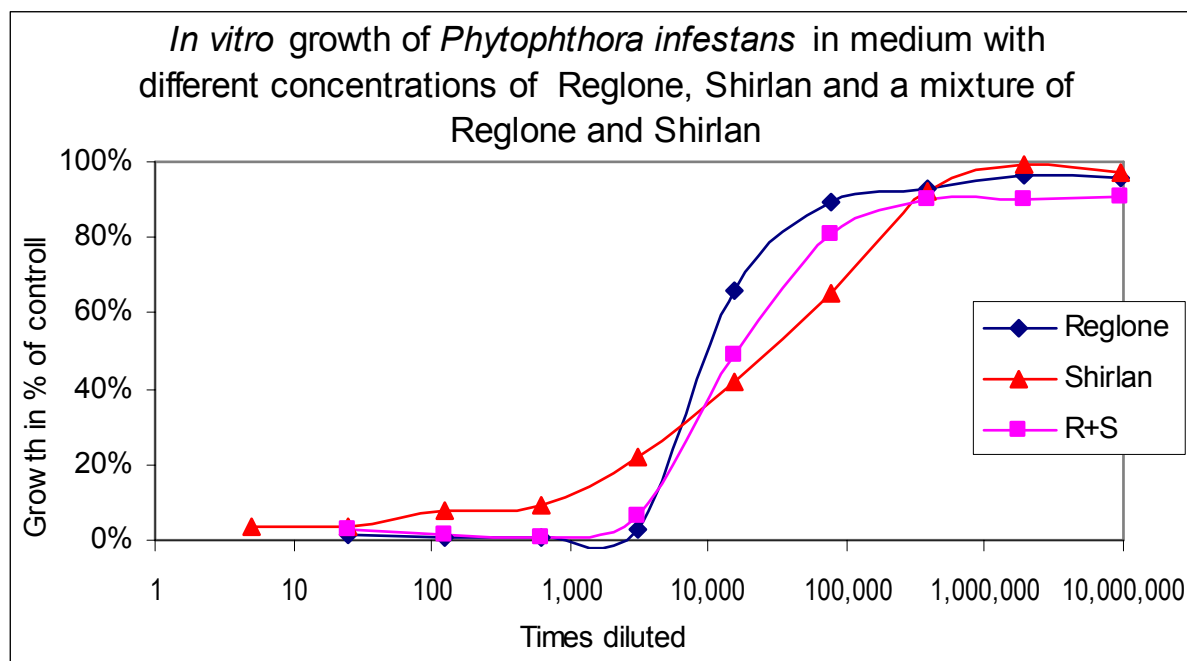


Figure 6. 1 time diluted is equivalent to the recommended application concentration. For Shirlan dilution level 1 is equivalent to 300 ml in 300 litre water per ha, for Reglone it is 3 litre in 300 litre per ha, and for the mixture dilution level 1 was equivalent to 300 ml Shirlan and 3 litre Reglone in 300 litre water.

Discussion

There was large variation between years in the efficacy of the different vine killing methods, and there was large variation between years in the tuber infection, but there was no correlation between the efficacy of the vine killing and tuber infection over years. Hence other factors must have been more important for tuber infection than the vine killing. Unfortunately this field trial was designed in such a manner that it is impossible to exclude the probability of tuber infection before the application of vine killing treatments. In 1997 there was a relatively dry period before vine killing, so the probability of tuber infection before application of vine killing treatments is low. The climatic conditions in 1998 were probably suitable for tuber infection in the period before application of vine killing treatments. This might have caused the lack of differences between treatments, but the significant difference in tuber blight between cultivars highlighted the importance of field resistance to tuber infection. In 1999 there were some light rain showers in the middle of august that may have caused some tuber infection before application of vine killing

treatments. However, there was significant more tuber infection in the untreated plots, so there must have been some tuber infection after application of vine killing treatments in 1999. All years the climatic conditions have probably been suitable for tuber infection in the period from application of vine killing treatments to harvest, so it is difficult to tell if the tuber infection happened mainly in this period or at harvest.

In 1998 there was much late blight in the bait tubers in the contamination potential test at all treatments (Figure 3). There should have been included a negative control in the contamination potential test, to show whether this lack of difference was caused by high contamination potentials at all treatments or by contamination of the bait tubers prior to the test. The contamination potential of vine of the various cultivars differed significantly in 1998. Hence, a considerable amount of the blight in the bait tubers must have been caused by inoculum from the vine remnants. Even though the vine killing treatments seemed to be very efficient in 1998 (Figure 2), leaving nearly no viable vine in the treated plots, the vine remnants must have contained significant amounts of infectious inoculum at all treatments.

The large differences between years in the amount of tuber infection at harvest underlines the importance of the climatic factors in the tuber infection process. The large differences in the amount of tuber infection between the cultivars underlines the importance of the tuber resistance. Although there is some information on what factors predispose potato crops to tuber blight, this information is inadequate and has generally not been used to identify the risk of tuber infection (Bain & Möller, 1999). Soil contaminated with sporangia may retain its infectivity for 15 – 45 days depending on the conditions (Andrivon, 1994), so killing the vine may not be enough to prevent infection at harvest. Bochow *et al.* (1979) reported reduced tuber blight when lifting was delayed until the second and third week after haulm death, even after four weeks tuber blight decreased. Lacey (1965) reported that the surface soil remained infective for at least four weeks after haulm killing, but the concentration of viable spores declined to a small value during the first week after killing. Delaying the harvest for a longer period after vine killing will reduce the risk of infection at harvest, but is not common in Norway because of the short growing season.

The vine killer Reglone was as toxic to *P. infestans* as the fungicide Shirlan, and there was no extra effect of combining the vine killer and the fungicide. Hence, this result does not support the idea of including fungicide at the application of chemical vine killers to prevent tuber infection. When killing vine with sporulating late blight lesions just before a period with

rain, it might be safer to kill the vine chemically with Reglone than mechanically because the vine killer is directly toxic for the pathogen. However, there are no indications of this from these field trials. There was not significant difference in the contamination potential of the vine treated with full dose of vine killer and the vine killed mechanically by cutting and there was no differences in the amount of tubers infected either.

The lack of difference in the amount of tuber blight between the different vine killing treatments indicates that the input of chemical vine killers can be reduced. The large difference in the amount of tuber blight between the cultivars indicates that tuber resistance should be an important part in integrated late blight disease management.

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First results from an *Alternaria solani* field trial in potatoes

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Summary

In the year 2001 a field experiment was conducted to observe the epidemiology of *Alternaria solani* and even of *Alternaria alternata* and to investigate the effect against early blight of some commonly used fungicides and a new experimental substance. Unfortunately the field trial was destroyed by a hail storm before any significant results could be achieved. But some trends were visible in the action of the fungicides and the development of early blight could be observed under Bavarian weather conditions.

Keywords: *Alternaria solani*, *Alternaria alternata*, early blight, fungicide, disease development

Introduction

During the last years early blight of potato, caused by *Alternaria solani* and *Alternaria alternata*, became more and more important in Europe. There are some possible reasons for this: An improved late blight management has generally reduced the use of preventive fungicides. Several new fungicides against *Phytophthora infestans* include less or even no Mancozeb, like Shirlan[®], which is often used in Germany. As Mancozeb has a good effect against early blight, the use of Shirlan[®] reduces the preventive protection against this disease. Finally, there is a change in the European weather. Mild winters and hot summers with enough humidity make it possible for *Alternaria sp.* to survive from crop to crop and cause epidemics. In Germany farmers are not aware of the problem of early blight like those in warmer surroundings (USA or Africa), where potatoes and tomatoes are often infected. So they are not prepared to control the disease and *Alternaria sp.* can cause severe damages by reduction

of the assimilating leaf surface and tuber losses in storage.

First early blight symptoms are small brown to black spots on the older, lower leaves. The lesions enlarge and are often limited by leaf veins. Typical irregular concentric rings are visible on the spots surface. Infected tubers show so called dry rot. The fungus overwinters as mycelium, conidia or chlamydospores on plant debris, infected tubers or in the soil. Potato leaves are infected directly, through stomata or wounds; tubers are infected through wounds or lenticels. High temperature and high moisture favour an epidemic. The susceptibility of the host plant is influenced by several factors. Older plants are more susceptible, in the same way as early maturing cultivars or cultivars with smooth peel. High nitrogen and low phosphorus rates can be able to reduce early blight.

Up to now, there are no truly resistant cultivars, so the disease has to be managed by cultural and chemical methods. Weeds and volunteer potato as a source of infection should be eradicated. Susceptible crops should be planted in an at least three year rotation. At last farmers should wait 4-14 days after vine-kill before digging potatoes. Active substances against early blight are Maneb, Mancozeb, Metiram and Chlorothalonil.

The field trial of the TU München was investigated to confirm the literature dates about *Alternaria solani* and to test several fungicides.

Material and methods

The field trial was located at Kirchheim, near Munich, on a sandy loam. Potatoes of the susceptible cultivar Karlena were planted on 25th of April. The 17 variants were arranged in a randomized block and replicated four times. Assessments of the necrotic leaf area were started end of May, two weeks after emerge, and continued until 3rd of August, when the field trial was destroyed by hail.

Late blight was treated with Dimethomorph[®] (180g a.i./ha) seven times and once with Cymoxanil[®] (120g a.i./ha).

For *Alternaria* treatment the following fungicides were applied, compared to an untreated control:

Amistar [®] (500 ml/ha)	Manex [®] (400 ml/ha)	Gemini [®] (1250 g/ha)
Tanos [®] (700 g/ha)	Bravo [®] (2000 ml/ha)	Electis [®] (1800 g/ha)
Shirlan [®] (400 ml/ha)	Aviso DF [®] (2500 g/ha)	Acrobat Plus [®] (2000 g/ha)
Polyram WG [®] (1800 g/ha)		

experimental fungicide (200 ml, 250 ml and 300 ml per ha)

Spraying was started in the middle of June when plants began to blossom and continued in 7-10 day intervals. The experimental fungicide (Exp) in the highest dose was also started at different times (with third, fourth and fifth spray) to find out the best spraying start.

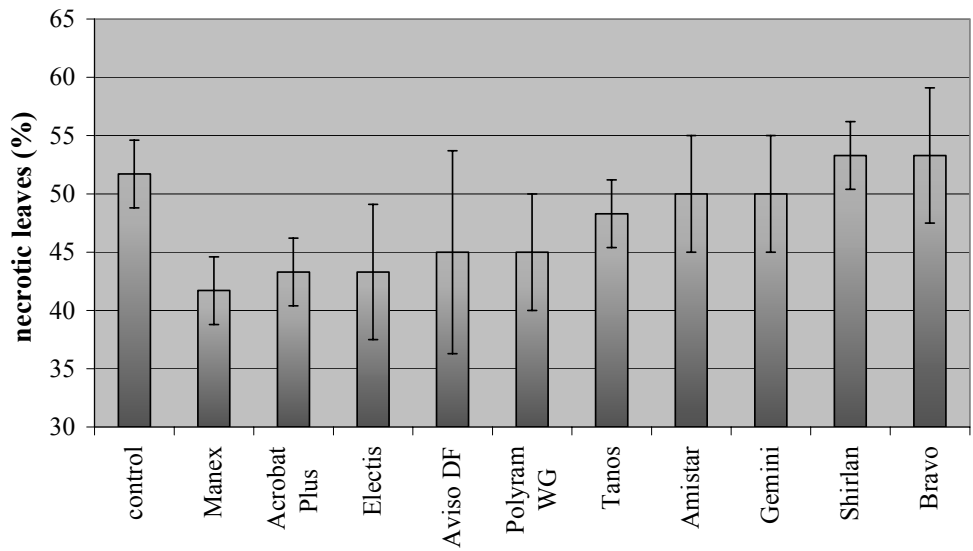
Results

In a few variants some *Phytophthora infestans* stem infections appeared in spite of the late blight treatment.

The first early blight symptoms appeared two weeks after emerge. Weather conditions were favourable for the development of *Alternaria sp.*: high temperature with enough moisture. Four weeks later all plants showed the typical small spots on the lower leaves. The disease developed slowly and no differences between the variants were observed until the beginning of August. Disease severity was still lower than 1% in the middle of July.

Only one assessment with variant differences could be made before the trial was destroyed by a hail storm, so only some trends in the effectiveness of the fungicides were evident.

Except Shirlan and Bravo all fungicides showed better results than the untreated control (fig.1). The best effect against early blight had Manex[®], followed by Acrobat Plus[®] and Electis[®]. Aviso DF[®] and Polyram WG[®] showed good effects as well.



: *Alternaria* effect of different fungicides

The experimental fungicide also showed good effects, but it was not as good as Manex[®] (fig.2). The higher dose had the better effect. The variant with the highest dose failed. Spraying started later did not appear to have as good effects as the applications started closer to blooming.

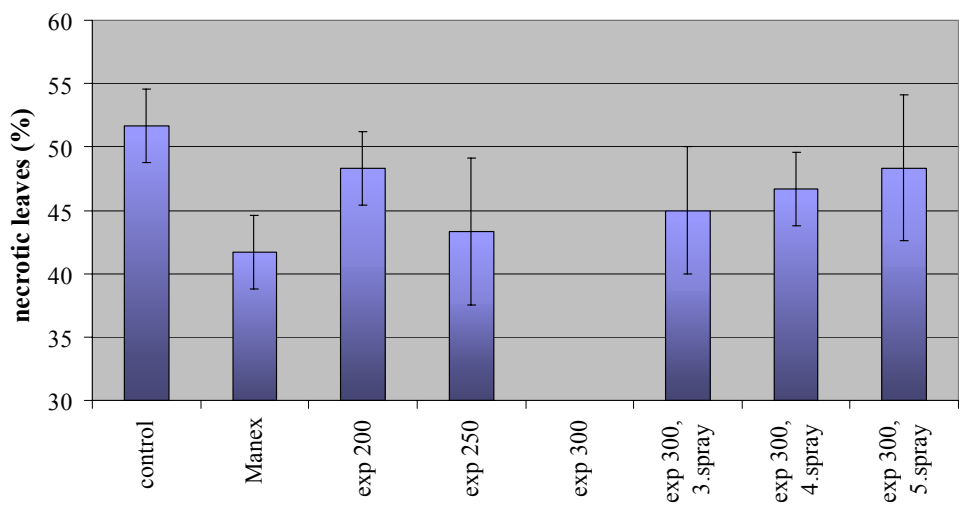


Figure 2: experimental fungicide

Discussion

It can be stated that first early blight symptoms appeared very early in the year 2001.

Fungicides including Maneb, Mancozeb or Metiram (Manex, Acrobat Plus, Electis, Aviso DF, Polyram WG) caused good effects against early blight. It was surprising that Bravo (Chlorothalonil) showed no effects.

There seems to exist a dose response and a timing effect for the experimental fungicide. Spraying applied to late in the season can not reduce early blight.

Conclusions

Early blight can cause severe damages in potatoes.

The beginning of the fungicide applications has to be adapted to the progress of the disease and the weather conditions.

Common fungicides are partly not useful for *Alternaria* treatment.

A special design has to be created for *Alternaria* field trials to avoid the influence of *Phytophthora infestans* or other diseases.

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Posters

Uptake and translocation of the fungicide dimethomorph by stems of potato plants

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Abstract

Stem sections of potato plants were treated with ^{14}C -labelled dimethomorph. Plants were sampled after different growing periods and investigated by autoradiography. The autoradiograms revealed that the uptake and movement of radioactivity in an acropetal direction started immediately after application. After 1.5 and 5 days treatment time, the dimethomorph concentrations taken up through the stem had significantly increased and all plant parts above the treated stem section contained ^{14}C -labelled dimethomorph.

Introduction

Dimethomorph is a cinnamic acid amide fungicide which has activity against the family Peronosporaceae and the genus *Phytophthora*. The biological properties of dimethomorph are presented in Albert *et al.* (1991) and Albert & Heinen (1996). The mode of action of dimethomorph is disruption of cell wall synthesis during active growth (Kuhn *et al.*,1991). Radiochemical tests were conducted to investigate the uptake and movement of dimethomorph in the potato plant.

Materials & Methods

Cellulose collars of approximately 1.5-2.0 cm wide were wrapped around stem sections of young pot-grown potato plants measuring 20 cm in height. The collars were drenched with 0.3 ml treatment solution containing 70 mg dimethomorph (of which 10 mg was ^{14}C -labelled) with 10 ml water, resulting in a concentration of 1 mg active substance per ml. Immediately after treatment, the plants were placed in a field plot beneath a plastic tent simulating outdoor conditions. Dimethomorph treatments were applied for 1.5 hours, 1.5 days and 5 days. After the specified treatment time, one plant was cut above the ground and taken for autoradiographic investigation. Each plant was fixed between two sheets of filter paper and dried in a drying chamber (48 h at 50°C).

Autoradiography was carried out using a Fuji bio-imaging analyser BAS 1000 and ultra-sensitive Fuji imaging plates type BAS-IIIIS. The radioactive energy emitted luminescence which was collected by a photo-multiplier tube and converted to electrical energy for the production of autoradiograms.

Quantification of the ^{14}C -dimethomorph was not conducted in this study.

Results

Autoradiograms to show the distribution of ^{14}C -dimethomorph 1.5 h, 36 h and 5 days after application to stems of potato plants are shown in Figures 1, 2 and 3, respectively

Penetration and translocation in an acropetal direction started immediately after treatment. One and a half hours after application, dimethomorph had entered the leaf veins above the treated stem segment. One and a half days later, all leaves above the treatment zone displayed radioactivity, indicating the acropetal movement of dimethomorph from the treated stem segment. The autoradiogram showing the distribution of ^{14}C -dimethomorph 5 days after application showed detectable levels of dimethomorph in the newly grown plant material.

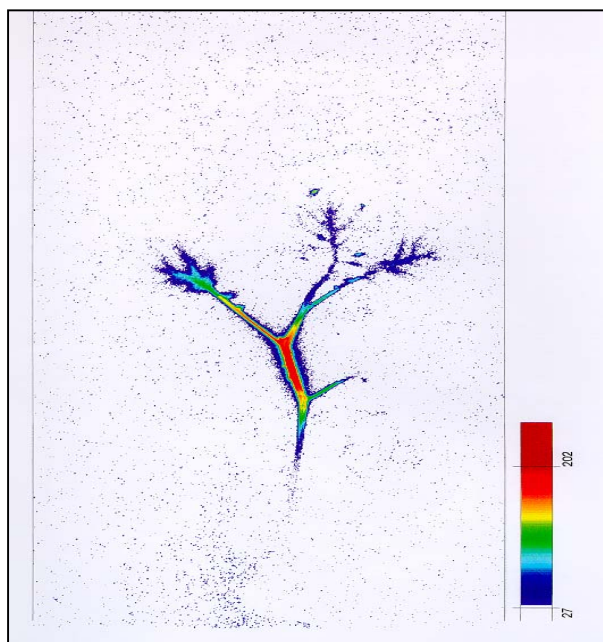


Figure 1. ^{14}C -Dimethomorph distribution 1.5 hours after application onto the stem of a potato plant.

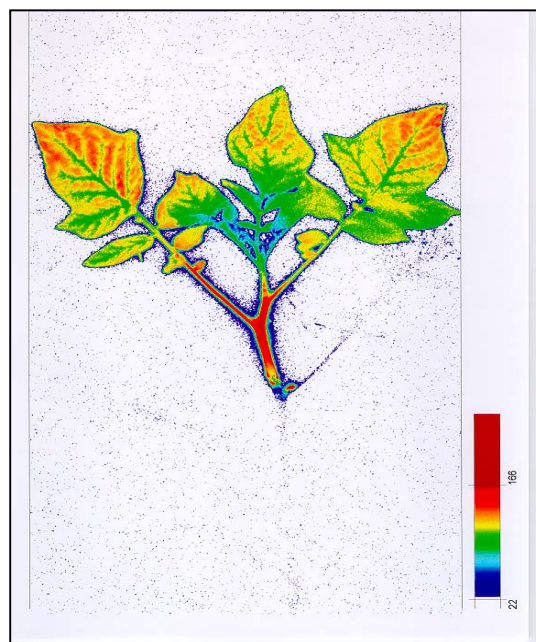


Figure 2. ^{14}C -Dimethomorph distribution 36 hours after application onto the stem of a potato plant.

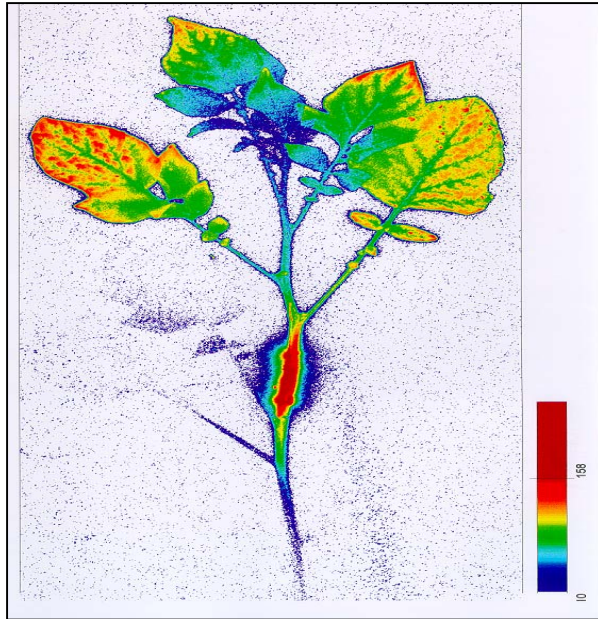


Figure 3. ¹⁴C-Dimethomorph distribution 5 days after application onto the stem of a potato plant.

Conclusion

The experiment shows the acropetal translocation of dimethomorph from stem applications to the foliage. The penetration and translocation occurred rapidly, with significant movement in the plant within 1.5 hours of application and an even distribution to the foliage 36 hours after application. Following application to the aerial plant in normal agricultural practice with the rapid acropetal translocation of dimethomorph, the entire foliage should be protected from infection by *Phytophthora infestans* within hours of application.

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Development of insensitivity of *Phytophthora infestans* to Metalaxyl and Propamocarb hydrochloride in Finland in 1990-2000

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Abstract

The use of fungicide metalaxyl rapidly selects tolerant isolates from potato late blight *Phytophthora infestans* (*P. i.*) from population finally ending in failures in blight control (Cohen and Samoucha, 1989; Dowley and O' Sullivan, 1985; Fry et al., 1991). There are no indications of severe problems in blight control due to propamocarbHCL intolerance (Bardsley et al., 1996). Insensitivity of *P. i.* to metalaxyl- has been monitored in Finland since 1990 and to propamocarbhydrochloride since 1992 (Hermansen et al., 2000). Growth and sporulation of *P. i.* on potato leaf disks floating in different concentrations of fungicides was studied.

Metalaxyl resistant strains were present at all sampled fields in the beginning of 1990's. Towards the year 2000 the level of insensitivity has decreased and in certain regions only sensitive isolates were present. In regions, where high insensitivity level was acquired by incorrect use of metalaxyl in the beginning of 1990's, the proportion of metalaxyl insensitive strains is still very high after 6-7 years break in use of the compound.

The sensitivity to propamocarb has not remarkably changed during period 1992-1999. Propamocarb was registered for blight control in Finland in 1995, while some *P. i.* populations collected in 1992-1994 already contained a few isolates tolerating high dosages of propamocarb. During period 1995-1999 there seems to be slight shift towards increased insensitivity to propamocarb but there are no indications of decreased efficacy of propamocarb in field situations.

No indications of cross-resistance between metalaxyl and propamocarb has been found (Klinkenberg et al., 1998). Also in this study the proportion of isolates having high tolerance to propamocarb was equal among metalaxyl resistant and metalaxyl sensitive strains. However strains of *P. i.* having high tolerance to both fungicides can be developed.

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Control of potato late blight with Caraway and Dill extracts

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Abstract

Many different plant extracts have reported to have antifungal effects against *Phytophthora infestans* (*P. i*) on potato and tomato (Blaeser et al., 1912; Schmitt, 1996). Extracts of caraway (*Carum carvi*) are effective sprout inhibitors in potato storage and they also inhibit growth of storage pathogens (Bang et al., 1995). Chemical components in dill (*Anethum graveolens*) extracts are basically the same as in the extracts from caraway. In preliminary experiments in 1998 caraway extracts inhibited growth of *P. i* on rye agar plates. Control efficacy tests on detached potato leaves encouraged to initiate field trial to study late blight control by these compounds.

In organic potato production there is an acute demand for alternative ways for potato late blight management. Therefore the current study was started to investigate the potential of caraway and dill extracts for late blight control.

Extracts of caraway and dill for the project were provided by small private companies and the procedure of extraction is still 'confidential'. The efficacy of caraway and dill extracts was tested on detached potato leaves of cultivar Bintje produced in green-house. Spore suspension of *P. i* was sprayed onto potato leaves placed in Petri dishes on moist filter paper. Different concentrations of caraway and dill extracts were sprayed thereafter, and the percentage of affected leaf area was estimated after one week incubation at 18 °C. Phytotoxicity of the extracts to potato was tested by spraying undiluted extracts and dilutions ranging from 0.1 to 75 % on test plants grown in greenhouse.

On base of the tests with detached leaves the concentrations which provided adequate blight control without causing injuries for plant tissue were selected for the preliminary field trial carried out in 2001. Dill and caraway extracts at concentrations of 10 %, 7,5 % , 5 % and 2,5 % were sprayed at 7 day interval. The treatments were compared to untreated control and treatment with fluazínam (Shirlan 0.4 l/ha) at 7 day interval.

In field conditions 10 % and 7.5 % caraway extracts delayed the onset of late blight epidemic for 10 days and delayed the defoliation by 14 days compared to untreated control. Dill extracts did not protect the crop in field trial though on detached leaves the efficacy was similar to that of caraway extracts. Very mild phytotoxic injuries in form of necrotic spots were detected after spraying with 10 % dilution of the extracts.

The efficacy of caraway and dill extracts in blight control was not very good in comparison to standard product Shirlan. In organic production 14 days delay in defoliation at tuber development can remarkably increase yield in Finnish climate where development of potato is very fast.

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