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Applied Plant Research
AGV Research Unit

Address	:	Edelhertweg 1, 8219 PH Lelystad, The Netherlands
	:	P.O. Box 430, 8200 AK Lelystad, The Netherlands
Tel.	:	+31 320 29 11 11
Fax	:	+31 320 23 04 79
E-mail	:	infoagv@ppo.dlo.nl
Internet	:	www.ppo.dlo.nl

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 companies active in late blight control the series of Workshops continued. In 2000 and 2001 the fifth and sixth Workshop were organised in Munich, Germany and Edinburgh, Scotland. The Plant Breeding and Acclimatisation Institute, Branch Division Bonin organised the seventh Workshop in Poznan, Poland from 2-6 October 2002. Avebe, BASF, Bayer, Dacom, Dow, DuPont and Syngenta sponsored the Workshop.
The Workshop was attended by 45 persons from 12 European countries. Representatives from all countries presented the late blight epidemic in 2002 and recent research results regarding integrated control and decision support systems of late blight in potatoes. Since early blight seems to be an increasing problem in Europe, it was decided to include reports on this disease in the Workshop also. The papers and posters presented at the Workshop and discussions in the subgroups are published in this Proceedings, PPO-Special Report no. 9.
For further information please contact the network secretariat where also additional copies of this Proceedings can be ordered.

Secretariat

PPO-AGV Lelystad
Att. H. Schepers
PO Box 430
NL-8200 AK Lelystad
The Netherlands
Telephone: + 31 320 291111
Telefax: + 31 320 230479
E-mail: huub.schepers@wur.nl
Internet: www.ppo.dlo.nl

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Posters

The development and control of *Phytophthora infestans* in Europe in 2002

H.T.A.M. SCHEPERS

Applied Plant Research, P. O. Box 430, 8200 AK Lelystad, The Netherlands

Introduction

From 2-6 October 2002 a Workshop was held in Poznan (Poland) on control of *Phytophthora infestans*. Representatives from 17 European countries presented the development and control of late blight in their country in 2002. In this paper these presentations are summarised. The weather conditions of 2002, the disease progress and the input of fungicides are presented and condensed in Table 1 and 2 (pages 21 and 22).

Weather conditions & blight epidemic

In the Po valley in **Italy**, a wet and warm climate in April, May and to some extent in June was very favourable for late blight on both potato and tomato. Since tomatoes were transplanted earlier in the season, both potato and tomato plants were found susceptible in the same period. Late blight symptoms occurred on potato and tomato on 16 May and 15 May respectively. Late blight caused particular problems on tomato because of the critical weather conditions close to the harvest in mid-July. On potato 4-6 MISP infectious period were recorded compared with 8-10 on tomato. Most the *P.infestans* isolates from tomato affected plants were recorded as A2. So far, no isolates were found resistant to phenylamides and strobilurines.

In the Basque country in **Spain** the coldest summer was recorded in 50 years. Early June there were favourable conditions for the development of blight but, the crops were very young and no blight was recorded. Most part of July was very cold and dry. Just at the end of July, climatic conditions were again favourable for blight. Blight was first recorded on 6 August.

In **Switzerland** the epidemic started on 22 May in a field that was flooded 10 days before. As

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weather conditions were very favourable at the end of May and especially at the beginning of June, blight could spread very fast. This wet period was followed by hot and dry weather until the end of June, which reduced the speed of the epidemic. During July the infection pressure was low to moderate (rain in the first part of July) and the beginning of August was again very wet. The western and central part of Switzerland were more attacked than the eastern part, but in the eastern part the late blight was recorded already in June compared to July in 2001.

In the intensive production area in the north east of **Austria** (Weinviertel) first blight was observed on 14 June. This is on an average over the last 20 years. After a short period of favourable weather conditions (16-19 June) infection pressure was very low due to a dry and warm July. From 6-27 August farmers had to cope with around 150 mm precipitation and infections of late blight could be found in many fields. In the seed production area in the north of Austria (Waldviertel) late blight occurred on 27 June. This is on an average over the last 20 years. The first period of critical weather conditions with an infection pressure from medium to high according to Simphyt III was between 18 June and 8 July. After some days with low to very low infection pressure a period with warm weather and medium infection pressure followed. From 6 August to the beginning of September infection pressure increased dramatically due to heavy rainfalls, leading to many flooded fields. Infection level reached 50 % in many fields. In Petzenkirchen in western Lower Austria late blight occurred first on 19 June, this is 1 month earlier than the average over the last 20 years. Infection pressure was low during July. In August infection pressure rose because of rainy weather (over 200 mm precipitation in 2 weeks) and the untreated controls were damaged very quickly. In September, harvest was also interrupted by rainfall and we could find many tuber infections in our trials. In the intensive production area in Upper Austria, in the Eferdinger Becken, late blight was first found on 15 June in early potatoes grown under plastic cover. In late crops first symptoms showed up 1 month later. Even infection pressure was medium to high in July farmers could control late blight very well and no severe outbreaks were mentioned. In the Innviertel in Upper Austria first observations were made on 8 July. From the beginning of July until the end of the season, the infection pressure was high to very high and farmers had big problems with blight. They sprayed every 8-12 days, 8-10 treatments were necessary. In the Grazer Becken in Styria late blight appeared early on 18 May in potatoes grown under cover. But during the season late blight did not cause any problems.

July was very dry and during August when infection pressure rose most crops already had been desiccated.
In **Germany**, blight was observed very early in the growing season. It was remarkable that the first blight observed were stem lesions. There might be a correlation with the poor quality of the seed potatoes. Especially in the eastern and southern parts of Germany heavy rainfall was recorded which led to a high disease pressure in these regions.
On the northwestern coasts of Brittany (**France**), polythene covered crops suffered the first blight outbreak as early as 10 April. Weather conditions remained very favourable for blight dispersal during April, requiring first fungicide treatments when the polythene was removed. During May, wet conditions favoured blight dispersal but cold temperatures kept blight pressure low. At harvest, from end May to mid June, the disease pressure increased with increased temperatures. Early harvested crops escaped tuber blight but the other remaining crops with infected foliage created inoculum at emergence of ware and seed potato crops in inland Brittany. Early crops in the north-eastern coast (Saint Malo) escaped blight contamination until harvest in June. In the north of **France**, crops were planted 3 weeks earlier than in 2001. Blight was first observed on a dump (15 May), this coincided with the second generation of blight in the DSS. In Ardenne Champagne blight was first seen in the end of May. In the beginning of June the infection risk increases. The pressure is stronger in Picardy, in Pas-de-Calais, North and Champagne Ardennes. The pressure is lower in the Central Region. In unprotected fields the first symptoms on leaves and stems are seen from 20 June onwards. High temperatures in June decrease the infection pressure but in July infection pressure again increases. Blight can be found on the edges of most fields in the north of France and Picardy. Infection pressure remains high due to regular rainstorms (20-30 mm). In the beginning of August conditions are dry but later in August rainstorms again increase the infection pressure in the North and in Picardy. The sporulation potential calculated by the model MILSOL remained very high during the whole of the growing season.
In Wallonia (**Belgium**) the initial inoculum pressure was again very high. The high level of infection at the end of 2001 probably resulted in many blighted tubers (seed, waste piles, volunteers). The winter was again relatively mild enabling potatoes to survive in the soil and develop into volunteer plants in 2002. In Wallonia uncovered dumps, home gardens and early potatoes under plastic are also important sources of primary inoculum. In Flanders

(**Belgium**) late blight was first observed on a dump pile (29 April). More lesions were observed in the first half of May, all on dump piles. From 21 March until the end of April, weather conditions were dry and sunny, suitable for early planting but not for late blight. The end of April and beginning of May were wetter and more suitable for the disease (some attacks were observed) but the rest of May until half of June were only moderately favourable for the disease. Moreover, spraying conditions were good and the crops could be effectively protected with protectant treatments. High temperatures combined with high humidity and rainfall after 15 June caused light but widespread attacks of late blight. From then on until the end of August, weather conditions were mostly favourable for a high to very high disease pressure.

In **The Netherlands**, blight was reported on volunteers early May. Several weeks later (end May) blight appeared in unsprayed fields. On average, fungicides effectively controlled blight. Mid July, weather conditions were critical for blight development. In the second half of August there was heavy rainfall in some areas. There was an early decline of most crops, the harvest was early and easy (dry conditions).

In **Ireland**, weather conditions during June, July and most of August were very suitable for the development and spread of blight. This resulted in the early onset of disease and a rapid development of the epidemic. Most of the initial outbreaks of the disease were recorded in June and were associated with the southern and coastal areas. Later in the season the disease spread inland.

On **Jersey** blight was first observed in glasshouse grown crops as early as 8 January! In polythene covered crops blight was reported on 11 March and several weeks later also in open fields (3 April). The number of outbreaks recorded in 2002 was 373, slightly less than in 2001.

Potato blight was a serious problem in **Scotland** in 2002. Most growers saw potato blight on their farms. One reason for the problem was that Smith Periods were recorded early. The first was on 5 and 6 June in East Lothian and the Borders. Blight risk was also high in mid and late July, early, mid and late August and mid September. The greatest threat was from the prolonged high risk conditions that started on 28 July and were almost continuous until the 6 or 11 August, depending on region. These conditions, combined with heavy rain, made control extremely difficult. Travelling in very wet fields was difficult. There was also a high risk of fungicides being washed-off shortly after application. Such a prolonged period of risk is unusual for Scotland. Also unusual was that on several days during the prolonged high risk the relative humidity was greater than 90% for close to 24 hours. The first report of blight was received on 27 June for several crops in the Southwest. However, generally favourable spraying conditions for most of the country until the middle of July resulted in good control initially. Outbreaks of blight were reported in the main potato growing areas (east of Scotland) from the second week of July. By the end of July 40% of crops of susceptible varieties were blighted.

In **England & Wales** the majority of second early and main crop potatoes were planted to schedule in 2002 and there was no spread of plantings as happened in 2001. Following a mild winter with very few sustained frosts, volunteer potatoes were reported in the following spring mainly in sugar beet crops. Prolific haulm growth was also found on dumpsites. Although very few Smith Periods were recorded up to the end of May (thought to be due to low night temperatures), blight was reported on dump sites in the south-west of England (24 April) and in East Anglia (Norfolk, 16 May: Cambridgeshire, 30 May). There were periods of very humid and misty weather over much of England & Wales in early June and by the third week of June there were reports of blight in crops in the north west of England (Lancashire & Cheshire), the west Midlands and the south west of England. These outbreaks were associated with infection on dumps and volunteers combined with extended spray intervals. By the end of June, blight was also present in crops in the south east of England and on dumps on the east Midlands. The epidemic continued to develop in July with outbreaks reported in crops in many areas. However, with the exception of Cheshire where it was particularly serious, there was no general epidemic. In particular, there were few outbreaks reported in East Anglia. This was due to a period of dry weather in July coupled with intensive spray programmes. At the end of July and into early August blight favourable conditions occurred in virtually all potato growing areas of England & Wales. These conditions again stimulated blight development and the disease became widespread in crops in the southern counties of England. By the middle of August, blight was present in crops in most areas with infection ranging from light infections on the 'heads' of isolated plants to primary and secondary foci.

In **Northern Ireland** it was an exceptionally wet year and many crops were very late planted with some fields water-logged. In some, growth was poor due to nutrient leaching. Blight was first observed on a dump on 6 June and this was followed by many outbreaks in field crops from 17 June onwards; blight was reported in all potato-growing areas during July and August. Late August and September were slightly drier, although still humid, providing a better end to the season.

In **Poland**, blight appeared in potato crops very early (21 May). It was the earliest occurrence of blight in recent years. During the growing season, the weather conditions were in most regions not favourable for the development of blight. From half of June to the end of August, temperature was high and rainfall low. Generally, 2002 was not a late blight year in Poland. In **Latvia** blight was first observed in both susceptible and resistant varieties on 12 July. The weather conditions were drier and sunnier than in 2001. In **Estonia** potatoes were planted 1-2 weeks earlier than usual (end of April, beginning of May). Most of growing period was unusually dry and average temperatures were 2-3 °C higher than usual. Rainy June favoured late blight development. First outbreak was recorded in 3 July in a home garden located in the central part of Estonia. Many findings were reported from central and southern regions within the next 3-4 days. In the northern part the infection started much later (24 July). Later the disease development slowed down and stopped because of high temperatures and almost no precipitation in second half of July and August. Harvest time was dry and risk for infection with tuber blight was minimal.

In **Denmark** the development of the potato crop was 10-15 days earlier than normal. A general warning was given for risk of primary attacks on 10 June. This warning coincided with the findings of the first blight in early potatoes. The infection pressure was high in June and July and low in August and September. At the end of the season 70-80% of the conventional fields was infected at a low level.

In **Norway** blight was first reported in plastic covered potatoes at 29 May, a week earlier than in 2001. The first report of late blight in uncovered fields was at 26 June. During the first half of July, late blight was found in most potato districts as far north as to Trøndelag. Warm weather with some wet periods resulted in a high infection pressure early in the season. In some districts this caused great losses in early crops. The disease pressure was very high in some districts during the summer, especially in Hedmark (inland counties). The local advisory services in the most important potato areas looked for the first symptoms of late blight. Unsprayed fields were inspected every week. All early findings of late blight were reported in Web-Blight, and were available on the Internet with easy access from our forecast system, VIPS (www.vips-landbruk.no). Unfortunately, some private gardens with heavy infections of late blight may cause infection pressure although no late blight is registered in commercial fields in the area.

In **Sweden** blight was first observed 25 May in early potatoes grown under cover and in one potato field without cover. These very early infections originate from oospores. Many fields in this area were infected seven to ten days later. Dry weather from July saved the situation for most of Sweden and kept the infection pressure comparatively low. However, in some locations the disease level was surprisingly high despite the dry weather. As usual, the biggest problem with late blight occurred in the Southwest where the rainfall was higher. Many fields had late blight in late June in this area.

In **Finland** blight was not found in early potatoes grown under cover due to dry weather. In open fields blight was first observed on 18 June. The symptoms were on stems. The first blight that originated from oospores was found on 29 June. During the first two weeks of July late blight was reported from all parts of Finland including Lapland where blight is normally not present. The weather was very favourable for blight between 15 June and 15 July. The majority of potatoes in home gardens was destroyed at that time. Farmers started their spray programs in last week of June or first week of July and no large-scale epidemics were reported on these farms. In some individual cases, it was not possible to spray due to the continuous rain and blight lesions were found in these fields. The end of the season from 15 July until harvest was exceptionally dry and warm and the spread of blight was prevented even in fields where blight lesions were found in early July.

Fungicide input

In the Po Valley **(Italy)** the first spray usually was carried out with metalaxyl or fluazinam when the plant canopies cover the row. Afterwards, the normal control strategy using cymoxanil and dimetomorph was applied. Overall, 5-8 sprays were carried out on potato and 6-10 on tomato to control the disease. Copperoxychloride was also used particularly at the end of the season.

In **Spain** the first treatment on a developing crop was carried out with metalaxyl. When the first blight symptoms appeared in August, translaminar products like cymoxanil and dimethomorph were applied. At the end of the growing season, copper was used.

In **Austria** early crops were sprayed 3-5 times, late crops 8-12 times. The first two sprays were carried out with systemic fungicides (metalaxyl, propamocarb). Followed by 1-2 times a translaminar product (dimethomorph) to which fluazinam was added depending on the infection pressure. Contact fungicides (mancozeb, fluazinam) were sprayed 2-4 times at the end of the season. The last spray was mostly fluazinam.

In **Switzerland** 5-6 fungicide treatments were carried out (mean value of 141 PhytoPRE participants). On average they used 2 sprays with a contact fungicide and 3 sprays with a translaminar fungicide. Systemic fungicides are rarely recommended, therefore hardly any sprays (0.3) with such a fungicide were recorded.

In **Germany**, on average 1-2 sprays more than in 2001 were needed to control blight due to an early start of the spraying schedules. In regions with a low disease pressure 3-6 sprays were sufficient to control blight. In regions with a high pressure 7-16 sprays were needed to control blight.

For early production in Brittany (**France**), the number of treatments ranged from 8 to 12 according to local conditions. Contact fungicides were favoured when there was a low blight pressure. Cymoxanil and other translaminar products were applied during high blight pressure. In the north of **France**, Pas-de-Calais area and Picardy, 12-13 sprays were needed to control blight. In the Ardennes Champagne region, 8-10 sprays were needed. On susceptible varieties, the first spray was on 1 June on other varieties on 8 June. Systemic fungicides provided a protection of new growth during the active growth period. The use of rainfast fungicides provided a better protection of the foliage and allowed a reduction in the number of treatments. Products containing cymoxanil were used when blight was observed in the field. Fluazinam and cyazofamid are recommended to prevent tuber blight.

In Flanders (**Belgium**) blight was controlled in cultivar Bintje with an average of 13 applications. In July more than 60% of the applications was made with cymoxanil or dimethomorph containing products. Almost no phenylamides were used. Towards the end of August, crop senescence was already considerable and many fields died off naturally. Fentin containing products were on average sprayed more than 4 times.

In **The Netherlands** only 4 fungicides were registered to control blight in 2002. Shirlan was the most widely used fungicide (protectant, tuber blight). Ranman (protectant, tuber blight) was used on a much smaller scale. Aviso (metiram+cymoxanil) and Tattoo C (propamocarb+chlorothalonil) were used in situations with a high risk of infection.

Despite the favourable weather conditions in **Ireland**, disease control at farm level was excellent irrespective of the fungicide used. Fungicide programmes consisted mainly of phenylamides followed by Shirlan or Shirlan alone and most of the spraying was at 7-day intervals.

In **Scotland**, the most effective fungicide programmes were those that managed to maintain short intervals and those that incorporated a full rate of cymoxanil. Growers using low drift nozzles appeared to have more problems.

In **England & Wales** there were unconfirmed reports of a trend towards more use of translaminar fungicides early in the growing season replacing the use of systemic products during the rapid haulm growth phase of crop growth. A number of new products were available in the UK in 2002 increasing grower choice. In particular, the availability of a straight cymoxanil formulation increased the flexibility of using protectant fungicides. One of the major concerns of UK growers was/is the withdrawal of fentin containing products and the availability and effectiveness of possible replacements for the control of tuber blight.

The main fungicides used in the early season in **Northern Ireland** were Merlin (Tattoo C), Trustan/Ripost and Fubol Gold. Some growers commenced with Shirlan or mancozeb when plants were small. During Mid-season, Curzate+Tin, Invader+Brestan and Shirlan were used. Late in the season the main fungicides used were Invader+Brestan, Curzate+Tin and Shirlan+Tin.

In **Poland** 42% of the applications were systemic fungicides (Tattoo C, Ridomil Gold, Sandofan M). The proportion of translaminar fungicides (Curzate M, Acrobat MZ, Pyton) was 26% whereas in 32% of the sprayings contact fungicides (Altima, Antracol, Dithane) were used. In **Latvia** the most important strategy consists of 2 sprays with a systemic fungicide (Tattoo) followed by two sprays with a contact fungicide (Dithane, Shirlan). Despite the lower infection pressure in **Estonia**, the fungicide input was higher than in 2001. The number of treatments was the same as in 2001 (3-5) but they were used on a larger scale, namely on 10100 ha in 2002 compared to 7300 ha in 2001. Approximately half of the potato acreage is not treated. The main strategy consists of two treatments with (locally) systemic fungicides (metalaxyl, propamocarb, dimethomorph) followed by two treatments with a contact fungicide (mancozeb, fluazinam, metiram).

In **Denmark** 4-6 sprays were needed in seed potatoes, 7-8 in ware potatoes and 10-12 in starch potatoes. Shirlan and Tattoo were used more than in 2001, whereas Dithane and Acrobat were used less.

In **Norway** early crops are often unsprayed, or only 1-2 sprays are applied before harvest. In general, the main crops were sprayed 6-8 times. The main fungicide is Shirlan, while Tattoo constitutes maybe 1/3 of the fungicide applications. Other fungicides used are Dithane, Acrobat and some Epok. Epok is not recommended because of fungicide resistance.

In the southern region of **Sweden** the first spray against blight was again earlier than last year. However, due to the dry weather during the season, the number of sprays in Sweden as a whole is probably lower compared to last year. It is estimated that blight is controlled with 6-8 sprayings in the South, 4-6 in Mid Sweden and 2-4 in the North. The standard fungicide is Shirlan. There is a lot of discussion whether Acrobat or Tattoo should be used as an alternating fungicide. Epok is used for the second and/or third spray in the program, but is also used curatively. As usual, there were reports of failing effects of metalaxyl.

In all parts of **Finland** the first spray against blight was again earlier than last year. Due to the dry weather at the end of the season spraying in Finland as a whole is expected to have been reduced compared to last year. This probably results in 4-8 sprayings depending on region. For this summer, it was typical that the rainfall and number of sprays varied a lot within regions. In any part of the country within a radius of 20 km there were areas with practically no rain and areas where potato rotted due to too much rain from very heavy local thunder storms. The most widely used fungicides were Shirlan and Dithane. Acrobat and Tattoo are used to some extent in 1-2 first applications. A very small proportion of the growers used Epok as a first application. As usual, there were reports of failing effects of metalaxyl.

Tuber blight

No tuber blight was recorded in the Po Valley **(Italy)**. In the Basque Country (**Spain**), August had three favourable periods for the development of blight. Crops had to be burnt early. A considerable number of growers reported problems with tuber blight in storage. Favourable weather conditions in August and September caused severe problems with tuber infections in Upper **Austria**. The processing company in Lower Austria in the Weinviertel did not have problems with tuber blight. In Brittany (**France**) the incidence of tuber blight was rather low irrespective of production type (early, organic, ware, seed), possibly explained by the use of a fungicide treatment at haulm killing and a new effective desiccant. In Flanders **(Belgium**), September was relatively dry, leading to good conditions for crop lifting. However, a considerable degree of tuber rot and tuber blight was observed later in the storage season. The very high rainfall during the second half of August led to a higher incidence of tuber rot and tuber blight than initially expected. Although in **The Netherlands** weather conditions were dry during harvest, tuber blight was observed in some cases in storage probably caused by heavy rainfall in August. In **Ireland** weather conditions in late August and September became very warm and dry. This, together with the use of the tuber resistant cultivar Rooster, resulted in very low levels of tuber blight at harvest. In **Jersey** a trial was carried out to investigate control of tuber blight using different fungicides strategies. In **Scotland** some crops were desiccated early because of significant foliage blight. The first reports of tuber blight were received within a week or two of desiccation. In **England & Wales**, main crops generally tended to produce fewer tubers and consequently, met their size specification earlier than normal. A significant proportion of crops was therefore desiccated earlier than usual. Drier weather conditions from the end of August and into September would also have reduced the risk of tuber infection during the desiccation period. In **Northern Ireland**, drier weather during late August and September gave good harvest conditions, which resulted in no tuber blight in most crops and only low levels in the remainder. In **Poland** no tuber blight was observed at the time of harvest and after 4 weeks of storage in fungicide treated fields and untreated fields, respectively. In **Latvia**, the amount of tuber blight that was observed at harvest was <0.7%. From two regions in **Norway** (Hedmark & Troms) tuber blight was reported although no visible symptoms of blight were found in the foliage. In **Sweden** and **Finland**, dry weather in the later part of the growing season and excellent harvesting conditions resulted in a high quality harvest. No problems with tuber blight were reported except in home gardens.

Organic crops

In **The Netherlands**, organic crops became heavily infected in July and were desiccated prematurely by propane flamers. In Brittany (**France**), organic crops planted mid April, escaped major blight pressure. Susceptible cultivars were effectively protected with 4-6 copper-based treatments. In the north of **France**, many organic fields were 100% destroyed from the end of July. Problems with tuber blight were not recorded. In **Latvia**, all organic fields were infected with blight. In early July, a blight epidemic occurred in organic crops in **Denmark**. The expected yield of organic potatoes is approximately 20 tonnes/ha. In some areas of **Norway**, organic farmers had to destroy the foliage earlier than normal because of severe infections of late blight. Problems with tuber blight were not reported. Despite the dry weather, blight was a problem in organic crops in **Sweden** and **Finland**. Some fields were heavily attacked early in the growing season. As a whole the situation was better compared to 2001. In many organic fields, late blight can develop freely for long periods. Surveys in 2001 and 2002 showed that in the majority of such fields oospores are formed.

Alternaria

The eastern parts of **Austria** had problems with early blight in the last years. Severe infections of Alternaria lead to early maturation of the crops and less yield in the eastern province Burgenland, in Lower Austria in the intensive production areas of the Tullner Becken and the Marchfeld, in the south eastern part of Styria the Grazer Becken. In the eastern province Burgenland no late blight could be found but because of dry weather the foliage was seriously damaged by Alternaria in July. In some regions of **The Netherlands**, Alternaria destroyed the potato foliage at the end of the growing season causing a reduction in yield. In Brittany (**France**), severe Alternaria outbreaks were found, mainly on inland crops. Foliage of susceptible cultivars was seriously damaged. The correlation between reduced use of mancozeb and increased importance of Alternaria cannot be excluded. Alternaria appeared relatively early (5 June) in the north of **Poland**. The infection pressure was high in the North and rather low in the South which is opposite compared to other years. In **Latvia**, 80% of the potato fields was infected with Alternaria.

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Table 1. The estimated use[1] of fungicides to control *P. infestans* on potato in 1996-2002

	Average number sprays/season						
	1996	1997	1998	1999	2000	2001	2002
Austria	4-6	5-6	4-6	4-12	4	4-7	3-12
Belgium							
* Flanders	8-12	14-15	12-14	10	12-20	11-13	12-14
* Wallonia	8-9	10-11	10	11-15	13-16	11-13	12-16
Denmark	5.5	5.5	8	7.5	7-8	8-9	8-9
Estonia						3-5	3-5
Finland	3-4	4-5	3-8	2-6	5-9	4-8	4-8
France							
* Nord-Pas-de-Calais	9-11	11-14	?	15	16-17	10-19	12-13
* Brittany							8-12
Germany	5-6	7-9	3-10	4-5	2-14	2-16	3-14
Italy	6-8	6-8	4-5	8-10	6-8	4-7	5-8
Latvia	?	?	?	?	2	4	2
Netherlands	5-12	7-15	7-15	7-16	15-20	10-18	8-16
Norway	2.9	4	5	5-6	6-7	5.5	6-8
Poland	1.6	1.7	1.7	2	2	1-8	1-5
Spain (Basque Country)	3	5-6	3	4-5	2-6	2-3	3-4
Sweden	4-7	4-7	4-12	4-11	?	?	2-8
Switzerland	6-7	7-9	5-7	6-10	7	6.3	5-6
United Kingdom							
*Northern Ireland	2-10	3-15	4-16	4-14	3-12	3-14	3-14
*England/Wales	2-10	4-18	8-15	4-16	?	8-12	8-14
*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 2002 in relation to other years

	May	June	July	Aug.	Sept.	First outbreak				
						2002	**2001**	**2000**	**1999**	**1998**
Austria	*	**	*	***	**	18 May[1]	19 June	14 July	8 May	25 June
Belgium										
* Flanders	*	**	**	***	**	29 April[2]	2 May[2]	30 April[2]	29 April[1,2]	28 April[1]
* Wallonia	*	**	***	***	**	2 May	15 May	15 May	15 May	
Denmark		***	***	*	*	10 June[4]	18 June[4]	20 June	18 June	16 June
Estonia	*	**	**	*	*	3 July				
Finland	*	***	***	*	*	18 June	2 July[1]	4 July[1]	2 June[1]	20 June
France										
*Nord-Pas-de-Calais	**	**	***	***		15 May[2]	Early April[2]	End April[1,2]	Early April[2]	20 April[2]
*Brittany	**	**				10 April[1]				
Germany	**	**	***	***		2 May[1]	2 May[1]	11 May[1]	28 April[1]	5 June
Italy	***	**	*	**		16 May	14 May	11 May	10 May	No blight
Ireland		**	**	**	*	June	June	4 July	20 July	1 July
Latvia		*	**	**	*	12 July	6 July	24 July	19 July	24 June
Netherlands	**	**	***	***	**	Early May[3]	17 May[1]	April[2]	26 April[2]	1-10 May
Norway	**	***	***	**	**	29 May[1]	6 June[1]	16 June[1]	15 June[1]	20 June[1]
Poland	*	**	**	**	**	21 May	6 June	23 June[2]	27 May	1-10 June
Spain (Basq Country)	*	**	*	**		6 August	2 August	15 June	21 June	15 June
Sweden	**	**	**	*	*	25 May[1,4]	17 May[1,4]	5 June[1]	20 May[1]	15 May[1]
Switzerland	*	**	**	**		22 May	11 May[1]	3 May[1]	8 May[1]	15 May[1]
United Kingdom										
*Northern Ireland		***	***	***		6 June[2]	2 July	22 June	16 June	8 June
*England/ Wales	*	**	**	***	**	24 April[2]	End May	10 May[2]	mid-May[1]	31 May[1]
*Jersey	***					11 March[1]	20 March[1]	20 March	10 March	31 March
*Scotland	*	**	***	***	**	27 June	6 July	22 June[1]	12 May[3]	25 June

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

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

Subgroup Fungicides: review ratings given to various fungicides at Edinburgh workshop & rate efficacy of fungicides to Alternaria

N.J. BRADSHAW

ADAS Consulting Ltd., Henstaff Court Business Centre, Groesfaen,
Cardiff, Wales CF72 8NG, UK.

Participants:

Nick Bradshaw (UK)
Erno Bouma (The Netherlands)
Rosemary Collier (Jersey)
Piotr Daniel (Bayer Crop Science, Poland)
Ludovic Dubois (France)
John Edmonds (Dow AgroSciences, UK)
Guntis Gulbis (Syngenta, Latvia)
Asko Hannukkala (Finland)
Dagnija Hincenberga (Syngenta, Latvia)
Howard Hinds (UK)
Klaas Jildera (BASF, The Netherlands)
Jozefa Kapsa (Poland)
Jan-Dries Luijks (The Netherlands)
Bent Nielsen (Denmark)
Berit Nordskog (Norway)
Priit Palumaa (Estonia)
Michel Petit (Syngenta, France)
Huub Schepers (The Netherlands)(Chairman)
Oleg Shevchuk (Dow AgroSciences, Poland)
Kees Vogelaar (The Netherlands)

Objective:

The objective of the sub-group meeting was to review and update the ratings given at the Edinburgh workshop in September 2001 for the various properties and characteristics of late blight fungicides (PPO-Special Report No 8, pp 21-24).

The ratings given are based on publicly available information and the experiences of the independent members of the sub-group. They are intended as a guide and are based on label recommendations for the individual active substances. The scores are NOT additive for mixtures of active substances and the inclusion of an active substance is NOT indicative of its' registration status either in the EU or elsewhere in Europe. The tables for 'existing' and 'recently introduced' fungicides given in the previous PPO report have been amalgamated into one table. There have been a number of modifications compared with the 2001 tables

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and this will continue following on from similar discussions at future workshops, as new information becomes available and will include new fungicides as they become registered within the EU.

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.

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 i.e. where 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 table 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.

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 Poznan workshop, 2002

	Effectiveness				Action mode			Rain-	Mobility
Active Ingredient [1]	Leaf blight	New growing point	Stem blight	Tuber blight	Protectant	Curative	Eradicant	fast-ness	in the plant
chlorothalonil	++	0	(+)	0	++	0	0	++(+)	contact
copper	+	0	+	+	+(+)	0	0	+	contact
cyazofamid	+++	0	+	+++ [5]	+++	0	0	+++	contact
dithiocarbamate [2]	++	0	+	0	++	0	0	+(+)	contact
famoxadone	++	0	+(+) [5]	N/A	++	++ [4]	+ [4]	++	contact
fentin acetate	++	0	+	++	++	0	0	++	contact
fentin hydroxide	++	0	+	++	++	0	0	++	contact
fluazinam	+++	0	+	++(+)	+++	0	0	++(+)	contact
zoxamide	+++	0	+ [5]	++	+++	0	0	++(+)	contact
cymoxanil	++(+)	0	+(+)	0	++	++	+	++	translaminar
dimethomorph	++(+)	0	+(+)	++	++(+)	+	++	++(+)	translaminar
fenamidone	++(+)	0	+(+) [5]	++	++(+)	0	0	++	translaminar
benalaxyl [3]	++	++	++	N/A	++(+)	++(+)	++(+)	+++	systemic
Metalaxyl-M (mefenoxam) [3]	+++	++	++	N/A	++(+)	++(+)	++(+)	+++	systemic
oxadixyl [3]	++(+)	++	++	N/A	++(+)	++(+)	++(+)	+++	systemic
propamocarb-HCl	++(+)	+(+)	++	++	++(+)	++	++	+++	systemic

[1] *The scores of individual active ingredients are based on the label recommendation and are NOT additive for mixtures of active ingredients. Inclusion of an active substance in the list is NOT indicative of its' registration status either in the EU or elsewhere in Europe.*

[2] *Includes maneb, mancozeb, propineb and metiram.*

[3] *See text for comments on phenylamide resistance .*

[4] *Provided by the active ingredient cymoxanil in Tanos (famoxadone+cymoxanil).*

[5] *Based on limited data.*

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

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 ratings are based on the label recommendation for a particular product. Where the disease pressure is low, intervals between spray 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.

Early blight – *Alternaria solani & Alternaria alternata*

Problems have been experienced in some countries with the early blight disease complex caused by *Alternaria spp (A. solani and A. alternata)*. Limited information is available on the efficacy of certain late blight fungicides against this disease and in the table below they are rated in the same way as for late blight fungicides.

Table 2. Efficacy of fungicides for the control of early blight caused by *Alternaria solani and Alternaria alternata*.

Active Ingredient	Efficacy [1]
fluazinam	(+)
mancozeb	++
propineb	++
chlorothalonil	+(+)
famoxadone+cymoxanil	+(+)
fenamidone+mancozeb	++
zoxamide+mancozeb	++(+)

[1] *Key to ratings : 0 = no effect ; + = reasonable effect ; ++ = good effect ; +++ very good effect*

Subgroup Decision Support Systems: results 2002 & possibilities of co-ordination in 2003

G.J.T. KESSEL

Plant Research International, P.O. Box 16, 6700 AA Wageningen, The Netherlands

Participants 2002:

Pieter Vanhaverbeke
Tomke Musa – Steenblock
Johan Wander
Geert Kessel (notes)
Daniele Haine
Elke Rauscher
Jan Hadders
Wim Nugteren
Gunita Bimsteine
Mati Koppel
Jaroslaw Wankowicz
Catherine Chatot
Nigel Hardwick
Moray Taylor
Paul Gans

Results 2002 and co-ordination in 2003

In 2002 participants of the meeting did not carry out comparisons of DSS systems in Europe. In the Netherlands two experiments were carried out aimed at developing and incorporating reduced fungicide dose rates on resistant cultivars in DSS systems.

Trials comparing DSS-systems or modules are not planned by any of the participants in 2003. Three years of DSS comparisons across Europe have indicated that using a DSS system reduced the fungicide input, as compared to a seven-day routine schedule, while maintaining adequate control of late blight. Overall it was not possible to identify the “best system”. It proved difficult to measure and analyse DSS performance using single or compound parameters.

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The need for support by the provider, necessary to get the systems up and running satisfactorily in this type of experiment, was high. Since the start of EU.NET.ICP valuable knowledge on the set up and use of DSS systems has been exchanged between DSS providers. In contrast, the benefit of this type of experiments to the providers at present is relatively low. DSS providers participating in the discussion were not in favour of continuing this type of experiment. Comparison of the behaviour of separate DSS modules was considered a better and more meaningful alternative. In addition, exchange of meteorological data and first records of blight would enable systems to be validated across countries. However, the degree of information sharing necessary for meaningful comparisons may conflict with commercial interests of DSS providers.

Future improvements

Where can we efficiently improve DSS systems?

Timing of the first spray application.

In order to improve timing of the first spray application it is necessary to improve estimates for local disease pressure, a complex parameter combining meteorological data and epidemiological information. There was a discussion on whether better knowledge on the amount of (local) air-borne sporangia would be beneficial to the DSS systems. In general this hypothesis was confirmed but practical implementation was considered difficult. Automatic systems determining sporangial concentrations in the air are not (yet) available. Currently available spore traps may not be sensitive enough for the job and results are only available after laborious manual counting of sporangia. Networks of 'tell-tale' plots or 'trap' plots, planted with (a) highly susceptible cultivar(s) require frequent (laborious) visits and only display results after completion of the latent period. Practical experience with networks of 'trap' plots (Switzerland) has shown that this method gives valuable information but is not fool proof. It was concluded that scouting for primary infections (or early secondary infections) has to improve to increase accuracy of the first application. All methods discussed above may contribute to this goal. Additionally, meteorological data from the late winter may be required to enable a more accurate estimate for emergence of volunteers as potential sources of primary inoculum.

Analysis of databases.

It was discussed whether analysis of existing databases on meteorological and epidemiological factors could contribute to our knowledge and predictive ability on the carry over of inoculum between growing seasons. It was concluded that it will be possible to identify trends but accurate predictions remain difficult and should be supported by scouting.

Timing of the last spray.

In practice there is an increasing trend for blight fungicides to be included with the desiccant, or even post desiccation, to reduce the risk of tuber blight and of blight building up at the end of the season. It was discussed whether this was necessary. In contrast it was suggested that it may be possible to relax the decision rule for timing of spray applications shortly before desiccation, accept a slightly higher risk on late blight attack at the very end of the growing season and thus save one application. In general the risks of omitting the last treatment were considered to be (very) high. Moreover, some thought that infected crops pose a danger to neighbouring crops. However, consideration of soil cover, soil structure and weather conditions probably play an equal part in protecting tubers from blight spores washed onto the soil surface. Also, lifting well after complete haulm death is important in reducing the risk of spores contaminating the tubers. In conclusion, knowledge on tuber resistance and tuber infection is insufficient to quantify the risks associated with these alternative spray schedules at the end of the growing season.

Communication

What are we doing to convince farmers to use a DSS?

There was a discussion on whether retail organisations are sufficiently aware of the possibilities of DSS systems for late blight control. Especially as the current requirements of EUREPGAP on late blight control strategies are well below the present possibilities. Support for DSS use by retail organisations was deemed necessary for further uptake of the systems into daily farming practice.

Action point:

Inform EUREPGAP about EU.NET.ICP and the possibilities of present day DSS's. The aim is to bring focus into EUREPGAP requirements on late blight control strategies.

Action by:

Catherine Chatot, Geert Kessel, Jan Hadders and Huub Schepers. Initial letters will be distributed to EU.NET.ICP members for comments and approval before sending.

Seventh Workshop of an European Network for development of an
Integrated Control Strategy of potato late blight
Poznan, Poland, 2-6 October 2002

WURBlight: an experimental decision support module linking fungicide dosage to late blight resistance

G.J.T. KESSEL[1], D.M. JANSEN[1], H.T.A.M. SCHEPERS[2], J.G.N. WANDER[2], H.G. SPITS[2] AND W.G. FLIER[1]

[1]Plant Research International, P.O. Box 16, 6700 AA Wageningen, the Netherlands.
[2]Applied Plant Research, P.O. Box 430, 8200 AK Lelystad, the Netherlands.

Key words: Potato late blight, cultivar resistance, fungicide dose rate, decision support systems

Introduction

In the Netherlands, a highly aggressive, genotypically diverse and sexually reproducing population of *Phytophthora infestans* has displaced the old, clonally reproducing, population during the 1980's and early 1990's (Drenth *et al.*, 1993). This event was one of the factors responsible for ending a period, during the 1970's, in which potato late blight appeared to be under control (Zwankhuizen and Zadoks, 2002). At present, the new *P. infestans* population is more difficult to control than in the past, requiring accurately timed and frequent fungicide applications amounting to 10 – 18 sprays per growing season (Schepers, 2002). In contrast, a restrictive government policy on the use of pesticides and an increasing public concern regarding food safety and the environment call for drastic reductions of the chemical inputs in agriculture. As a result, potato late blight has become the most serious constraint to sustainable potato production in the Netherlands.

One way to reduce the fungicide input against potato late blight is to better exploit the possibilities of partial resistance in potato cultivars. In a four-year project, started in 2002, options for reducing the fungicide input on partially resistant potato cultivars will be explored. At the start, three options were available:

Increase the spray interval on more resistant cultivars using recommended dose rates.
Reduce the dose rate on more resistant cultivars using spray intervals as recommended for susceptible cultivars.
Reduce the dose rate and increase the interval on more resistant cultivars.

Based on the hypothesis that (higher levels of) partial resistance can be supplemented with (reduced dose rates of) fungicide to provide an adequate and reliable level of protection against *P. infestans*, option two was selected for exploration.

Materials and Methods

Four field experiments were carried out. Base line research was done at Lelystad and Wageningen in two field experiments with 30 commonly grown cultivars. Four components of resistance (Infection Efficiency [IE], Latent Period [LP], Lesion Growth Rate [LGR], and Sporulation Intensity [SI]) were measured for each cultivar at the Wageningen site. A reduced dose rateexperiment was carried out at Lelystad where all 30 cultivars were treated with Shirlan (a.i. fluazinam, 500g/L) at each of 6 dose rates (0, 0.08, 0.16, 0.24, 0.32 and 0.4 L Shirlan/ha). Timing of the spray applications was provided by the DSS PLANT-Plus. Spreader rows surrounding the replicate blocks were inoculated on 24 June with a mixture of thirteen current *P. infestans* isolates. At several occasions prior to inoculation, components of resistance, as mentioned above, were also determined in this experiment for 5 cultivars and 6 Shirlan dose rates.

Table 1. Fungicide dose rates recommended by WUR-Blight in two field experiments aimed at evaluating decision rules linking fungicide dose rate and cultivar resistance.

Lelystad (ware potatoes)			Valthermond (starch potatoes)		
Cultivar	Resistance rating[1]	Shirlan Dose rate	Cultivar	Resistance rating[1]	Shirlan Dose rate
Bintje	3	0.4 l/ha	Bintje	3	0.4 l/ha
Santé	4.5	0.32 l/ha	Starga	5.5	0.32 l/ha
Agria	5.5	0.24 l/ha	Karakter	6	0.24 l/ha
Remarka	6.5	0.16 l/ha	Seresta	7	0.16 l/ha
Aziza	7.5	0.08 l/ha	Karnico	8	0.08 l/ha

[1]: Foliar resistance rating according to the Dutch National Variety List.

Performance of a first set of experimental decision rules (described below) linking the level of cultivar resistance to a fungicide dose rate was evaluated in field experiments in Lelystad and Valthermond. Both field experiments included 5 cultivars and were depending on natural infection (Table 1). WUR-Blight was used for advice on timing and dose rate of fungicide applications. The main purpose of WUR-Blight is to develop a (preferably independent) decision support module advising on the dose rate of fungicide applications based on cultivar resistance and crop characteristics. Timing of spray applications is not a research priority.

Decision rules: In this first year, dose rates advised by WUR-Blight were fixed per cultivar based on their resistance rating in the Dutch National Variety List (Table 1). The first spray application was applied at 90% emergence. Follows up applications were timed using SIMCAST decision rules developed for susceptible cultivars (Grünwald, et al., 2002) incorporated in WUR-Blight. Historical weather data (measured on site at 1.5m above ground) and actual late blight management (recommended versus implemented sprays) were used as input. Spray recommendations were issued when the threshold for Blight Units or Fungicide Units was reached. The range of available fungicides was limited to Shirlan to achieve a purely preventive fungicide-based control strategy. Figure 1 shows a schematic representation of the modular set up of WUR-Blight. WUR-Blight was implemented using Visual Fortran.

Decision rules are evaluated annually using results from all four field experiments and will be subsequently modified and improved.

Data analysis: Sigmoid curves were fitted to severity observations for the period 24 June (inoculation) – 19 July when unprotected susceptible cultivars were affected up to 90% severity. From the fitted curves, three parameters were estimated: the apparent infection rate (slope), the number of days between inoculation and 10% severity (delay) and the standardised area under the disease progress curve (stAUDPC).

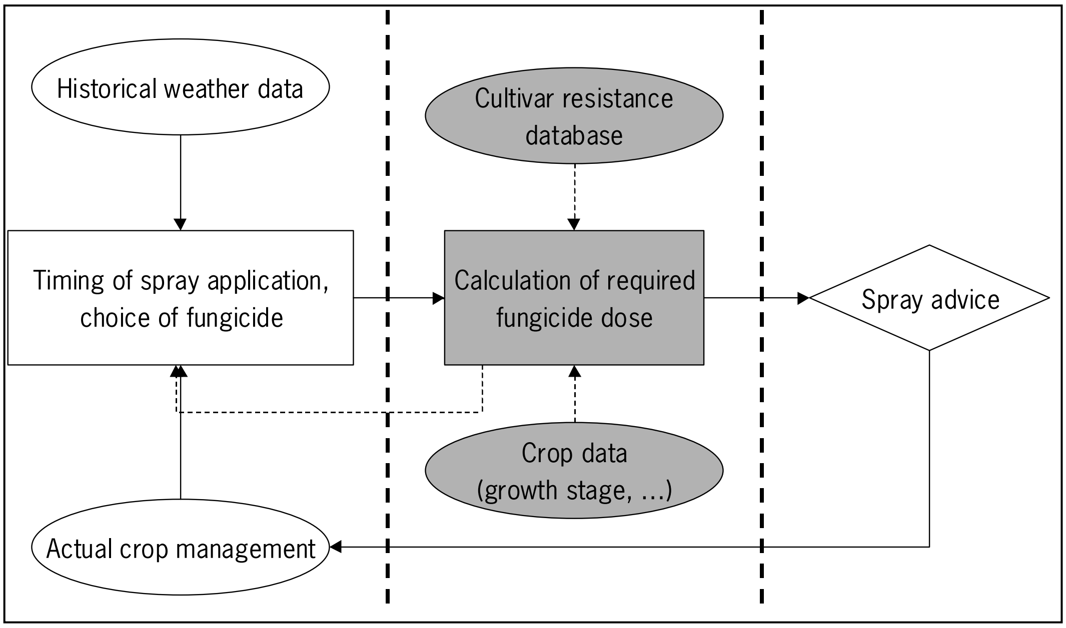

Figure 1. Schematic representation of the modular set up of WUR-Blight. Purpose of WUR-Blight is to link the level of cultivar resistance to a (reduced) fungicide dose rate, primarily by developing relations between the components in gray.

Results

Components of resistance: Infection efficiency (IE) was increasingly reduced with increasing Shirlan dose rates. Shirlan effects on other components of resistance were not detected. Figure 2 illustrates the effects of a range of Shirlan dose rates on IE as measured for cultivars Desiree and Santé.

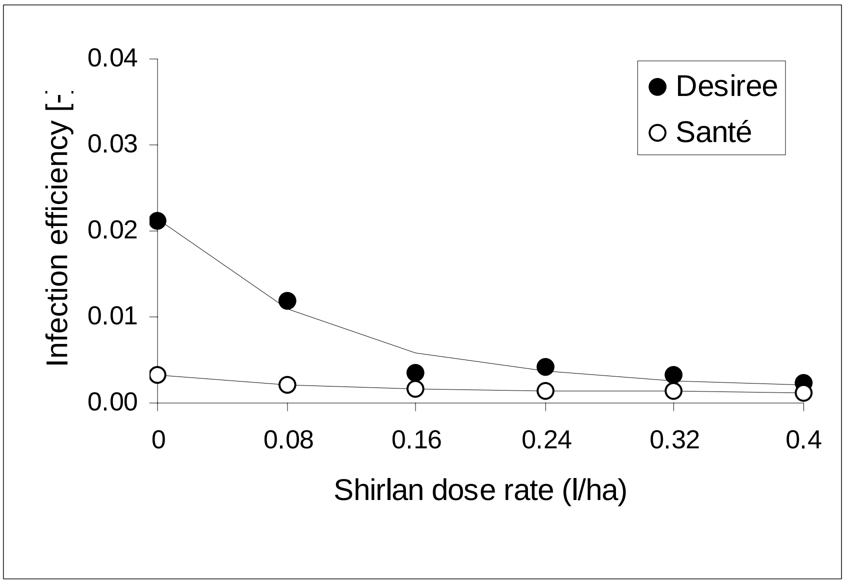

Figure 2. Effect of a range of Shirlan dose rates on the infection efficiency of *P. infestans* sporangia on cultivars Desiree and Santé.

Reduced dose rate experiment: Spreader rows were inoculated on 24 June. During the first week of July, a spray was recommended which could not be carried out for four days due to adverse weather conditions. Consequently, many lesions were found on 9 June. Lesion counts revealed cultivar effects but no dose rate effects on the average number of lesions indicating that the crop had been unprotected during this critical period. From this point on, spray recommendations were carried out according to DSS recommendation resulting in a reduction of the epidemic growth rate. This is illustrated by a Shirlan dose rate effect on the apparent infection rate (slope), the delay and the stAUDPC (illustrated for 9 cultivars in Figure 3).

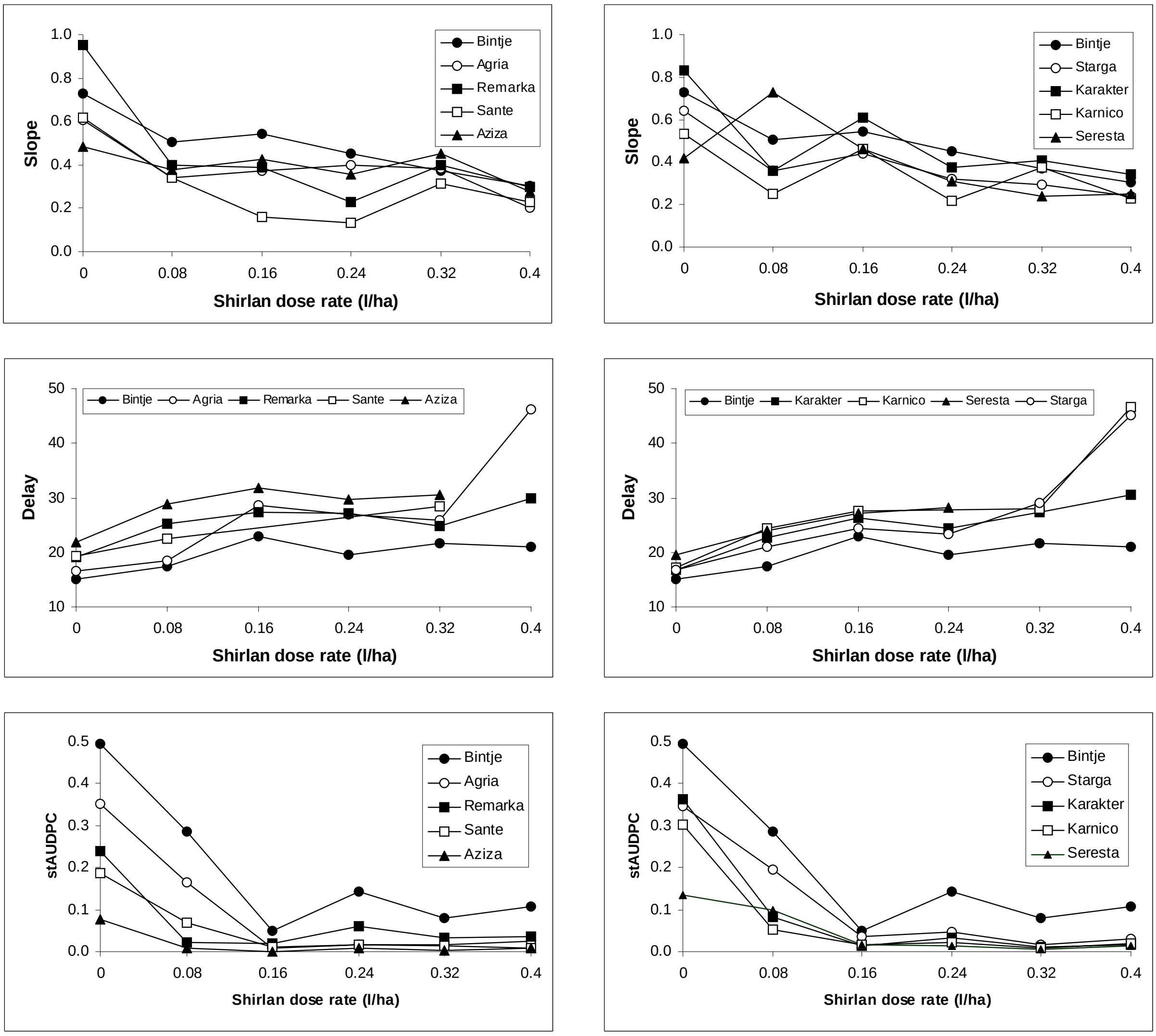

Figure 3. Effect of a range of Shirlan dose rates on (regression) parameters describing the potato late blight epidemic for 9 selected cultivars.

The epidemic growth rate (slope) is generally decreasing with increasing Shirlan dose rates, whereas a delay in the onset of the epidemic is positively associated with increasing Shirlan dose rates. The combined effect on both regression parameters explains the significant decrease in stAUDPC with increasing Shirlan dose rates (Figure 3).

Evaluation experiments: Two evaluation experiments were carried out: one in Lelystad (ware potatoes) and one in Valthermond (starch potatoes). Cultivars were sprayed using the WUR-Blight dose rates given in Table 1 while timing was provided by the SIMCAST decision rules incorporated in WUR-Blight.

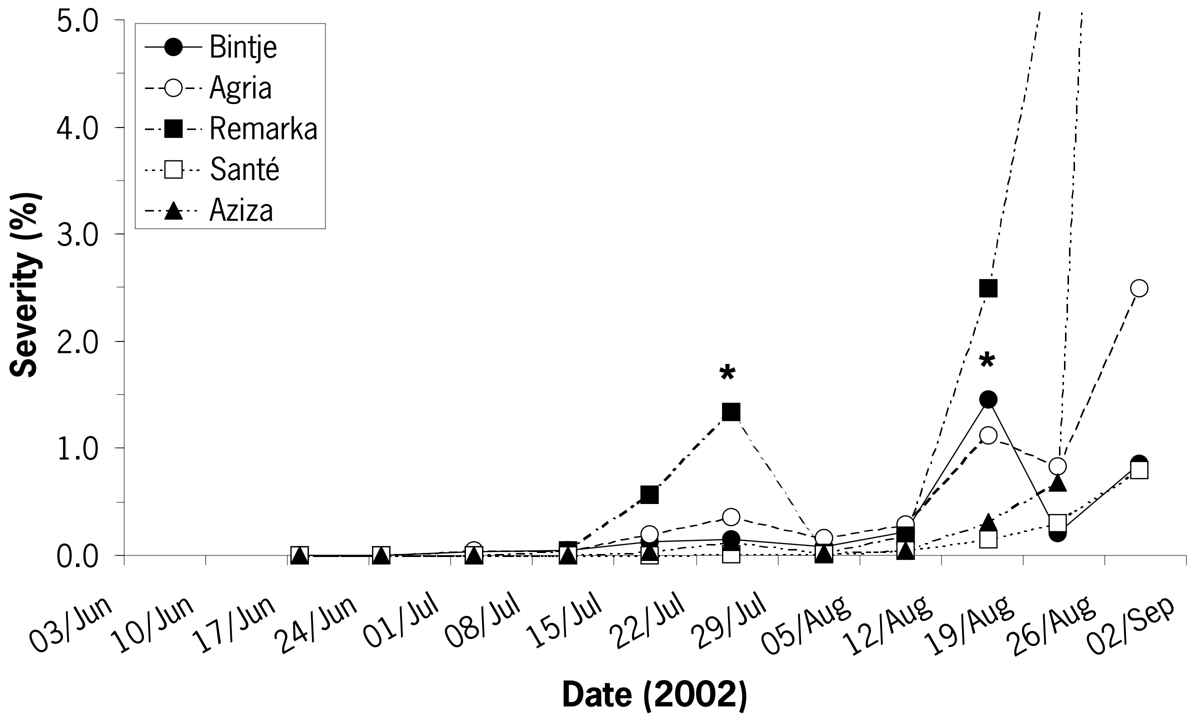

Figure 4. Disease progress curves of 5 potato cultivars representing a range from susceptible to resistant against *P. infestans*. Cultivars were sprayed with reduced dose rates of Shirlan according to Table 1. Single plots of Remarka (24 July) and Agria and Bintje (19 August) were prematurely desiccated (*).

Disease pressure in the Valthermond experiment remained low during the entire growing season and hardly any potato late blight was detected in any of the cultivars. Critical evaluation of the dose rate decision rules based on this experiment was thus rendered futile.

Disease pressure in the Lelystad experiment was high resulting in early detection of potato late blight in the experiment. Disease progress curves are given in Figure 4. Plots were sprayed 11 times before they were desiccated on 29 August. 1 plot of Remarka (24 July) and one plot of both Agria and Bintje (16 August) had to be desiccated prematurely, accounting for a reduction of the average disease severity per cultivar in Figure 4. The total fungicide input over the season per cultivar is equivalent to 4.4 l Shirlan/ha for Bintje, 3.52 l/ha for Santé, 2.64 l/ha for Agria, 1.74 l/ha for Remarka and 0.88 l/ha for Aziza. However, blight control proved not satisfactory for all cultivars tested. During the first week of July, disease pressure was very high due to bad weather and nearby inoculum sources, resulting in a general increase of disease severity for all cultivars but especially for Remarka. Following this event, one severely diseased Remarka plot had to be prematurely desiccated. Similar high disease pressure during the first week of August again caused a sharp increase of disease severity for Remarka, Bintje and Agria. Santé and Aziza plots only got severely infected in late August when maturation set in.

Discussion

Multiple field- and laboratory experiments were carried out to explore possibilities of reducing fungicide dose rates applied to control potato late blight on more resistant cultivars. This approach was adopted to avoid potential problems caused by fungicide wear off and re-distribution. Shirlan was selected because it is the most widely used protectant on the Dutch market. The final goal of the project is to be able to reliably link cultivar specific disease resistance, expressed in each of 5 components of resistance and stored in a database, to a minimal fungicide dose rate providing adequate protection against potato late blight. Considering the preventive nature of most control strategies, infection efficiency (IE) is probably the most important of the five components of resistance largely defining the possibilities for application of reduced dose rates. Since partial resistance, by definition, will not provide plant immunity, disease pressure and possible effects of physiological ageing on the level of partial resistance will also have to be taken into account in future versions of WUR-Blight.

Spray recommendations issued for the reduced dose rate experiment in Lelystad during the first week of July could not be carried out due to bad weather. The crop was thus left virtually unprotected during this critical period. Multiple infections were found shortly after. Nevertheless, epidemic progress was increasingly reduced with increasing Shirlan dose rates following this event and differences between cultivars were evident (Figure 3). Future experiments should however include the possibility of curative measures.

The Lelystad evaluation experiment clearly shows that it is possible to adequately protect more resistant cultivars using reduced fungicide dose rates (Figure 4). Disease pressure in the experiment was high as illustrated by the disease progress curve for Bintje, which was sprayed using the recommended dose rate. However, Aziza and Santé, sprayed with dose rates of 0.08 and 0.32 l/ha, performed well except for the last part of the growing season when maturation set in. Agria and especially Remarka were under-protected. Apparently, resistance ratings from the Dutch national variety list are ill suited as a base for recommending reduced dose rates on more resistant cultivars. A more solid base for dose rate recommendations is urgently needed. A data base comprising information on all 5 resistance components and field performance of potato cultivars, as is being created based on the Wageningen base line experiments, will very likely fulfil this need.

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Monitoring of potato late blight for seed potato production: preliminary field validation

C. CHATOT[1], S. GUTMANN[2], L. LEFEVRE[3] AND S. MEVEL[1]

[1] GERMICOPA R&D, Kerguivarch, F-29520 Chateauneuf du Faou

[2] Fédération Régionale de Défense Contre les Ennemis des Cultures – Bretagne,
BP 80118, F-35701 Rennes Cedex 7

[3] Service Régional de la Protection des Végétaux – Bretagne,
BP 60116, F- 35701 Cedex

Summary

Potato late blight is also a major threat for seed potato production (15 % of total French potato production). Control strategies need constant improvement to maintain a high quality standard for seed certification. Nevertheless for environmental reasons, seven-day routine strategy has to be banned in favour of more integrated control measures. For two consecutive years (2001 and 2002), field trials have been implemented in seed potato crops. Thorough field inspections for late blight and crop monitoring added to official met data (temperature and relative humidity) validated for different environments of field trials were plugged into epidemiological models (Milsol and Guntz-Divoux) in order to deliver field-specific recommendations. Fifteen seed growers have monitored late blight control for seed production with such strategy for 2 seasons. Due to high late blight pressure (2002), there has been no reduction in fungicide use (10 and 8 applications) but very few foliar late blight foci were observed and healthy certified seeds were harvested even from the most susceptible cultivars. Such monitoring of blight control did not interfere negatively with seed crop specific requirements like insect control. Further experiments will attempt to integrate cultivar's genetic resistance into epidemiological models and confirm, under more continental conditions, whether some reduction of pesticide use could be possible with more accurate monitoring.

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Keywords: Monitoring, late blight, potato seed production, field validation.

Introduction

French potato crops cover annually 170 000 ha. Major production basins (ware, industrial & seed) are located in the half-northern part of the country and along the western and southern Atlantic coasts, with a great diversity of agro ecological environments. Potato late blight, *Phythophthora infestans*, remains one of the major threats during the growing season that runs from early April (earliest production) to end October (late maturing starch cultivars). As a consequence, successful production of healthy potato crops relies on chemical protection.

Recently, as a response to ecological concerns, the ware potato industry has strongly influenced potato growers to follow up good agricultural practices (Anon, 2000) where crop protection should implement as many as possible efficient cultural practices limiting chemical inputs. Use of regional warning systems and/or any other DSS for late blight control strategies have been implemented; several field validation trials have been set up with official warning systems (Duvauchelle *et al*, 2001) or with DSSs (Gaucher & Chambat, 2002) in ware and industry production areas.

Seed potato production (15 % of total French potato area) has to comply with strict technical regulations for seed certification: at harvest, seed lots must carry less than 0.2 % of blighted tuber. Beside this criterion, consumer safety is not until now a concern for seed production.

Nevertheless, late blight control relies solely on chemical inputs, usually on a routine basis. Monitoring its overall control on seed crops can be a technical progress for growers who will need, in a near future, to justify their agricultural practices (Anon. 2001).

A collaborative late blight monitoring has been implemented on fields of seed growers who volunteerd in this project in 2001 and 2002. The official warning system was provided by the Service Régional de la Protection des Végétaux-Bretagne (SRPV) and its co-operator with field expertise, Fédération Régionale de Défense des Ennemis des Cultures (FEREDEC) and the support of Germicopa technical advisors.

Methods

Field & Cultivar

On a voluntary base, seven seed growers in 2001 plus eight new participants in 2002 actively contributed to late blight management in collaboration with official services

(SRPV/FEREDEC) and technical support of Germicopa's advisors. Potato fields (one per grower) were located around 2 met stations (in a radius of 10 kms around each station). Met stations were located in 2 different geographical units, one with a rather oceanic climate: 30 kms inlands from the northern coast of Brittany, the other with a rather continental climate. These small size farms are characterised by 70 ha of total cultivated land with 25 % of seed potato production. The observed fields have an average area of 3 ha. The agronomical characteristics of the cultivars grown differ in term of late blight susceptibility (Table 1).

Table 1. Agronomical characteristics of cultivars grown in trial fields in 2001 and 2002.

	Official LB Foliage Score	AUDPC (x 10-4) (2002 data)	Official LB Tuber Score	Growth cycle (in days)
Early Season Ware & Export				
YESMINA	5	1800	2	100
SPUNTA	5	2350	5	100
MARINE	3	3212	5	80
Salad / Firm Flesh				
VIOLETTE	4	2119	5	100
AMANDINE	6	2420	4	80
CHARLOTTE	4	2435	6	100
CHERIE	3	2920	5	80
General Ware & Export				
SUPERSTAR	7	1540	5	120
ATLAS	5	2200	5	140
STEMSTER	5	2378	7	140
SAMBA	5	2398	6	120
ROSANNA	4	2596	4	80

Field inspection and data flow

One month after planting, every trial field is visited twice a week by 2 different inspectors. They retrieve, by fax to the SRPV/FEREDEC, all data concerning the crop and its surrounding waste piles, volunteers, growth stage and late blight occurrence (first attacks) and its development. Growers report to SRPV/FEREDEC, at least once a week or at any relevant climatic event, like irrigation, rain (above 5 mm), local increase of relative humidity and pesticide application (type, timing, dose).

Met data and monitoring

From each geographical unit, an official MétéoFrance met station provides weather data on a tri-hourly basis (temperature and relative humidity). Milsol and Guntz-Divoux models are run with the met data from each region and completed with growers' informations. Late blight risk periods can then be identified and field-specific warning informations and recommendations are submitted to the grower. Forecast data are not integrated in the models but are taken into account for more precise warning information. As a rule, the grower is expected to react as soon as possible after receiving the informations. Fungicide recommendations include active ingredient and dosage; they are also expected to comply with the recommended active ingredient and dosage.

Results

Late blight Epidemic

In 2001, the climatic conditions during early spring have been very cold but dry. Early productions were established at normal timing, planting in January under plastic covers, but limiting temperatures slowed crop growth down. Late blight was first observed early April (10/04). As a consequence, seed growers in the vicinity of early production crops had ideal planting and emerging conditions end of April-early May with no serious threat of late blight. The situation became more critical early June in the surrounding of observed fields but no blight was reported in any of the trial fields. In the more continental unit, planting time was delayed until mid May; no late blight was reported in the area.

In 2002, late blight first attacks have been observed as early as April 16 in earliest crops, with favourable conditions for extension of the epidemic during April and May. Later planted crops, like seed crops, faced high-risk periods at emerging in May (17/05) and during most of the growing season in June. Occurrence of blighted foci developed on more susceptible cultivars first and a high pressure remained until haulm killing. Likely, in the more continental unit, late blight pressure has been higher than usual. First attacks in trial fields happened in the second half of May and the climatic conditions remained favourable for late blight until haulm killing; however only few plants per field were blighted.

Model validation and control effects

In 2001, 7 trial fields have been inspected; 5 were located in the oceanic unit around one of the met stations. Two fields were located in the continental unit with its own met station. Before the launching of the project, late blight pressure has been rather mild. DSS operators and growers have been very conservative, respectively, in their recommendation and reaction. In the oceanic unit, the models indicated the risk of primary attacks (third sporulation generation) end of May, triggering the first spray. No blight was found in any of the fields but indeed in its surrounding. Later in the season, late blight pressure was limited and intervals between applications have been extended. The average number of applications was 9.

In the continental unit, after late planting (end of May), climatic conditions were not conducive to late blight. The models indicated the first risk period early July when the first attacks had already been observed in the vicinity of the trials. The average number of applications has been very low, 5 applications for the moderately susceptible cultivar Charlotte. In both units, harvested tubers were healthy.

The following campaign 2002 has been more challenging because climatic conditions have been more favourable to late blight.

In the oceanic unit, the table 2 summarizes the situation for each trial field. According to the models, the first risk periods occurred mid June (3rd sporulation generation) and late blight was first observed in 3 fields around June 16. The first spray was done, in most of the cases, some 15 days before, because 100 % of the crop had emerged. This is one of the compulsory technical constrains of seed production: the first insecticide protection has to be carried out when 100 % have emerged. Cvs Marine, Spunta and Samba, were the cultivars first blighted. Eight fields out of 11 have experienced late blight spots. For cv Marine fields, late blight monitoring has been difficult at the end of the growing season, but blighted tubers were found in only one field (5 %). Two other occurrences of tuber blight (1%) were observed even in a situation where no foliar late blight had been recorded. The average number of applications slightly increased to 10 compared to the previous campaign.

In the continental unit and according to the models, late blight could potentially appear end of May. It did in the vicinity of one of the observed fields on a refuse pile, on May 27 and later on during the growing stage, some scattered plants have been infected. The first spray has been done on May 21. Though the risks of late blight remained high for most of the growing season, the average number of sprays per field did not exceed 8 with a good control of tuber blight. The short (80 days) growth cycle of cv Charlotte and its less susceptibility to tuber blight probably contributed to the end result.

Table 2. Results of 2002 validation trials (Oceanic unit)

Comparison of Control Strategies, Routine vs Guntz-Divoux and Control Effect, LB incidence on harvested crop

Cultivar	First LB attack	Day first treatment[1]		Chemical Control starting at 70 % emergence[2]	TotalNo App	Blighted foliage at haulm killing (%)	LB Severity in field	Tuber blight (%)
Spunta Amandine	25-6	5-6	R	C,C,C,C,T,C,C,C,C,C,C	11			
			G-D	*T,T,P,P,P,T,P,C,C,P,C,C*	*12*	10	(++)	0
Rosanna Violette	none	19-5	R	C,C,C,C,C,C,C,C,C,C	10			
			G-D	*C,T,C,T,T,T,C,C,P,C,C*	*11*	0	0	0
Yesmina	20-6	23-5	R	C,C,C,C,T,C,C,C,C,C,C	11			
			G-D	*C,P,T,P,S,P,T,T,P*	*9*	5	(++)	0
Charlotte	none	16-5	R	C,C,C,C,C,C,C,C,C,C	10			
			G-D	*C,C,C,C,C,C,C,C,C,C,C*	*11*	0	0	0
Spunta	18-6	16-5	R	C,C,C,C,T,C,C,C,C,C,C	11			
			G-D	*C,C,T,C,T,P,C,C,T,P,C,*	*11*	15	(++)	1
Samba	17-6	23-5	R	C,C,C,C,T,C,C,C,C,C	10			
			G-D	*T,C,T,T,C,C,P,C,C*	*9*	5	(+)	0
Marine	20-6	24-5	R	C,C,C,C,T,C,C,C,C	9			
			G-D	*T,C,T,T,P,P,C,P,C,C*	*10*	30	(+++)	5
Stemster	24-6	15-5	R	C,C,C,C,T,C,C,C,C,C	10			
			G-D	*C,C,P,T,T,T,C,P,P,P,C*	*10*	5	(+)	0
Marine	17-6	20-5	R	C,C,C,C,T,C,C,C,C,C	10			
			G-D	*T,T,T,P,T,P,C,C,C*	*9*	30	(+++)	0
Superstar	none	15-5	R	C,C,C,C,C,C,C,C,C,C	10			
			G-D	*C,C,C,T,T,T,C,C,C,C,C*	*11*	0	0	1
Rosanna Violette	20-6	20-5	R	C,C,C,C,T,C,C,C,C,C	9			
			G-D	*C,T,P,T,T,T,T/P,C,T,T*	*10*	5	(+)	0

1 (70-100% emergence)

2 (T / P: translaminar ; C: contact; S: systemic)R: routine / G-D: Guntz-Divoux

Warning data and growers' responses

The limited number of participants of the first year trial made the flow of information rather easy to handle back and forth, from the growers to the models. For the second year, data flow has been optimised by all means: fax and mobile phones helped keeping up dated all relevant information. The weekly edition (paper or fax version) of specific recommendations for each grower has run for 14 consecutive weeks, starting mid May. It was then the grower's responsibility to follow up the recommendations (time and product). Table 3 gives an indication of the active ingredients that have been used during the season. Most of them have complied with recommended products, slightly more so in the oceanic unit.

Table 3. LB control in 2002 in the 2 geographical units: incidence (%) of active ingredients

Geographical Unit	Average number of applications per trial field	Contact		Systemic	Translaminar	Translaminar (~ Penetrant)
		mancozeb	fluazinam	oxadixyl	dimethomorph, propamocarb-HCl	cymoxanil
Oceanic Unit	10.2 (11 rep)	20	29	1	28	22
Continental Unit	8.3 (4 rep)	27	3	0	21	49

Conclusion and discussion

This project demonstrates that monitoring late blight for potato seed crops is possible. One of the potential constraints of late blight monitoring for this type of potato crop depends on the fact that insecticide treatments have to be planned on routine basis. More field expertise will help solving this handicap.

Growers have followed with interest the course of the project: for those who used to decide field treatments from their office were forced to go back into the field, others confirmed they had good intuition about weather perception and late blight monitoring when comparing their own decision with models' recommendations.

With relevant met data, the models confirmed their accuracy and adaptation for identifcation of late blight risk periods, at least in Brittany. Some adjustment might be necessary in the future to react even better during epidemics. Comparing different control strategies in an one year trial on one site is difficult. We chose the routine schedule (recommended by Germicopa technical service), which is an integrated version of the seven-day spray routine as the reference compared to the models' recommendation. As a consequence, the comparison between the two schemes for chemical input does not show much difference. The initial objective of the project was not to reduce the number of sprays but instead "to harvest healthy tubers from plants protected with the right product, at the correct dose, at the right time and to be able to prove it". This goal has been achieved.

This field trial will be repeated during the 2003 growing season supplemented with a cultivar assessment trial, in order to provide new components for introducing cultivar resistance (or less susceptibility) into the models.

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The authors wish to thank the collaboration of Germicopa Production technical team. Without their co-operation and convincing attitude towards the growers, this project had not been achieved.

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Implementation of the NegFry decision support system in Baltic countries in 1999-2002

M. KOPPEL[1], J.G. HANSEN[2], P. LASSEN[2], I. TURKA[3], G. BIMSTEINE[3] AND A. VALSKYTE[4]

[1]Jõgeva Plant Breeding Institute, 48309 Jõgeva, Estonia
[2]Danish Institute of Agricultural Sciences (DIAS) Department of Agricultural Systems, Research Centre Foulum, DK-8830 Tjele, Denmark
[3]Latvian University of Agriculture (LIA) LV-3001 Jelgava, Latvia
[4]Lithuanian Institute of Agriculture (LIA) Dotnuva-Akademija, LT-5051, Kedainiai, Lithuania

Summary

The current paper gives an overview of the experiment of exportation and adaptation of existing late blight decision support systems (DSSs) between countries. The Danish decision support system for the late blight control NegFry was validated in Estonia, Latvia and Lithuania in the frames of the project "Development of a Decision Support System for Integrated Pest Management in the Baltic Countries" (http://www.ipm-baltic.dk) in period 1999-2002. The results of adaptation of NegFry programme to local varieties and climatic conditions are analysed from the following aspects: timing of the first treatment, number of fungicide applications, late blight incidence at the end of growing season and total tuber yield. NegFry recommendation was compared with untreated control and routine application of the same fungicide at fixed intervals. Efficiency of NegFry was estimated by the effect of reduction of number of fungicide applications on late blight incidence and tuber yield.

Key words: *Phytophthora infestans*, potato late blight, decision support system, NegFry.

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Introduction

The average number of fungicide applications in the Baltic countries has been 2-4, although the probable need has been much higher before the validation period. By the local practice late blight control have been started after the first disease symptoms appeared which enabled reduction of late blight development for some extent, but not the full protection of potato crop. Today is the trend line in addition to the local practice to increase the number of application according to advice from chemical companies. Danish decision support system for the control of potato late blight NegFry (Hansen *et al.*, 1995) gives the forecast of primary attack (initial spray) and recommend subsequent times of fungicide applications during the season. This enables to use optimal number of fungicide applications for crop protection.

This paper describes results of the validation of NegFry in Estonia, Latvia and Lithuania in 1999-2002. Preliminary results and problems in the implementation of NegFry in the three Baltic countries have discussed in EU.NET.ICP meeting in 1999 (Hansen *et al.*, 2000). Classification of late blight resistance of local varieties according to scale used in NegFry, build-up a system for obtaining real time weather data and translation of the programme into local languages were necessary prerequisites before the use of NegFry at farmers level.

Materials and methods

Extended and large plot trials were conducted in the period of 1999-2002. Every year NegFry was validated in Lithuania at Voke-Branch of Lithuanian Institute of Agriculture (three small plot trials), in Estonia at Jõgeva Plant Breeding Institute (two or three small plot trials), in Latvia at Vecauce Experimental Farm of Latvia University of Agriculture (two small plot trials), at Stende Experimental and Breeding Station and Skriveri Research Centre (one trial at both locations). Replicated 4-row plots in randomised order were used for each treatment where disease scoring and yield estimation was done in two central rows only in these trials. Large plot trials in one replication were conducted at Priekuli, Saldus and Bauska Units of State Plant Protection Service (Latvia). All together results of 49 trials are analysed in the current article. There were conducted more trials in each of three countries every year. Due to technical problems with Hardi Metpole weather stations and some constraints and mistakes made during the conduction of the trials there were serious weather data gaps in some locations. These locations and trials were rejected from the current analyse.

Varieties of different resistance categories (susceptible, moderately susceptible and moderately resistant) were used (Table 1). Varieties originating from the local breeding programmes were used together with varieties of Dutch breeding companies. Variety Sante was classified as moderately resistant according to resistance description given by a breeder in the first three years. According to the results of disease observation trials, resistance of the variety Sante was reclassified as moderately susceptible for 2002.

Some upgrades of NegFry programme were made in validation period. A PC-based programme NegFry99 version 5.11 was used in 1999. The programme was amended with possibility to use historical weather data from the nearest ordinary weather station for the year 2000. An Internet based NegFry with weather forecast for forthcoming four days was used in 2001 and 2002.

Table 1. Varieties used in NegFry validation trials

Location	1999	2000	2001	2002
Jõgeva	Adora (B1*)	Adora (B1)	Berber (B1)	Berber (B1)
Jõgeva	Ants (B2)			Piret (B2)
Jõgeva	Anti (B3)	Anti (B3)	Anti (B3)	Anti (B3)
Vecauce	Mutagenagrie (B1)	Mutagenagrie (B1)	Mutagenagrie (B1)	Mutagenagrie (B1)
Vecauce	Sante (B3)	Sante (B3)	Sante (B3)	Sante (B2)
Stende	Sante (B3)	Sante (B3)	Sante (B3)	Sante (B2)
Skriveri	Sante (B3)	Sante (B3)	Sante (B3)	
Priekuli	Sante (B3)	Sante (B3)	Sante (B3)	Sante (B2)
Bauska	Sante (B3)	Sante (B3)	Sante (B3)	Sante (B2)
Voke	Venta (B1)	Venta (B1)	Venta (B1)	Venta (B1)
Voke	Mirta (B2)	Mirta (B2)	Mirta (B2)	Mirta (B2)
Voke	Aistes (B3)	Aistes (B3)	Aistes (B3)	Aistes (B3)

** - resistance categories of the varieties to late blight: B1 – susceptible, B2 – moderate susceptible, B3 – moderate resistant.*

The methods for validation of NegFry were based on the trial guidelines defined for validation of late blight decision support systems in EU.NET.ICP in 1999 (Jörg, Kleinhenz, 1999). NegFry recommendation was compared with untreated control and routine application of the same fungicide in all the trials. The routine programmes consisted of mancozeb (Dithane DF, Rohm & Haas) 2,5 kg/ha at 10-day intervals (1999-2000) and fluazinam (Shirlan, Zeneca) 0,4 l/ha at 10-day intervals (2001-2002). Translaminar fungicide dimethomorph (Acrobat Plus, Cyanamid) 2.0 kg/ha at 12-day intervals was used in some trials of routine treatments for first two sprays in 1999. Applications started at row closing in late June to mid July depending on crop development and continued at regular intervals until haulm desiccation in mid September.

Weather data were recorded by use of Hardi Metpole in-crop weather stations established in trial area. According to NegFry recommendation fungicide applications were carried out following advises given by the programme or when an advice was likely to pass the threshold value the next day. Some cases happened when sprayings were impossible at a given day because of continuous rain or heavy wind, then the treatment was made at the first opportunity. Sprayings were carried out with bicycle sprayers equipped with Hardi flat spray nozzles.

Results and discussion

Variation in disease severity. NegFry was validated under varying conditions of late blight infection pressures. The accumulated risk value as measured by the NegFry decision support system is a good measure of the conditions suitable for the spread of late blight during the course of growing period. The growing seasons of 1999 and 2002 were characterised by dry and hot weather with low accumulated risk values (ARV). These years should be regarded as years of late blight depression. Rainy growing periods with moderate temperature in 2000 and 2001 were characterised by high accumulated risk values (Figure 1). In both of these years conditions were suitable for the spread of late blight. The highest accumulated risk value was recorded in Saldus Latvia in 2001 (819), the lowest value in Voke, Lithuania in 2002 (259). Accumulated risk values are consistent with the levels of foliar blight in untreated control plots at the end of growing period.

Timing of the first spray. Timing of the first spray was determined by the number of days between NegFry recommendations for the first treatment and appearance of late blight in the trial area. The data from 43 trials are used. Late blight infection did not occur in trials in Voke in late blight unfavourable years of 1999 and 2002 and these trials were not used for current analysis. The time span between predicted and observed date of first appearance ranged from 6 days before to 30 days after. In four trials (Bauska in 2001, Vecauce Sante and Mutagenagrie in 1999 and Sante in 2001) late blight was found before the NegFry recommendation for the first treatment. In trial at Skriveri in 2001 the difference was only 2 days, there the crop had to be already infected, but visible symptoms were not established. The timing of the first spray given by NegFry was too late in these trials. The late timing could be caused by the late planting of the trials relative to crop in the region, as it is also mentioned for the NegFry validation trials in the Netherlands in 1999 (De Visser, Meier, 2000). Inoculation originating from soil infection could also lead to early infection. In five trials (Sante in trials at Vecauce in 2000, Stende 2001 and Bauska 2002; and Anti in trials at Jõgeva in 2000 and 2002) NegFry recommendation was given 29-30 days before the late blight was found in the trial area. Timing of the first spray was too early in these trials. The long time span could be caused by the differences in local populations of *Phytophthora infestans* and race specific resistance of varieties used in these trials. In the majority of the trials (33 out of 43 or 76,7 %) NegFry gave timely recommendation, the time span ranging from 5 to 23 days (Figure 2).

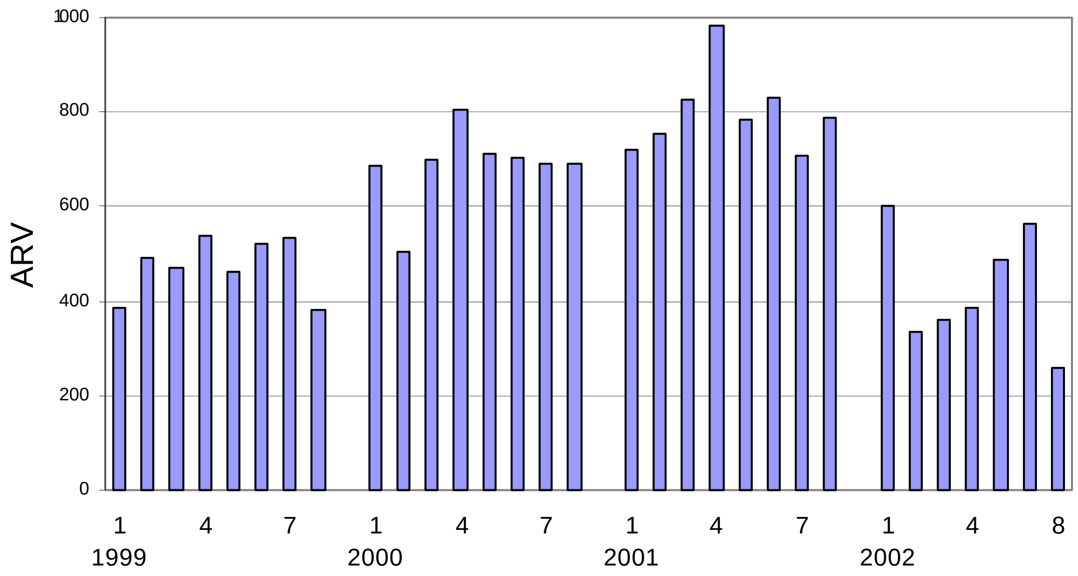

Figure 1. Accumulated risk values (ARV) at trial locations, 1999-2002.
Locations: 1- Jõgeva, 2 – Bauska, 3 –Priekuli, 4 – Saldus, 5 –Skriveri, 6 – Stende, 7 – Vecauce, 8 - Voke

Number of fungicide applications. Results from 45 trials are used. Three trials from Voke in 2002, where Hardi Metpole broke down in mid of spraying season and the trial with an early variety Mutagenagrie in Vecauce in 2000, where no treatments were made are excluded from the current analyse. Routine fungicide applications started in mid June, early July at row closing and continued at 12- (dimethomorph) or 10-day (mancozeb and fluazinam) intervals up to the date of desiccation. The number of treatments made in the NegFry variants depended from the time spans between individual applications and the length of growing period of the varieties. Thirty percent of applications were saved by use of NegFry in average (Table 2). The reduction is in the same level with results of Negfry validation trials in Ireland (Leonard, *et al.*, 2002). Biggest reduction in fungicide use was achieved in trials carried out in conditions of late blight depression. The number of applications was reduced from 5,4 to 2,2 in average of 11 trials where untreated control was not infected by late blight. NegFry reduced fungicide treatments to 2,7 times in 1999 and 2002 years of late blight depression, when treatments were reduced for more that 40 %. Lowest reduction was in late blight favourable year of 2001. Almost no reduction was achieved in trials with susceptible (B1) varieties, where only 0,2 treatments were saved. NegFry recommended even more treatments than routine regime in trials conducted at Jõgeva with susceptible (B1) varieties Adora in 2000 and Berber in 2001. In average 1,4 and 1,2 applications were saved in moderately susceptible and moderately resistant varieties respectively.

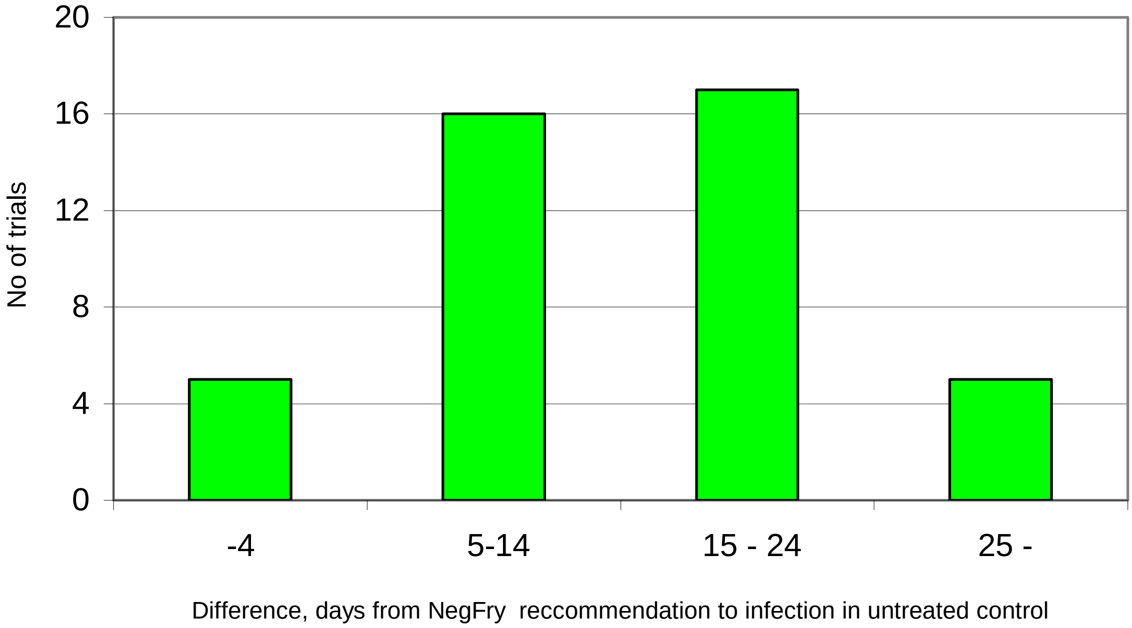

Figure 2. The time span between predicted date for the first treatment and observed date of first appearance of late blight infection in the trial area.

NegFry was superior compared with routine treatment regime in more resistant varieties and in conditions of late blight depression, and had almost no advantages in susceptible varieties and in late blight favourable conditions.

Table 2. Average number of fungicide applications in NegFry and routine treatment regimes.

	No of trials	No of treatments		Reduction, %
		NegFry	Routine	
Year				
1999	13	2.7	5.3	49.3
2000	8	4.5	5.6	20.0
2001	12	4.1	4.7	12.5
2002	12	2.7	4.6	41.8
Variety resistance class				
B1	6	4.3	4.5	4.4
B2	7	3.0	4.4	32.3
B3	21	3.9	5.1	25.0
Trials without infection	11	2.2	5.4	59.6
Total	45	3.4	5.0	30.0

Effect on foliar blight. Effect of NegFry and routine treatment regimes on late blight incidence is analysed only in these 34 trials where untreated control was infected. Both fungicide treatment regimes significantly reduced the incidence of foliar blight at the end of the season compared with the untreated control in all the trials (Table 3). Infection at NegFry regime was slightly, but not significantly higher.

Table 3. Late blight infection at the end of growing season, measured as percentage of infected leaf area at untreated control, NegFry and routine treatment regimes.

	No of trials	Late blight infection, %		
		NegFry	Routine	Untreated
Year				
1999	5	0.8	0.8	11.9
2000	8	19.2	14.1	77.0
2001	12	12.9	11.6	64.0
2002	9	2.9	3.2	59.1
Variety resistance class				
B 1	6	8.5	7.5	84.3
B 2	7	5.2	4.5	54.6
B 3	21	12.5	10.0	51.7
Total	34	9.9	8.4	58.1

Effect on tuber yield. Tuber yields varied considerably between the years and locations. All fungicide treatments resulted in significantly higher yield compared with the untreated control (Table 4). There were no significant differences of tuber yield comparing 10-day routine and NegFry treatments.

Table 4. Tuber yield at untreated control, NegFry and routine treatment regimes.

	No of trials	Tuber yield, t/ha		
		NegFry	Routine	Untreated
Year				
1999	5	41.5	41.0	31.8
2000	8	49.7	49.4	40.8
2001	12	35.1	34.5	25.4
2002	9	43.0	42.8	38.0
Variety resistance class				
B 1	6	43.5	43.7	33.9
B 2	7	38.8	39.7	34.2
B 3	21	41.9	40.9	32.8
Total	34	41.6	41.2	33.3

Efficiency of NegFry use. The criteria of success for the DSS validation is defined as at least the same control effect as the use of a routine schedule, and at the same time, with less use of fungicide (Hansen et al, 2002). In the current paper success criteria is determined as at least the same late blight control effect as the use of routine schedule, but with less use of fungicides, or better late blight control effect compared with routine schedule. Better late blight control could be achieved with proper timing of fungicide applications. NegFry was effective in 16 trials where the same late blight control effect was obtained with less number of applications, in 6 trials where better late blight control was achieved with less number of applications, in 2 trials where better control was achieved with the same number of applications and in 2 trials where better control was achieved with bigger number of applications (Figure 3). In conditions of high disease pressure in trials carried out at Jõgeva (Estonia) in 2000 and 2001, more treatments recommended by NegFry resulted in better disease control in susceptible varieties. NegFry was inferior in eleven trials resulting in higher incidence of late blight at NegFry treatment regime compared with routine treatment. In total NegFry was superior compared with routine treatment in 67,6 % trials.

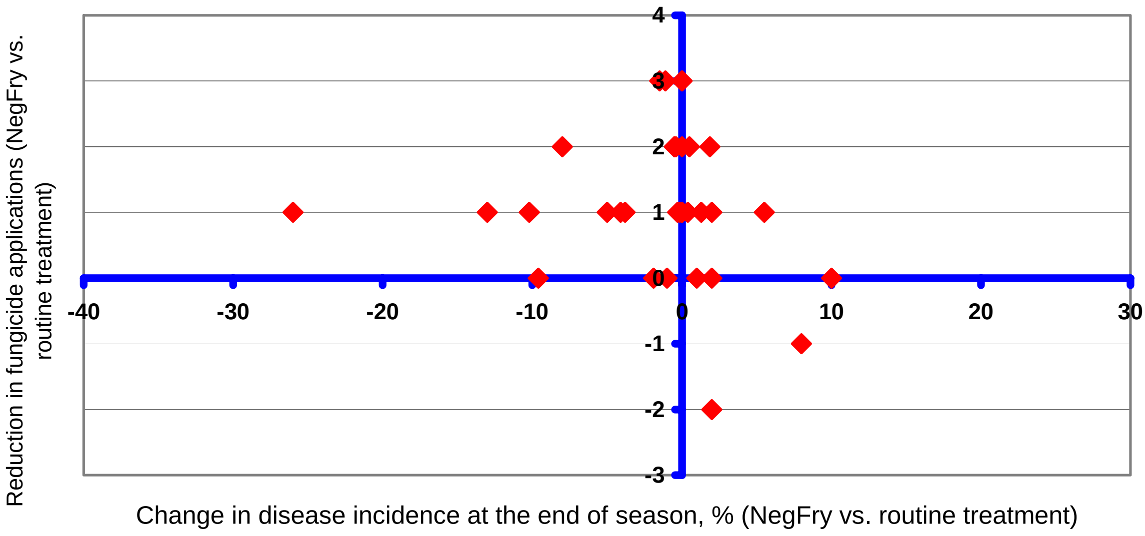

Figure 3. Relations between reduction of the number of fungicide applications and changes in late blight incidence at the end of growing season, NegFry versus routine treatment regime.

Tuber yield and cost efficiency are more important parameters for farmers than late blight incidence in the field. Success criteria in economical terms could be set as at least the same net income with less use of fungicide or higher net income with at least with same use of fungicide. Tuber net yield is used as an estimate for cost efficiency of treatment regime. Net yield is total yield decreased for a weight of tubers equal to cost used for fungicides and sprayings. NegFry was effective in 23 trials:

16 trials where higher net yield was achieved with lower number of applications;

5 trials where higher net yield was achieved with the same number of applications;

one trial where the same net yield was achieved with lower number of applications;

one trial where higher net yield was achieved with higher number of applications (Figure 4).

NegFry was inferior in 9 trials where reduction in fungicide use resulted in lower net yield and in one trial, where the same yield was obtained with higher number of fungicide applications. Both treatment regimes were equal in one trial with the same number of sprayings and same net yield. In total NegFry was superior compared with routine treatment in 70.6 % trials.

Analysing the trials where NegFry was inferior, one could propose following explanation:

Some treatments were made 2-3 days later than the moment of NegFry recommendation because of rainy periods. Infection got established in this period and as late blight control was not achieved with following treatments, it resulted in higher disease infection and lower yield. This illustrates the importance of a proper local weather forecast and a need for careful following it. In some trials disease incidence and yield were at the same level, with small, insignificant differences. NegFry was slightly, but insignificantly, inferior in these cases.

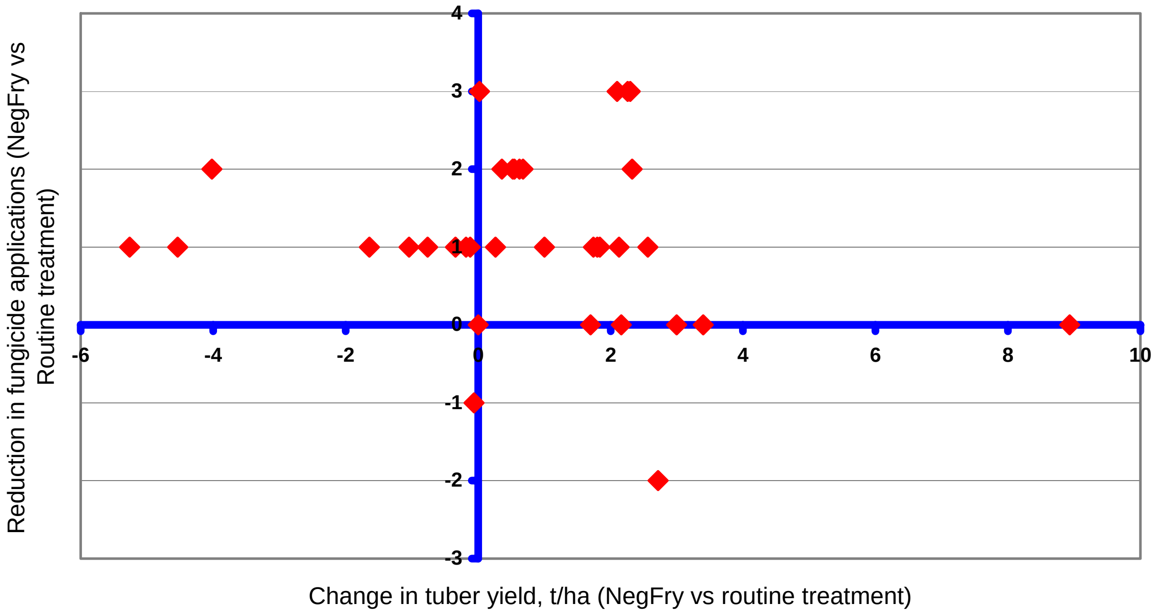

Figure 4. Relations between reduction of the number of fungicide applications and tuber net yield, NegFry versus routine treatment regime. Net yield is obtained from total yield decreasing it for a weight of tubers equal to cost used for fungicides and sprayings.

Conclusions

In general the DSS use resulted in a reduction in fungicide treatments with sufficient control of the fungus. In the majority of the trials (33 out of 43 or 76.7 %) NegFry gave timely recommendation, the time span between NegFry recommendation and appearance of late blight in the trial area ranging from 5 to 23 days.

Thirty percent of applications (1.6 sprays) were saved by use of NegFry on average. In reduction of fungicide treatments NegFry was superior compared with routine treatment regime in more resistant varieties and in conditions of late blight depression, and had almost no advantages in susceptible varieties and in late blight favourable conditions.

NegFry was more effective compared with routine treatment in terms of late blight control and tuber yield in 67.6 and 70.6 % trials respectively.

The results of NegFry use could be improved by having proper local weather forecast. The results are also improved together with growth of experience of people working with the DSS.

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The rational use of fungicides in combination with cultivar resistance

P. GANS

NIAB, Cambridge CB3 0LE

Summary

Evidence is reviewed that cultivar resistance to late blight can make a substantial contribution as a partial substitute for fungicide. In order to do so, cultivar resistance evaluation must be reliable and limits of confidence defined. An evaluation of a simple approach to integrating cultivar resistance with a decision support system was made.

Key words: *Phytophthora infestans*, cultivar resistance, integrated disease management, decision support systems.

Introduction

Plant breeders have been releasing late blight resistant cultivars since the early 20th century. Whereas resistance based on single genes, conditioning a hypersensitive response, has proven to be not durable, there are many examples of cultivars with field resistance, which have endured for many decades. Contemporary breeding programs continue to produce cultivars with potentially durable late blight resistance. In order to integrate cultivar resistance with a decision support system, cultivar resistance evaluation data must be reliable. Cultivar resistance may be integrated by delaying the trigger for treatment advice or by making fungicide applications at the same time for all cultivars but reducing the rate for more resistant cultivars. This paper reviews evidence that cultivar resistance can make a substantial contribution to crop protection as a partial substitute for fungicide. Variation between years for cultivar resistance evaluations occurs routinely and data are presented and discussed. PLANT-Plus (Plantsystems Ltd) is a decision support system providing treatment advice and a simple set of adjustments to fungicide rates, taking late blight cultivar resistance into account, applied in response to treatment advice or at fixed intervals was evaluated.

Materials and methods

Field experiments were located in Trawsgoed, Wales where rainfall is high or Cambridge where daily irrigation in 1991, 1992 and 1993 and accurately controlled mist irrigation in 2000 and 2001 ensured late blight development. Plots were 35 (5 rows of 7) or 30 (3 rows of 10) and separated by fallow pathways. A plant in the center was protected from fungicide and inoculated either by spraying with a zoospore suspension or by placing an infected pot plant adjacent to it. In 1991, 1992 and 2000 the response of late blight to varying fungicide rates or intervals between applications was studied for a range of cultivars representing a range of resistance levels. In 1991, 1992 and 1993, 12 cultivars were evaluated at Trawsgoed under identical conditions as the other field experiments. In 2001 an experiment in Cambridge compared a susceptible cultivar (Russet Burbank) with the full fungicide rate with an intermediate (Nadine) and a moderately resistant (Cara) cultivar for which the rates was speculatively reduced. The fungicide treatments were Invader (7.5:66.7% w/w dimethomorph and mancozeb) at 2, 1.5 and 1 k/ha respectively. Treatments were made at 10-day intervals or in response to the PLANT-Plus decision support system.

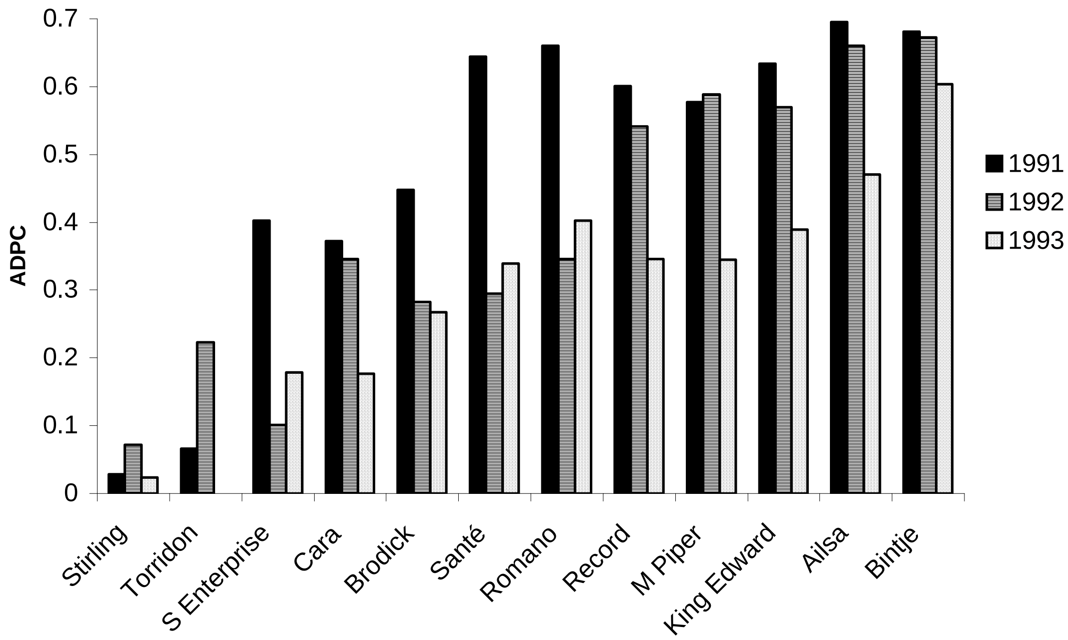

Figure 1: Area under disease progress curve (ADPC) in *P. infestans* inoculated plots for 12 varieties and 3 years.

Results

Cultivar resistance

Figure 1 shows observations of late blight in *P.infestans* inoculated plots and illustrates typical variation seen in cultivar resistance evaluations between years. The 1991 epidemic appeared most aggressive and placed Romano and Santé amongst the more susceptible cultivars and S. Enterprise and Cara, usually among the more resistant cultivars appeared to be relatively more susceptible compared to Stirling. Stormont Enterprise appeared more resistant in 1992 but Cara did not. A similar difference can be seen at the susceptible end of the scale where late blight was appreciably less in 1993 than in 1991 for King Edward, but for Bintje the difference was much smaller. A potential source of cultivar and year interactions is the effect of seed age on the stage of development when the epidemic occurs. In order to produce plots at different stages of development plots were planted with seed, which had been artificially aged by storage in a warm green house. A third treatment consisted of planting plots three weeks later than the other plots. Figure 2 shows the observations for late blight and the treatments appeared to have had little effect in King Edward (susceptible) and Cara (moderately resistant). In Record (moderately susceptible) and in Stirling (resistant) progressively more blight occurred in plots, which were older at the time of infection.

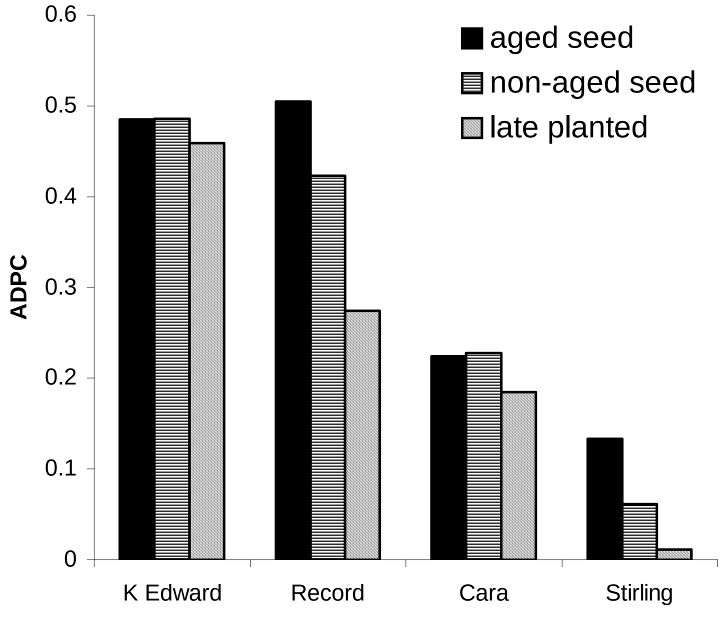

Figure 2: The effect of planting aged and non-aged seed and late planting ADPC in 4 cultivars

Varying fungicide rates and intervals between applications

Response curves to varying fungicide rates of Dithane 945 (80% w/w mancozeb) for 4 cultivars are shown in Figure 3. An exponential curve model (equation 1) accounted for 97.3% of the variation.

$$y = a_{cv} + b_{cv} R^{x} \qquad (1)$$

y = disease; x = fungicide rate

(separate parameters a and b are estimated for each cultivar, whereas the parameter R is common to all cultivars)

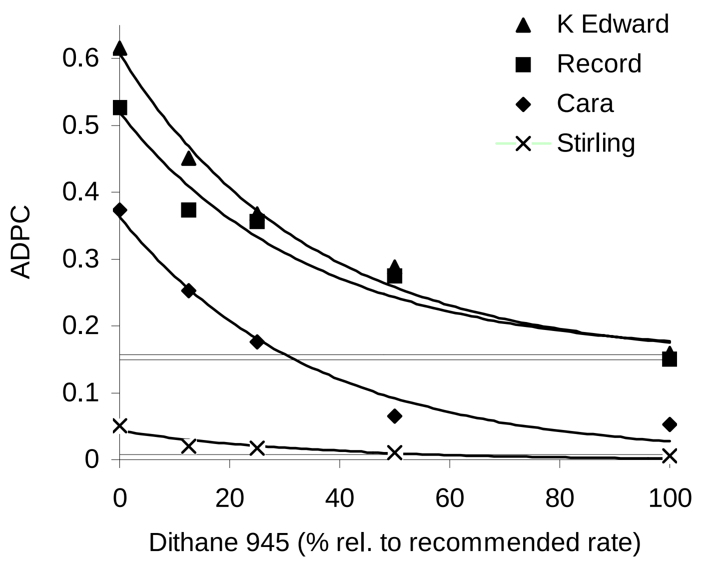

Figure 3: The relationship between the effects of fungicide application rate and cultivar resistance on late blight. The curves are the predicted values derived by fitting exponential curves for each cultivar.

At the full, recommended application (1.7 k/ha) the slopes of the curves are nearly horizontal and for Record (moderately susceptible) and King Edward (susceptible) an appreciable amount of blight indicated that protection was incomplete. The slope suggests that further increases in fungicide would not provide much added protection. For Cara (moderately resistant) the curve indicates that good protection might be achieved at appreciably lower rates. The near horizontal slope, even at lower rates, suggests that protection would still be robust, because small variations in the rate, for example as a result of operator error, would cause little change in the amount of predicted blight. Little blight developed even on untreated plots of Stirling (resistant) and consequently the differences between the effects of fungicide rate were small.

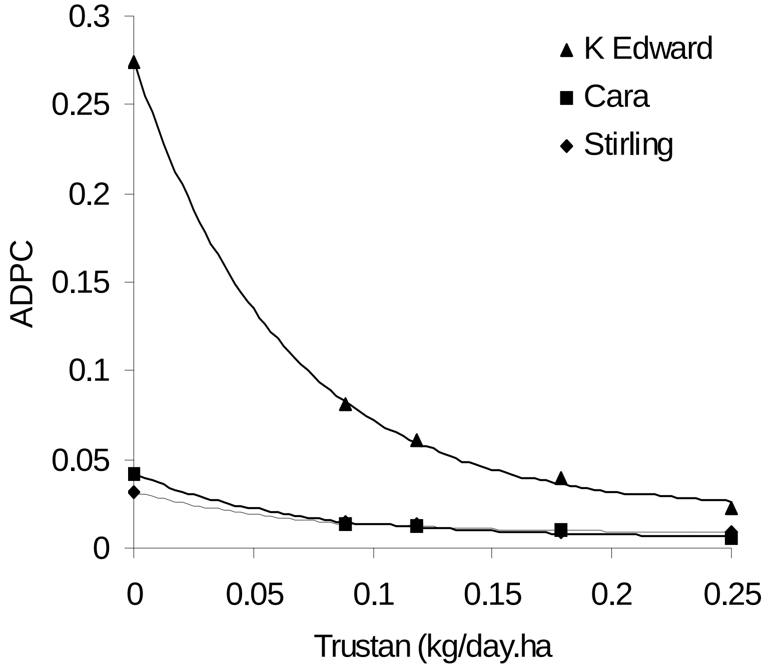

Figure 4: The effect of varying intervals between fungicide applications and cultivar resistance on late blight. The intervals of 10, 14, 21 and 28 days correspond to Trustan at 0.250 , 0.178, 0.119 and 0.090 kg/ha.day respectively. The curves are the predicted values derived by fitting exponential curves for each cultivar.

The effect of varying intervals between applications of Trustan (3.2: 56:, 8% w/w cymaxonil, mamncozeb and oxadixyl) is shown in figure 4. The fungicide was applied at the recommended rate of 2.5 kg/ha and at 10, 14, 21 and 28 intervals. This may be re-interpreted as applying the fungicide at 0.250 , 0.178, 0.119 and 0.090 kg/ha.day. Similar exponential response curves, showing the same characteristics as for varying fungicide rates, could be fitted to the observations of late blight expressed as ADPC (Figure 4). It is likely that there will be greater fungicide inefficiency at larger intervals as a result of unprotected new growth and gradual loss of deposited fungicide over time, compared with the same amount of fungicide applied at lower fungicide rates and with shorter intervals. Figure 5 shows the same response curves as in figure 4, but a second curve is shown for each cultivar, which is the result of changing the model parameters to illustrate the effect of this improved efficiency if the rate of application had been changed instead of the interval. The varying intervals curves were derived by reducing R (equation 1) by 2%.

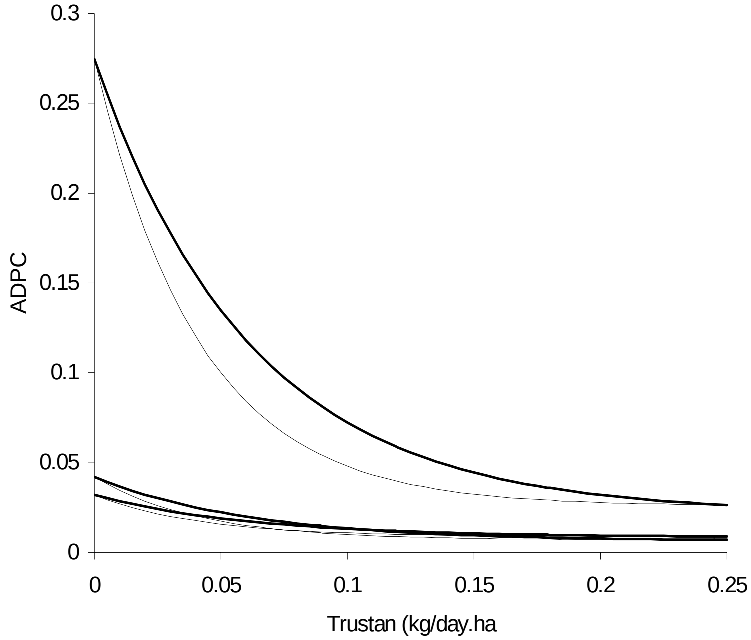

Figure 5: The effect of varying intervals between fungicide applications and cultivar resistance on late blight. The response curves are those shown in figure 4. A second curve, lighter than the first, is shown for each cultivar, illustrating expected greater fungicide efficiency as a result of varying fungicide rates instead of intervals.

Decision Support System

PLANT-Plus triggered 9 fungicide treatments on 9, 16, 23 July, 2, 9, 17, 21 August and 10 September, 2 more than the number of treatments at 10 day intervals. High-risk periods were artificially created on 24-30 July, 16-18 August, 27-28 August and 2-11 September with accurately controlled mist irrigation. Little blight developed in any of the plots despite the proximity of fungicide efficacy trials which included unprotected plots of a susceptible cultivar which were 98% destroyed by late blight by 1 September. Nadine showed symptoms of *Verticillium* wilt (caused by *V. dahliae*). No distinction was made between necrosis as a result of *V. dahliae* or *P.infestans*. Field observations on 2 September are presented in Table 1.

Table 1: The effect of fungicide in response to PLANT-Plus treatment advice or at 10 day intervals on the amount of necrotic tissue in 3 cultivars (%).

Cultivar	Invader	PLANT-Plus	10-day interval
Russet Burbank	2 k/ha	1.4	2.6
Nadine	1.5 k/ha	65.0	60.0
Cara	1 k/ha	0.6	0.8

Although differences were not statistically significant, there appeared to be more late blight in Russet Burbank with 2 k/ha Invader than in Cara with 1 k/ha. For both these cultivars there appeared to more late blight in plots treated in response to PLANT-Plus.

Discussion

The variation between years for cultivar evaluations shown in Figure 1 is typical of those seen at NIAB over many years. In many instances it appears improbable that variation in R-gene virulence is the cause. Although the trials are artificially inoculated, naturally occurring populations may also infect plots. Observations of the effects of planting aged seed or late planting support the view that environmental as well as genetic causes may contribute to the observed variation. Additionally there is concern that genetic variation of the pathogen may increase in the future (e.g. Flier 2001). There is a need to define the limits of confidence of cultivar resistance evaluation data, if they are to be used reliably in decision support systems.

The effects of varying fungicide rates (Figure 3) and intervals between application (figure 4) in combination with a range of cultivars with different levels of late blight resistance, could be described consistently with exponential regression models using a wider set of experimental data then described in this paper. The model has been further developed as a response to 2 variables, fungicide rate and cultivar resistance, expressed as a value on a scale from 1 to 9 (equation 2). This establishes a quantitative relationship between the effects of fungicide rate and cultivar resistance.

$$y = a + bR^{x_1} + cx_2 + dR^{x_1}cx_2 \qquad (2)$$

y = disease; x_1 = fungicide rate; x_2 = cultivar resistance

The conclusion from these studies was that the potential contribution from cultivar resistance was substantial. Lower fungicide rates in combination with moderate resistance appeared to give more robust protection than higher rates with low resistance.

In the light of these studies the speculative reductions chosen for the experiment comparing treatment in response to PLANT-Plus and at fixed intervals were conservative. Slightly more late blight developed with fungicide at fixed intervals than in response to PLANT-Plus, consistent with the greater number and timely targeting of applications. Despite intense pressure from near-by, infected plots, good protection was maintained with 50% of the recommended fungicide rate on Cara.

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Seventh Workshop of an European Network for development of an
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Observed changes in blight epidemics and their consequences for blight control during the latest decade in Finland

A. HANNUKKALA[1], A. LEHTINEN[1] AND A. RAHKONEN[2]

[1] MTT, Agrifood Research Finland, Plant Production Research, FIN-31600 Jokioinen
[2] Potato Research Institute, Ruosuontie 156 Lammi
asko.hannukkala@mtt.fi, ari.lehtinen@mtt.fi, anne.rahkonen@petla,fi

Summary
The onset and development of potato late blight epidemics was surveyed in variety trials and untreated control plots in fungicide trials during 1983-2002 at five locations in Finland and compared to related historical data collected in 1933-62. In Southern parts of the country the frequency of blight years has not changed. In Northern Finland blight was very rare during 1933-62 but in 1990's it was present most seasons. During 1990-2002 onsets of epidemics became one month earlier than before while the apparent infection rate was not changed remarkably during this period. The changes in epidemic development were similar in different potato cultivars. As a result of earlier epidemics the sales of blight fungicides was increased almost 4 fold compared to 1980's. The observations indicate that the increase in soil borne inoculum sources has an important impact on the onset of epidemics.

Key words: Potato, Potato late blight, *Phytophthora infestans*, epidemiology, fungicides

Introduction

Epidemics of potato late blight in Finland have been reported as early as in 1847. The disease caused considerable yield losses in early decades of 1900's approximately once in ten years (Mäkelä 1966). During the period 1931-62 late blight caused significant yield losses one year of three in Southern Finland while the disease hardly ever appeared before frost had defoliated the crop in Northern parts of Finland. During this period application of fungicides against potato late blight was not included in cultural practises (Seppänen 1971).

After the introduction of dithiocarbamates and other fungicides during 1960's blight seemed to be in control and not much attention was paid on the disease until the end of 1980's. The appearance of metalaxyl resistance in population (Hermansen *et al.*, 2000) and migration of the new blight population along 1990's (Spielman *et al.*, 1991) raised the blight again as major problem in potato production. The aim of this study is to point out the observed changes in blight epidemics and their impact on fungicide use from early 1980's to 2002 in comparison to 1933-62 in Finland.

Material and methods

The observation dates of the first potato late blight symptoms in untreated susceptible potato variety (mostly Bintje) at five locations in different parts of Finland in 1983-2002 (Ruukki, Ylistaro, Maaninka, Lammi and Jokioinen) were compared to those reported by Seppänen (1971) at the same locations during period 1933-62. Also the number of years when blight was not present at all was compared between the respective observation periods.

The dates of the appearance of first blight lesions and development of the epidemics measured as disease progress curves and apparent infection rates in cultivars Bintje, Asterix, Saturna and Kardal in untreated plots at Jokioinen were compared between years 1991-2002. Unfortunately cultivars except Bintje were not included each year in these trials.

The sales of late blight fungicides were collected from the statistics published by Hynninen and Blomqvist (1986-1999) and Londesborough *et al.* (2000). The theoretical number of fungicide applications was calculated by dividing the number of hectares possible to protect by the highest on label rate of fungicides sold and by the total potato growing acreage.

Results

The first observations of potato late blight in period 1933-62 fluctuated from the beginning of August to beginning of September. In Northern region (Ruukki) there were blight epidemics only occasionally while in Southern parts the frequency of blight epidemics was nearly the same as in 1993-2002 (Seppänen 1971).

During the period 1990-2002 the average date of the first observation was shifted 2-4 weeks earlier compared to that in1933-1962 or 1980's (Fig. 1). During 1990-2002 there were only 3 years when blight was not present in Northern and 1-2 years in Southern Finland respectively (Table 1).

Table 1. Proportion of years and the average date of the first observation when potato late blight was present in five locations in Finland in 1933-62 and 1993-2002

Location	Blight years %		First observation		Difference
	1933-62	1993-2002	1933-62	1993-2002	days
Ruukki	30	80	20.8.	7.8.	-13
Ylistaro	60	80	24.8.	8.8.	-16
Maaninka	70	80	16.8.	2.8.	-14
Lammi	87	80	15.8.	24.7.	-22
Jokioinen	60	90	17.8.	22.7.	-26

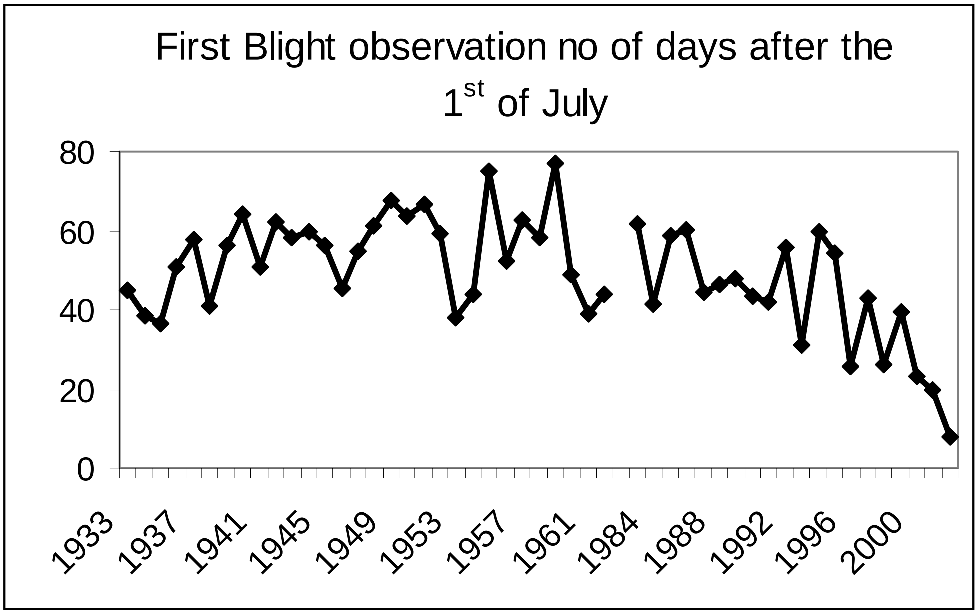

Figure 1. The first observation of potato late blight in days after July the 1st during 1933-62 and 1983-2002 in average of the five observation locations in Finland.

The shift towards earlier epidemics during 1990's and 2000's in variety trials in susceptible cultivar 'Bintje' at Jokioinen is obvious (Figure 2) and the tendency is similar in all varieties included in the experiments. The estimate of apparent infection rate from 1% to 90 % defoliation was not changed during the period. Occasional epidemics with very high apparent infection rate have been recorded also in 1980's and 1933-1962 (Seppänen 1971).

Due to the earlier epidemics along 1990's the use of late blight fungicides has remarkably increased. Until 1960's practically no fungicides were used against potato late blight in Finland. In 1980's the amount of fungicides sold yearly could cover 1 spray for 80 % of the total potato area. In the end of 1990's the fungicides sold provided almost four sprays for the total potato area (approximately 30 000 ha) in Finland (Figure 3)

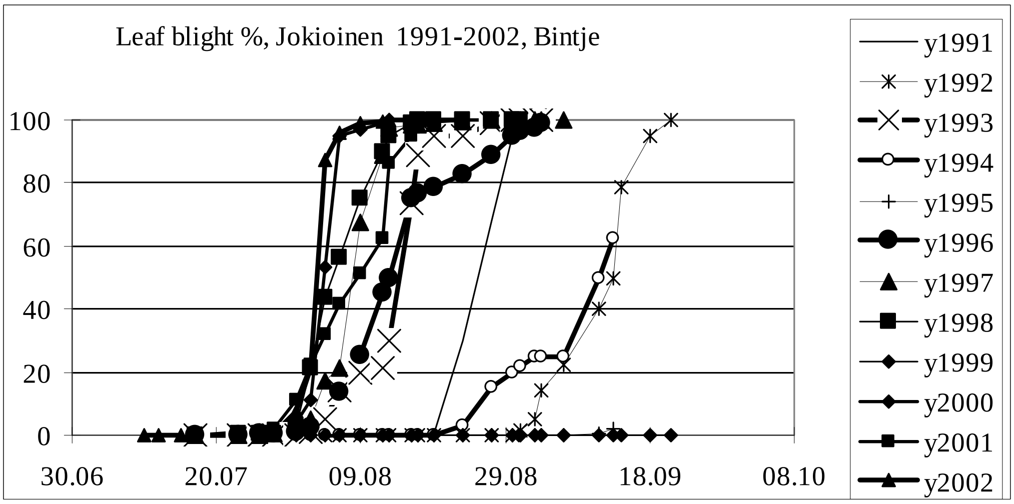

Figure 2. The disease progress curves of potato late blight in Jokioinen at susceptible cultivar 'Bintje' in 1991-2002 measured as defoliated leaf area.

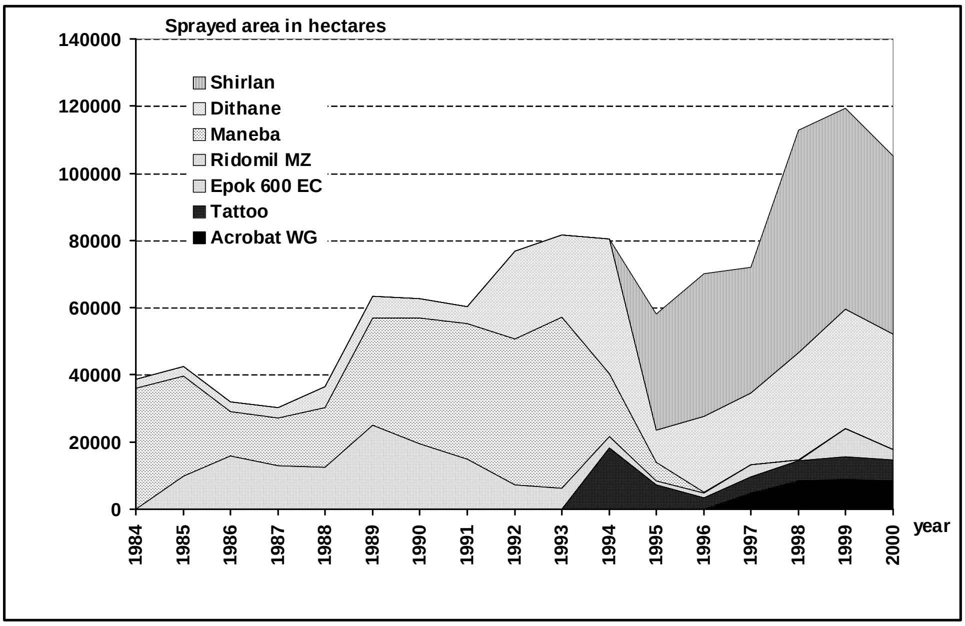

Figure 3. The sales of potato late blight fungicides in Finland 1984-2000 and the theoretical coverage of protected area in hectares by on label dosage.

Discussion

The observations made in experiments and potato fields show that blight epidemics have become earlier and more frequent during 1990's than before in Finland. This coincides with the migration of A2 mating type and the possibility of oospores to provide a new component for primary inoculum sources (Hermansen *et al.*, 2000).

The climatic factors certainly can explain the variation in epidemic development between individual years and locations as described by Zwankhuizen and Zadoks (2002). The regular shift towards earlier epidemics cannot be explained by climate alone and it is very probable that the phenomen is somehow connected with the soil borne inoculum.

Conclusions

Two major changes in blight epidemics could be detected. In Northern Finland the epidemics have become more prevalent and the onset of epidemics have became earlier in all parts of Finland. This has resulted in increased use of late blight fungicides. The obvious reason for the development is the soil borne inoculum component. Much effort should be paid to resolve and model factors affecting soil derived epidemics to keep the dsease in control without increaing the use blight fungicides.

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Validation of integrated control strategies including Guntz-Divoux based DSSs and cultivars

D. MICHELANTE[1], D. HAINE[1] AND A. VERLAINE[2]

[1] Agricultural Research Cente, Wallonia

[2] PAMESEB asbl.

Rue du Serpont, 100, B-6800 Libramont, Belgium

Summary

In Wallonia, late blight warnings are based on Guntz-Divoux epidemiological model. The model parameters are fixed for susceptible cultivars like Bintje. The aims of these experimentations were to validate the model for Bintje, to assess the effects of modifying the thresholds for the prediction of main contamination period and to evaluate the effect of doses reduction according to cultivars resistance in order to reduce the amount of fungicides applied. Results validate the model for Bintje and confirm that an additional reduction of treatments could be possible on less sensitive varieties (Desiree). Different reductions of doses are possible when epidemiological conditions are not too conducive. Nevertheless, in all the cases, when the climatical conditions are favourable and inoculum level is high, conditions generally observed at the end of the season, permanent protection is necessary. Extensive reduction of protection can be achieved with resistant cultivar but rapid overcoming of resistance is to be expected if R genes are involved.

Introduction

Under the cultural conditions met in Wallonia, the effective protection of potato fields against late blight requires high quantities of fungicides (12 to 14 treatments on average). In addition to prophylactic practices for reducing inoculum, both in the potato plots and in their environment, three types of protection strategies could be implemented in order to reduce

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the number of treatments:

- spraying according to warnings which take into account the climatic risks;
- using more resistant cultivars allowing either to reduce the doses of active ingredient applied at normal intervals, or to increase spraying intervals at full amounts of active ingredient (Fry, 1977);
- combining these two strategies.

Previous trials have shown that the epidemiological model Guntz-Divoux (G&D) allows both to ensure an optimal protection of the cultures and to reduce the number of treatments compared to a weekly protection schedule (Michelante, 1999). However, this model does not take into account the effect of cultivars resistance. In this test, we combined warnings with, either the reduction of fungicides amounts, or the additional reduction of the number of treatments. This reduction was achieved by fixing a higher level of risk threshold measured on base of the cumulated risks calculated by G&D. This procedure permits the occurrence of additional disease cycles before triggering a new treatment. This strategy is based on the fact that the reconstitution of the infectious potential (inoculum) is slower on the more resistant varieties.

Material and methods

Trials were set up in Libramont. Each experimental unit was 3 m by 8m with 4 rows and 20 plants/rows. Observations were made on the two central ridges. The plots were separated between them from 3,75 to 4 m. The homogeneity of the natural contamination was supported by intermediate rows of untreated plants of Desiree. The nitrogen fertilization was assessed using the software AZOBIL (evaluation of the needs based on the balance of N): for a targeted tubers gross yield of 40 to/ha, we had to apply 120 units N/ha.

Table 1.- Key dates – CRA-SSA, Libramont, 2002

Cultivar	Bintje	Désirée	Remarka
Planting date	25/04/02	25/04/02	25/04/02
Emmergence date (80%)	31/05/02	31/05/02	03/06/02
First appearance of Phytophthora infestans on the trial site/region	17/07/02	17/07/02	19/08/02

The cultivars Bintje, Desiree and Remarka whose notes for late blight sensitivity are, respectively, 3, 5 and 6 (Dutch catalogue of the cultivars, 2000) were submitted to 6 protection programmes (table 2): 3 doses of fluazinam (full, ½, 1/3), 3 spraying schedules (GD, GD10, GD20), routine (weekly treatments) and usual warnings (scheduled according to GD and utilization of different fungicides). On the 22nd of July, the disease severity for the object T7 for cv. Bintje reached 20% on one replication; the trial was stopped and routine programme of protection was applied.

Only the treatment programmes were randomised in a complete blocks design. In order to standardize the inoculum pressure and to reduce severe interactions between plots, cultivars were arranged in a 3 strips systematic design alterning respectively Remarka (fairly resistant), Bintje (susceptible) and Desiree (little susceptible).

With the exception of the modality T1 ("warnings") on which two treatments were carried out with ACROBAT EXTRA WG, all the other treatments were carried out with SHIRLAN. The infecting rows included in the trial field and the untreated references located near this field bring about a very high pressure of inoculum.

Table 2. Treatment programmes – CRA-SSA, Libramont, 2002

Id	TRT	Decision rules	Fungicides
NT		untreated reference	no
T1	warnings	warnings (Guntz-Divoux)	G1: Dithane M45 - G2: Shirlan - G3: Acrobat - G4: Ridomil Gold
T2	7d - flu	Routine 7 days - Shirlan full dose	Shirlan 0,300 - 0,400 l/ha (0,150 - 0,200 gr a.i./ha)
T3	GD - flu	Guntz-Divoux - Shirlan full dose	Shirlan 0,300 - 0,400 l/ha (0,150 - 0,200 gr a.i./ha)
T4	GD-flu 1/2	Guntz-Divoux - Shirlan 1/2 dose	Shirlan 0,150 - 0,200 l/ha (0,75 - 0,100 gr a.i./ha
T5	GD-flu1/3	Guntz-Divoux - Shirlan 1/3 dose	Shirlan 0,100 - 0,133 l/ha (0,50 - 0,66 gr a.i./ha)
T6	GD10-flu	Guntz-Divoux cumulated risks threshold: Rcum = 10 - Shirlan full dose	Shirlan 0,300 - 0,400 l/ha (0,150 - 0,200 gr a.i./ha)
T7	GD20-flu	Guntz-Divoux cumulated risks threshold: Rcum = 20 - Shirlan full dose	Shirlan 0,300 - 0,400 l/ha (0,150 - 0,200 gr a.i./ha)

Remarks : the evaluation of infection chances according to G&D is based on average temperature and the length of a period with RH>90%. Notes of risks : no risk=0 ; slightly=1 ; moderate=2 ; severe=3 ; very severe=4.

The first treatment was applied at the end of the incubation period of the second disease cycle calculated according to Guntz-Divoux model (warnings and GD modalities) or when the thresholds were reached (GD10 and GD20).

Results

First treatment

Date of first treatment according to GD was suitably predicted for cv. Bintje but was too early for Remarka. Concerning Desiree, GD10 makes it possible to move back the date of first treatment one week before apparition of first symptoms while allowing a further effective protection.

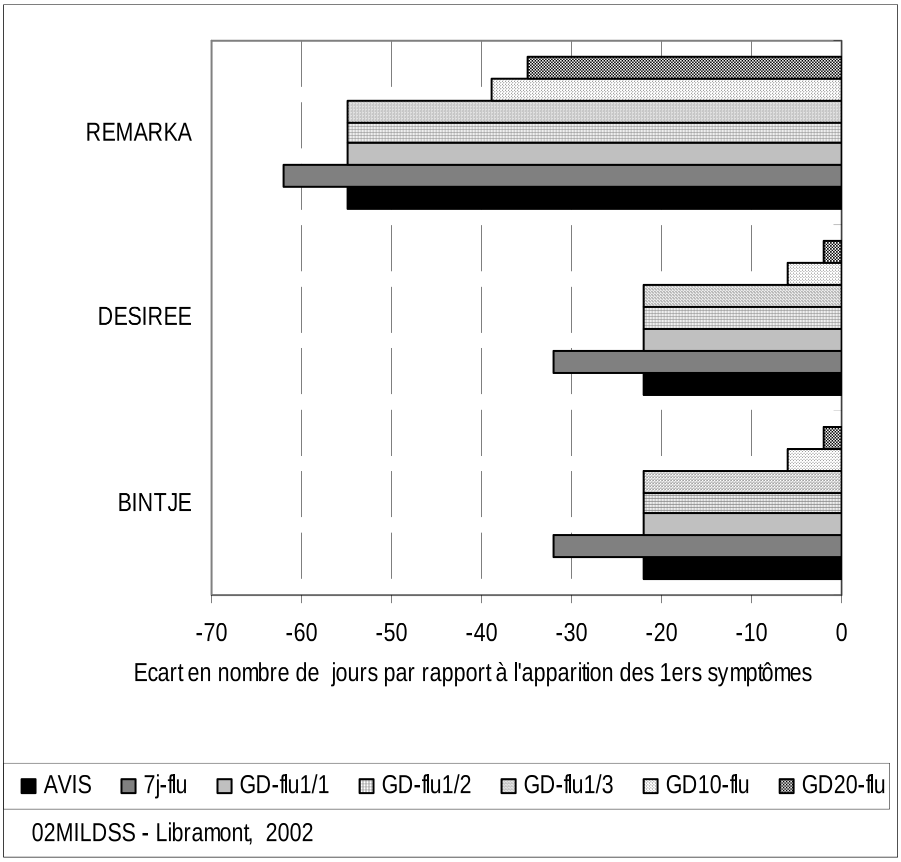

Figure 1. Difference between the date of first spray and the observed date of first late blight occurrence - CRA-SSA, Libramont, 2002

Programmes of treatments

The following figure shows the total quantities of active ingredients applied and the numbers of treatments for each programme. The model G&D and modified models GD10 and GD20 allowed to save, respectively, 2, 4 and 6 treatments compared to the routine. Gd-flu1/1 saved 24% of active substance compared to the routine.

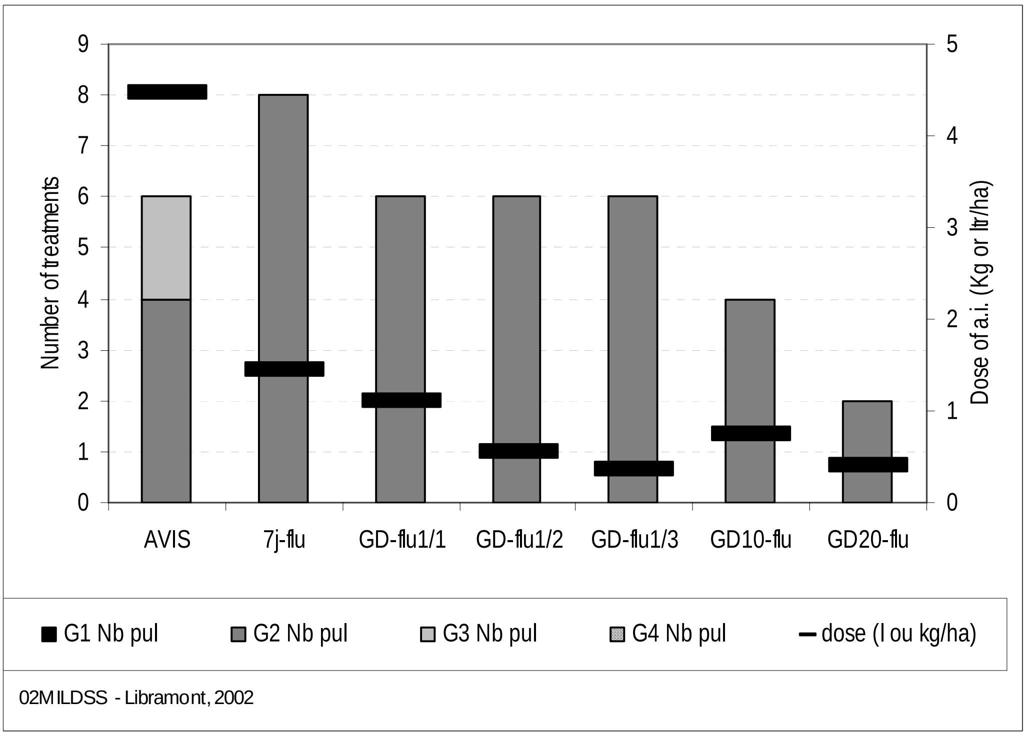

Figure 2. Number of treatment and amount of active ingredients applied

Efficacy of treatment programmes and cultivars resistance

The Warnings and GD-flu1/1 gave a similar level of protection than the routine. However, only this last method completely avoided any contamination on the cultivars Desiree and Remarka. Thanks to its resistance, only two treatments were able to ensure an effective protection of Remarka in spite of a strongly contaminated environment. The large delay in the apparition of first contamination on this variety is probably due to the presence of R gene.

Concerning cv. Bintje:

there is no effective strategies for additional reduction of fungicides, doses reductions could be considered during the first phase of epidemic, when inoculum is still relatively weak. But from the 1st week of august, the protection efficacy decreased along with the doses reductions,

GD20 was completely ineffective: the first spray was too late and foliar destruction increased very fast on these plots,

GD10 gave a better protection: the infection was moderately controlled during the first part of the epidemic; then from August 8th severity increased and exceeded 1%,

GD-flu1/3 was better than GD10 up to mid-August, then disease severity reversed: at this time the climatic pressure was very severe while intervals of spraying were similar.

Conclusion: GD classical model is well adapted to Bintje; reduction but also increasing of doses or reduction of intervals according to the inoculum pressure could be considered.

Concerning cv. Desiree: GD10 permitted a good protection level for the entire growing period with an additional reduction of two treatments compared to GD:

The delayed triggering of treatments according to GD10 ensured a similar level of protection than Gd-flu 1/1 during the first half of the epidemic period; then, in spite of higher rate of inoculum, this program allowed a good protection,

GD20 gave satisfaction in the beginning of epidemic but was not sufficient when the climatic conditions allowed the fast multiplication of inoculum.

The same comments could be done concerning the reduction of doses whose efficacy was similar on Desiree and Bintje in spite of the difference in cultivars resistance.

Table 3. Effects of treatment strategies on disease severity (relative AUDPC and final foliar destruction at 19/08/2002)

rAUDP						Disease severity, 19/08/2002					
object	BIN	object	DES	object	REM	object	BIN	object	DES	object	REM
T0	*31.160*	*T0*	*21.510*	*T0*	*1.360*	*T0*	*98.00*	*T0*	*98.00*	*T0*	*8.00*
T3	0.023 b	T2	0.006 b	T1	0.000 a	T2	0.13 b	T2	0.00 c	T1	0.00 a
T2	0.032 b	T1	0.015 b	T2	0.000 a	T1	0.15 b	T1	0.10 bc	T2	0.00 a
T1	0.034 b	T3	0.030 b	T4	0.000 a	T3	0.18 b	T3	0.27 bc	T4	0.00 a
T4	0.100 b	T4	0.085 b	T6	0.000 a	T4	0.58 ab	T6	0.30 bc	T6	0.00 a
T5	0.414 b	T6	0.093 b	T5	0.002 a	T6	1.58 ab	T4	0.60 bc	T5	0.03 a
T6	0.864 b	T5	0.226 b	T7	0.002 a	T5	3.15 a	T5	2.27 ab	T7	0.03 a
T7	4.361 a	T7	0.921 a	T3	0.005 a	T7	3.23 a	T7	4.53 a	T3	0.05 a
F	4.6		9.7				5.73		5.71		
P(0.05)	0.0053		0.0005				0.0018		0.0052		

TO: not included in the design

T7: on the 22nd of July the disease severity on cv. Bintje reached 20% on one replication; the trial was stopped and routine programme of protection was applied.

Discussions

In Belgium, there are no official regulations to oblige farmers to reduce the use of fungicides. Thus, the producers could only accept a strategy absolutely avoiding the appearance of symptoms. It is the only way to reduce chances of tuber late blight which can destroy potatoes during storage.

For the susceptible cultivars like Bintje, the classical GD model is convenient. Improvement could be considered:

in the beginning of the season when inoculum is still rare and if climatical conditions are not too conducive to disease development, the possibility to reduce doses ought to be assessed,

later, when high level of inoculum is present close to the field, protection provided by GD model is rather good but not so efficient as the 7 days routine programme. Extensive protection ought to be applied by reducing intervals or increasing doses.

For less susceptible cultivars like Desiree, the reduction of cadences according to higher threshold level of contamination chances based on climatical conditions seems to be efficient in conditions of low level of inoculum in the environment. These strategies gave better results than reducing doses when climatical conditions become conducive. But foliage destruction increases quickly when both climatical conditions are favourable to epidemic and large amount of inoculum are present.

From the beginning of observations, four years ago, Remarka have showed a very high level of resistance in our conditions. Only two treatment were sufficient to provide an optimal protection. R genes seems to be involved; in this case, a considerable reduction of protection could lead to a selection of virulent isolates able to overcome the resistance and, then, should to be avoided.

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Infection models for downy mildew fungi used in different crops with focus on *Plasmopara viticola*

H. DENZER

Pessl Instruments Ges.m.b.H, Werksweg 107, 8160 Weiz, Austria

Downy Mildew, caused by *Plasmopara viticola* is one of the most important fungal diseases in viticulture. Due to its economic importance it is one of the best known plant pathogenes. Its epidemic behavior was described by MÜLLER-THURGAU (1911), ARENS (1929a, 1929b), MÜLLER and SLEUMER (1934), GÄUMANN (1951), BLAESER und WELTZIEN (1978), WEIR and MAGAREY (1984) and LALANCETTE *et al.* (1988a, 1988b). Some work has been done studying the epidemic behavior of related fungi like *Pseudoperonospora humuli* by ARENS (1929c), RHOYLE and THOMAS (1972), RHOYLE (1973), KREMHELLER (1979), KRAUS (1983) and DOLINAR and M. ZOLNIR (1994), *Bremia lactucae* by SCHULZ (1937), VERHOEFF (1969) and SCHERM and van BRUGGEN (1992, 1993, 1994, 1995), *Pseudoperonospora cubensis* by BEDLAN (1987) and *Pseudoperonospora destructor* by HILDEBRAND and SUTTON (1981) and BASHI and AYLOR (1983). Regarding the big similarities in the epidemic of these Downy Mildew fungi we were looking for an universal structure for an infection model for Downy Mildew of different plants.

This universal structure was transformed into a computer model which is driven by a database containing values for the influence of temperature, relative humidity, rain, leaf wetness, light to the different steps of the infection process. With this database the program can be adapted to different Downy Mildew fungi.

Comparing the enviromental impact with the epidemics of these different fungi and adapting the universal structure for an infection model we found some open questions in primary infection and sporulation of Grape Vine Downy Mildew.

Plasmopara viticola is overwintering with its oospores. Zoospores from macrosporangias are the primary inoculum in the most viticultural areas. But not all vineyards are showing primary infections. In Lower Austria per example no primary infections are occuring on the light stony

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Universal Structure for Downy Mildew infection models

Macrosporangia
formation => discharge => primary infection => incubation
death
(hibernation in oospores, *Plasmopara viticola,* sometimes *Pseudoperonospora humuli*)
start of the secondary cycle

Sporangiaformation => discharge => infection => incubation
death
(several Downy Mildew pathogenes)
start of the next cycle

soils. But in the same villages there are vineyards on organic soils influenced by water table showing primary infections. Macrosporangias are formed by oospores on a moist surface in contact to free moisture in the laboratory within 6 hours at least. This would correspond to wet soil surface in field. Wet soil surface can be caused by a wet through rain followed by a period of leaf wettness or high relative humidity. Looking to different systems used by European viticulture advisory services to predict Grape Vine Downy Mildew primary infections we can find that they are mostly looking for a rainy period of 24 hours or several days before they are assuming primary infection to occure. Therefore we have to take an approximately 16 to 24 hours longer period of wet soil surface for macrosporangia formation in field. The zoospores inside the macrosporangias can be dispersed by a splashing rain. Released zoospores needs water to survive. Therefore infection process must be fulfilled within one period of leaf wettness caused by the zoospore dispersing rain.

Sporulation of Downy Mildew takes place at night during periods of high relative humidity. Grape Vine Downy Mildew models are looking for a steady period of high relative humidity during the night. Models for P*seudoperonsopora destructans* are looking for the total period of high relative humidity during the night. We know less about the influence of fluctuating relative humidity during night. In *Pseudoperonospora humuli* it is assumed that sporulation takes place at much lower relative humidity, what might be a result of a canopy climate wich differs from the climate at the corresponding climate station. Sporangias of Downy Mildew fungi can be dispersed by rain or by air. Dry distribution can only take place if the sporangias are dry. There is no qnuantification of the rain needed for spore dispersal.

Spore production for artificial inoculation in laboratory is limited by the survival of the oilspots. We don not know how often oilspots can produce sporangia before they are completly necrotic. Research on infection by zoospores has been carried out by ARENS and RHOYLE and THOMAS. They showed the mechanisms which are used to find stomata needed for infection. After the zoospores are settling at the stomata they will encyst and germinate. After approx 2 hours from a swimming zoospore the whole plasma has been remouved into the substomental hole and it is no longer susceptible to the end of leaf wetness. For modelling purpose we normally assume a leaf wetnes period of 50 °C to be needed for infection.

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Efficacy of zoxamide/mancozeb mixture against early blight (*Alternaria* spp.) and late blight (*Phytophthora infestans*) in Polish experiences

J. KAPSA[1], J. OSOWSKI[1] AND O. SHEVCHUK[2]

[1] Plant Breeding and Acclimatization Institute, Branch Division Bonin
Department of Potato Protection, 76-009 Bonin, Poland
[2] Dow AgroSciences Poland, I. Krasickiego 53, 02-608 Warszawa, Poland
jkapsa@wp.pl. j.osowski@wp.pl. oshevchuk@dow.com

Summary

The observations conducted by the Plant Breeding and Acclimatization Institute of Bonin in two different localities revealed variable time of occurrence and incidence level of early blight (*Alternaria* spp.) and late blight (*Phytophthora infestans*).
Field trials showed good efficacy of fungicides selected for controlling the early blight and the late blight compared with an untreated control. The mixture of zoxamide with mancozeb showed the greatest efficacy but was comparable with the effectiveness of fluazinam when fluazinam was applied at the highest doses.

Key words: potato, early blight, late blight, control of diseases, fungicide efficacy

Introduction

Late blight caused by *Phytophthora infestans*, is the major disease, which affects the potato crops and reduces yields due to premature defoliation (which depends on the date of outbreak and the rate of disease development), and losses of yield due to tuber infection.
Early blight – seen as dry and brown spot on potato leaves occurs commonly particularly in regions with high temperature and humidity. In Polish climatic conditions there were recorded high regional losses caused by the early blight, however, most related to cultivars with recognized susceptibility to this disease. The causal agents of the disease are fungi from

Alternaria genus: *Alternaria alternata* and *Alternaria solani* (Dorożkin, & Ivanjuk 1979, Droby et al. 1984).). As the disease development progresses the morphological symptoms induced by the *Alternaria* species do not differ in appearance. In Polish climate conditions this disease occurs usually earlier than late blight.

Material and methods

In the years 1997-2001 studies were conducted at the Plant Breeding and Acclimatization Institute of Bonin with the emphasis on estimation of the efficiency of selected fungicides in controlling the late blight and in limiting the development of the early blight.

Observations and field trials were carried out in 2 sites differing climatic conditions (Bonin – in northern Poland and Stare Olesno – in southern Poland). A randomized complete block design with 4 replications was used for the experiment. Each plot was 30 m^2. Estimation of fungicide efficiency to control the early blight was performed on cv. Frezja (very susceptible to the disease) and control of the potato late blight on cv. Rywal (intermediate susceptibility to the late blight, rated 4 in a 0 - 9 scale, where 9 means high resistance).

In the early blight control there were compared protectant fungicides such as mancozeb (Dithane M-45 80 WP) and chlorothalonil (Bravo 500 SC) and also mixtures of plant protection products with a contact mode of action i.e. zoxamide (=zoxium) with mancozeb (Unikat 75 WG). All treatments were applied at a dose of 2 kg/l per ha. Two to three sprayings were performed throughout the growing season beginning with the occurrence of the very first symptoms of the disease on the experimental plots.

In controlling the potato late blight there were compared the following active ingredients: fluazinam (Altima 500 SC) at a rate of 0.4 l/ha, mancozeb (Dithane M-45 80 WP) at a rate of 2 kg/ha, chlorothalonil (Bravo 500 SC) at a rate of 2 l/ha and also mixtures of zoxamide with mancozeb (Unikat 75 WG) at a rate of 2 l/ha. Control of the late blight began when the disease occurrence was detected in a region. Six to seven sprayings were applied throughout the growing season depending on the disease severity. In both field trials an untreated plot was a control.

The criteria for fungicide effectiveness assessment was assumed to be the percentage of haulm destruction at the end of growing season and area under the disease progress curve (AUDPC), or the late blight development rate defining an increase of destruction of above ground plant parts in unit time (according to Van der Plank, 1963), and also tuber yield. The results were analyzed in a 2-factorial ANOVA, the factors being years of experiments and the fungicide applied.

Results

The observations carried out at Bonin and Stare Olesno revealed that both time of occurrence and the severity of the early blight and the late blight differed and were dependent upon meteorological conditions and upon which year the survey was conducted (Tab. 1). The early blight occurred the earliest at Bonin in 2001 (June 15) and at Stare Olesno in 1998 (June 12). The earliest occurrence of the potato late blight was recorded in both experimental sites in 1999 (Stare Olesno – June 18; Bonin – June 24). In Polish climatic conditions, in both localities, the early blight occurred earlier than the late blight by 4-29 days.

Table 1. Time of occurrence of early blight and late blight in the years 1997-2001

Locality	Disease	1997	1998	1999	2000	2001
Bonin	Early blight	30.06.	18.06.	18.06.	19.06.	15.06.
	Late blight	04.07.	09.07.	24.06.	18.07.	02.07.
Stare Olesno	Early blight	01.07.	12.06.	14.06.	20.06	26.06.
	Late blight	08.07.	01.07.	18.06.	10.07.	01.07.

The conducted trials showed that all fungicides limited the early blight development compared to the untreated control.

In Bonin climatic conditions, all tested plant protection products revealed similar efficiency in inhibition of the haulm destruction (Tab. 2). Only in the year 1999, when the early blight severity was the lowest, the applied mancozeb and its mixture with zoxamide gave better protective results as compared with chlorothalonil treatment.

Table 2. Efficiency of selected fungicides in potato protection against early blight at Bonin (years 1997-1999, 2001)

Fungicide	1997		1998		1999		2001	
	% Haulm destruction	AUDPC	% Haulm destruction	AUDPC	% Haulm destruction	AUDPC	% Haulm destruction	AUDPC
untreated	64.3 a	0.194 a	97.2 a	0.260 a	50.0 a	0.161 a	92.5 a	0.195 a
chlorothalonil	18.3 b	0.064 b	70.6 b	0.139 b	50.0 a	0.142 a	78.8 b	0.123 b
mancozeb	14.6 b	0.056 b	73.4 b	0.150 b	32.1 b	0.103 b	67.9 b	0.102 b
zoxamide + mzb	14.8 b	0.060 b	63.4 b	0.149 b	32.1 b	0.131 b	53.6 bc	0.107 b

The comparison of the area under the disease progress curve (AUDPC) for a particular treatment confirmed that the utilized fungicide protection clearly limited the disease development.

In Stare Olesno climatic conditions under high infection rate of the pathogen there was observed a distinct differentiation of protection efficiency for different fungicides (Tab. 3).

Table 3. Efficiency of selected fungicides in potato protection against early blight at Stare Olesno (1997-1999, 2001)

Fungicide	1997		1998		1999		2001	
	% Haulm destruction	AUDPC	% Haulm destruction	AUDPC	% Haulm destruction	AUDPC	% Haulm destruction	AUDPC
untreated	95.4 a	0.319 a	93.4 a	0.497 a	94.4 a	0.342 a	90.2 a	0.523 a
chlorothalonil	93.4 a	0.257 a	35.6 b	0.283 b	42.8 b	0.124 b	33.0 b	0.230 b
mancozeb	88.7 a	0.219 a	32.1 b	0.258 b	32.1 b	0.099 b	4.3 c	0.123 c
zoxamide+mzb	32.1 b	0.078 b	14.8 b	0.115 c	35.6 b	0.114 b	3.3 c	0.101 c

In some years the efficiency of the mixture zoxamide with mancozeb in controlling the early blight development was similar to that obtained for chlorothalonil and mancozeb. In other years the effectiveness was significantly higher (years 1998, 2001).

Protection against the early blight effected indirectly the tuber yield obtained from protected plots (Fig.1). The yield increase obtained from plots protected against the early blight was statistically insignificant in some years (Bonin – 1999 and 2001, Stare Olesno – 1997 and 2001). In the remaining years the significant differences, in comparison to the untreated control, were calculated in the range from 21.9% to 60.9% for Bonin surveys and from 13.0% to 101.9% for Stare Olesno surveys. There were no significant differences found between treatments.

Also the high efficiency of tested fungicides in controlling the late blight development was noted as compared with the unprotected treatment (Tab. 4). The year 1999 did not favor the potato late blight development at Bonin. There was no high haulm destruction recorded on the untreated control. At the end of the growing season (about August 30) the performed observation showed that only 43% of plants were infected. The lowest numbers of plants infected with the late blight were recorded on plots with fluazinam and the mixture of zoxamide with mancozeb treatments (5% and 6%, respectively). Moreover, the spread rate of disease on protected plots did not differ between particular treatments.

However, the year 1999 favored the *P. infestans* development at Stare Olesno. At the end of August the potato plants were almost totally destroyed on the untreated control (95%). Under a high infection conditions the mixture zoxamide and mancozeb provided considerably better efficiency in inhibition of the disease spread.

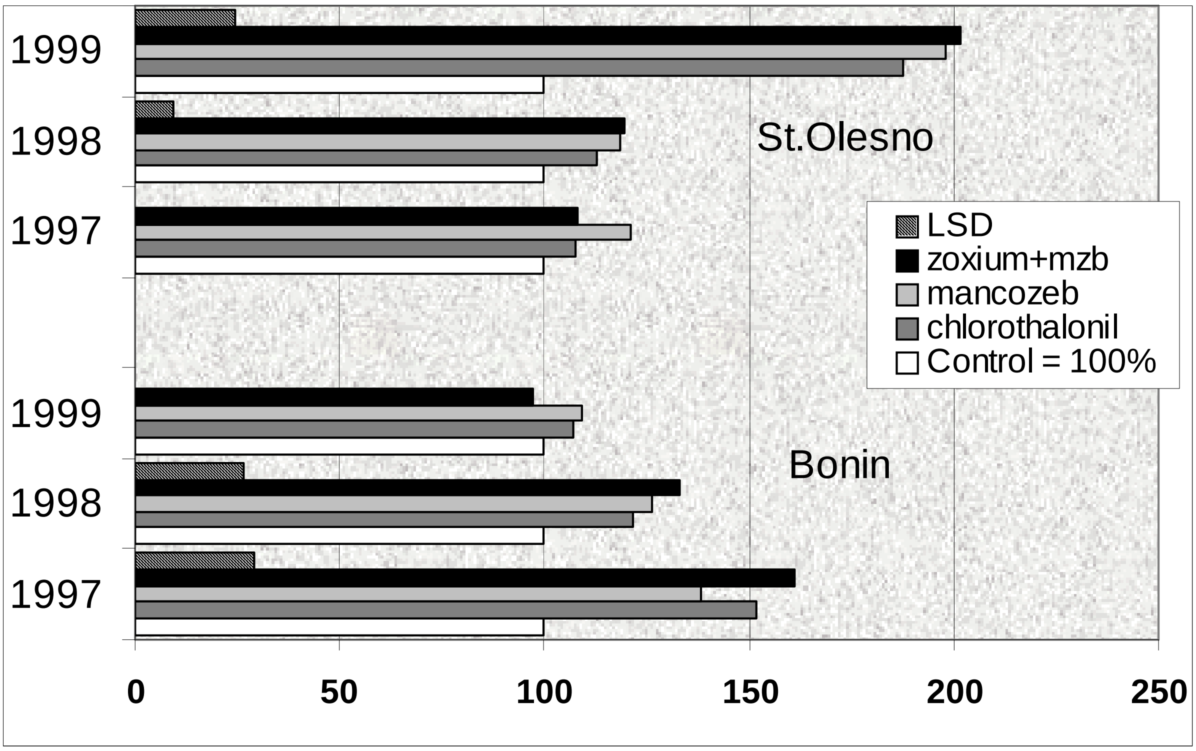

Figure 1. The influence of early blight control on tuber yield

Table 4. Efficiency of selected fungicides in potato protection against late blight at Bonin and at Stare Olesno (years 1999 and 2001)

Fungicide	Bonin				Stare Olesno			
	1999		2001		1999		2001	
	% Haulm destruction	Spread rate	% Haulm destruction	Spread rate	% Haulm destruction	Spread rate.	% Haulm destruction	Spread rate
untreated	43.0	0.184 a	99.8	0.249 a	95.0	0.156 a	100.0	0.200 a
fluazinam	5.0	0.117 b	25.0	0.098 c	57.5	0.132 b	30.0	0.149 c
chlorothalonil	10.0	0.117 b	30.0	0.106 b	70.8	0.127 b	75.0	0.179 b
mancozeb	13.0	0.117 b	27.0	0.106 b	62.5	0.127 b	45.0	0.167 b
zoxamide + mzb	6.0	0.095 b	10.0	0.083 c	57.5	0.115 c	22.0	0.143 c

The growing season of 2001 favored the disease development in both localities. At the end of August the plants on the untreated control plots were totally destroyed. The active ingredient fluazinam applied at a higher dose and the mixture zoxamide with mancozeb showed considerable better efficiency in potato protection in Bonin and in Stare Olesno.

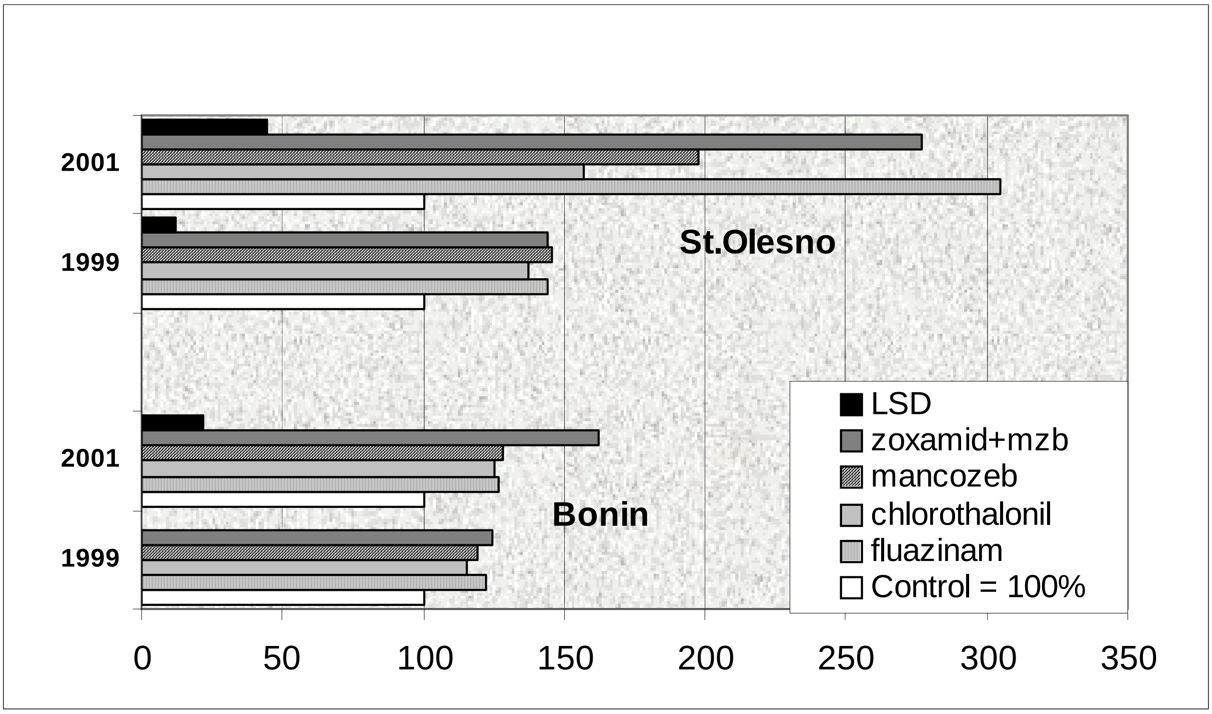

Figure 2. The influence of late blight control on tuber yield

The late blight spread rate on protected plots ranged from 0.156 to 0.249. Its value calculated for the fluazinam treatment was in a range of 0.098 – 0.149 in both sites while for the mixture zoxamide with mancozeb treatment 0.083 – 0.143. Both products effectively prolonged the period of tuber production by 13-40 days for the fluazinam treatment and 21-39 days for the mixture of zoxamide with mancozeb.

The chemical protection against the late blight effected the tuber yield (Fig. 2). The obtained yield increase in particular years was 15.4 – 61.9 % in Bonin and 37.4 – 204.8% in Stare Olesno as compared with the control.

Discussion

Early blight is a common disease of potatoes due to the worldwide distribution of the causal agent. However, its harmfulness is greater in regions with higher temperature and humidity. The 5-years of observations conducted at Bonin and Stare Olesno revealed that the occurrence of the early blight and the late blight depended mostly upon meteorological conditions in particular years in both localities. Time of occurrence of the early blight depends upon meteorological conditions in third decade of June and first decade of July (Dorożkin, Iwaniuk 1979). Previous observations carried out in the years 1987-1995 in Poland in 18 Experimental Stations of Cultivar Testing showed significant differentiation in disease severity depending on locality as well as which year the survey was conducted (Kapsa, Osowski, 1996).

In the foregoing investigations favorable conditions for the early blight occurrence were mainly observed in Stare Olesno (southern Poland). Higher temperatures in June and July in Stare Olesno (as compared with temperatures in Bonin) induced higher infection pressure of the pathogen.

The late blight, known all over the world where potatoes are cultivated, requires for its development mainly high relative humidity (RH 90-100%) and tolerates a relatively broad range of temperatures (12 - 20^{o}C). Depending upon climatic conditions the causal agent produces two kinds of spores. At low temperatures there are produced zoospores while at higher temperatures conidial spores (Rudkiewcz 1985; Harrison 1992).

In Polish climatic conditions the early blight occurred earlier that the late blight during the growing season. However, the important fact is that all observations were carried out on unirrigated fields and existing climatic conditions favored natural infection with the early blight.

The proper protection against the pathogen relies on few basics, among other things, the selection of fungicide, an application at appropriate dose, time of season, and correct spraying technique. Configuration of meteorological conditions during the growing season also effects the pathogen incidence. Fungicide efficiency is the essential factor in proper protection.

The field trials showed a good efficiency of all selected fungicides in controlling the early blight and the late blight compared with the untreated control. The sprayings limited the development of diseases and increased the tuber yield. The mixture zoxamide with mancozeb gave the best efficiency but was comparable with the effectiveness of fluazinam when fluazinam was applied at the highest doses.

Some investigators indicate low sensitivity of pathogens from *Alternaria* genus to most fungicides including almost all-systemic products (Borecki 1996). On the other hand the same author indicates that mancozeb gives a good efficiency in control of these diseases and he also recommends mancozeb, metiram, propamocarb and chlorothalonil for a control of *Deuteromycotina* fungi (*Alternaria* belongs to them). Osowski 1998 and Kapsa 2000 obtained similar results.

Various active ingredients are registered for the control of the early blight in different countries. In Poland this list includes chlorothalonil (Bravo, Clortosip, Gwarant), fluazinam (Altima), metiram (Polyram), and famoxadone+ cymoxanil (Tanos). It is well known that in case of the early blight, the disease, which is difficult to control the efficiency of applied fungicide (in field conditions) at a level of 60-70% is satisfactory. Zitter *et al.* 1984, Fry 1994 and Stevenson and James 1997 recommend routine chemical treatments against the early blight.

In some countries potato crops are regularly irrigated (USA and the Netherlands) and then the early blight occurs at the end of growing season on aging plants. The recommendations for potato protection against the early blight, aiming at tuber protection from pathogen infection, refer to the end of the season as the best time for fungicide application (Fry 1994).

The investigations also proved good efficiency for tested fungicides in controlling the late blight development as compared with the untreated control. The mixture zoxamide with mancozeb showed the best efficiency comparable with fluazinam when applied at a higher dose. The efficient protection extended the period of plant productivity by 11-40 days that caused a tuber yield increase.

Each year at Stare Olesno a significant increase of tuber yield from protected plots was recorded as compared with the untreated control. At Bonin the yield increase was noted only in some years. Generally the late blight occurs earlier in southern Poland (Stare Olesno) than in northern regions. Earlier devastation of above ground plant parts holding the tuber growth causes greater effect to tuber yield. It might explain more clearly influenced of the fungicide protection on the tuber yield, as compared with the untreated control at Stare Olesno.

Good efficiency of selected fungicides means the same products can be used in the control of both diseases, preventive in the late blight control and curative in the early blight control, in Polish climate conditions.

Conclusions

1. In both localities (Bonin and Stare Olesno) incidence of the early blight and its severity varied depending on climatic factors.
2. In both localities tested fungicides demonstrated good efficacy in the inhibition of the early blight development compared to the unprotected control. The efficacy of zoxium and mancozeb mixture was the best in most of years.
3. The mixture of zoxamide and mancozeb was also effective in a control of the late blight, giving an excellent inhibition of foliage destruction and an increase of tuber yield by 15.4% - 204.8%. Its effectiveness was the same as fluazinam in higher doses.

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Control of Early Blight (Alternaria) with Plant-Plus

J. HADDERS

Address

Dacom PLANT-Service BV, PO Box 2243

7801 CE Emmen, The Netherlands

Keywords: Alternaria solani, Early Blight, PLANT-Plus, disease forecasting, Late Blight, *Phytophthora infestans*, DSS, Decision Support System

Abstract

The common ground in the control of *P. infestans* and Alternaria in potatoes makes it interesting to make a presentation about Alternaria at the EU Phytophthora Workshop in Poznan, Poland.

Specific in the warmer parts of the world, Alternaria can cause a lot of damage to the potato crop. Yield losses of up to 50% have been reported. Because no curative chemical products to combat the disease are available, farmers have to depend on spraying with contact products. This results in unacceptable tight spraying schedules or longer intervals that result in missed infection events causing damage to the foliage.

Dacom PLANT-Service in the Netherlands has developed a model to predict an infection event in combination with the left over crop protection of the last spraying. The same set of crop parameters used for the Phytophtora advice could be used for Alternaria, just one had to be added. Also certain knowledge of Alternaria can be used for the control of Phytophthora and vice versa. Experience in countries like Egypt and South Africa show the advantage of the use of the PLANT-Plus model.

Why Alternaria at a Phytophthora Workshop?

As the disease occurs in the same crop at the same place, in the foliage, it seems logic to pay some attention to Alternaria in this Workshop. Also Alternaria is causing a lot of damage in

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some parts of the world making more study on this subject worthwhile. In the cooler parts however hardly any occurrence of Alternaria is seen. Sometimes, the Alternaria problem is disguised by chemical treatments for Phytophthora but pops up as soon as certain products are not used anymore.

It is good to understand the differences and the resemblances of both diseases in order to get a conscious control strategy for both. New knowledge of one disease might advance knowledge of the other disease.

Why Dacom to present Alternaria

Over the years, starting in 1994, Dacom has developed other fungus models besides the Phytophthora model. For Alternaria, models in different crops have been developed (see table 1)

Table 1. Models for Alternaria in different crops.

Leeks	*Alternaria porri*
Brassicas	*Alternaria brassicicola*
Carrots	*Alternaria dauci*
Citrus	*Alternaria alternata*

The experience with the carrot model is quite extensive. In the UK more then 50% of the carrot crop is grown with the PLANT-Plus advice. In France this figure is about 30%.

Besides Alternaria in other crops, over the years experience was gained in different countries with potatoes. Outside Europe, these countries are: Japan, Indonesia, South Africa, Egypt, the USA and Canada. In South Africa, specific research on Alternaria in combination with PLANT-Plus was done by Dr. Jacquie VanderWaals. She hopes to get her PhD on this subject in 2003.

Damage

Damage by Alternaria to a potato crop is caused by destruction of green leaf area while in fruit crops the damage by miss-formation of the fruits is a problem. The theoretical damage can be established if we estimate a reduction of 20% active leave area for a period of three weeks during a full production period of 1000 $kg.ha^{-1}.day^{-1}$. With these parameters, the yield reduction would be 6000 kg / ha. Alternaria is a disease that more likely infects a potato plant under stress. Therefore it is hard to distinguish between damage of Alternaria and other causes.

A more practical example of damage by Alternaria is found in North America where in 2002 on specific farm, damage was estimated by experts at "100 bags per acre at $ 7 per bag". In European currency, this loss would amount to € 1700 per hectare! Visual observations of the author in fields in the USA, Canada and The Netherlands confirm the potential of great yield losses (Picture 1.).

Picture 1. Severe damage in a potato crop due to Alternaria.

PLANT-Plus model

Disease forecasting models & principles

The PLANT-Plus disease forecasting model on *Phytophthora infestans* was discussed before at the Workshop in 1997. In this paper the system as presented for Alternaria will be explained in general terms and this information can also be used for the *P. infestans* presentation at this Workshop. As with all other fungus models, the Alternaria model is developed in close cooperation with well-known researchers such as J.A. VanderWaals.

Inputs and outputs are evaluated and calculated on hourly basis or three hourly for the forecast data. This implies the need for high quality continuous weather monitoring stations and regular updated weather forecasts.

The PLANT-Plus model is a biological model, that replays the life cycle of the fungus and reflects infection events to the (un)- protection of the crop by chemicals and new growth of leaves.

The model can be divided into the following sub-models:

1. Unprotected part of the crop
    a. Growth of new leaves
    b. Degradation and wear-off of chemicals
2. Infection events of the disease
    a. Formation of spores on each infected leaf
    b. Eject and dispersal of spores into the air
    c. Germination of spores into unprotected leaves
3. Combination of un-protected leaf area and infection events into treatment recommendations

Ad sub model 1a: Unprotected crop by growth of new leaves
This factor is the most underestimated one in standard crop spraying regimes. Rapid growth in early season can cause crops to be vulnerable for infection after 3-4 days. The growth of new leaves is dependant on field scout reports, which means the farmer or his consultant will have to go out into the field and score the development of new leaves compared to the last measurement (Hadders, 1997).

Ad sub model 1b: Unprotected crop by degradation and wear-off of chemicals
PLANT-Plus includes information about chemicals as part of the base of the system. This information includes active ingredients, recommended dosages, rate and duration of efficacy against the disease and factors for wear-off influenced by rainfall and solar radiation. The information is derived from independent trials and from the chemical manufacturing companies.

Ad sub model 1: Unprotected part of the crop
The results of sub models 1a and 1b are added up and represent the unprotected leaf area. Basically it is of no concern if the crop is unprotected, as long as the there are no possibilities for the fungus to attack the crop. Trials have learned that the interval can be stretched to 2-3 weeks without any problems.

Ad sub model 2: Infection events of the disease

This sub model replays the life cycle of the fungus on hourly basis. The epidemiological soundness and accuracy of the Dacom models for Phytopthora and Alternaria have been successfully evaluated in many field trials (Smith, 2000; Denner & MacLeod, 1998; Marquinez, 1999; De Visser & Meijer, 2000; Wander & Spits, 2001). The relation between a general fungus life cycle and the PLANT-Plus sub-models is presented in figure 1.

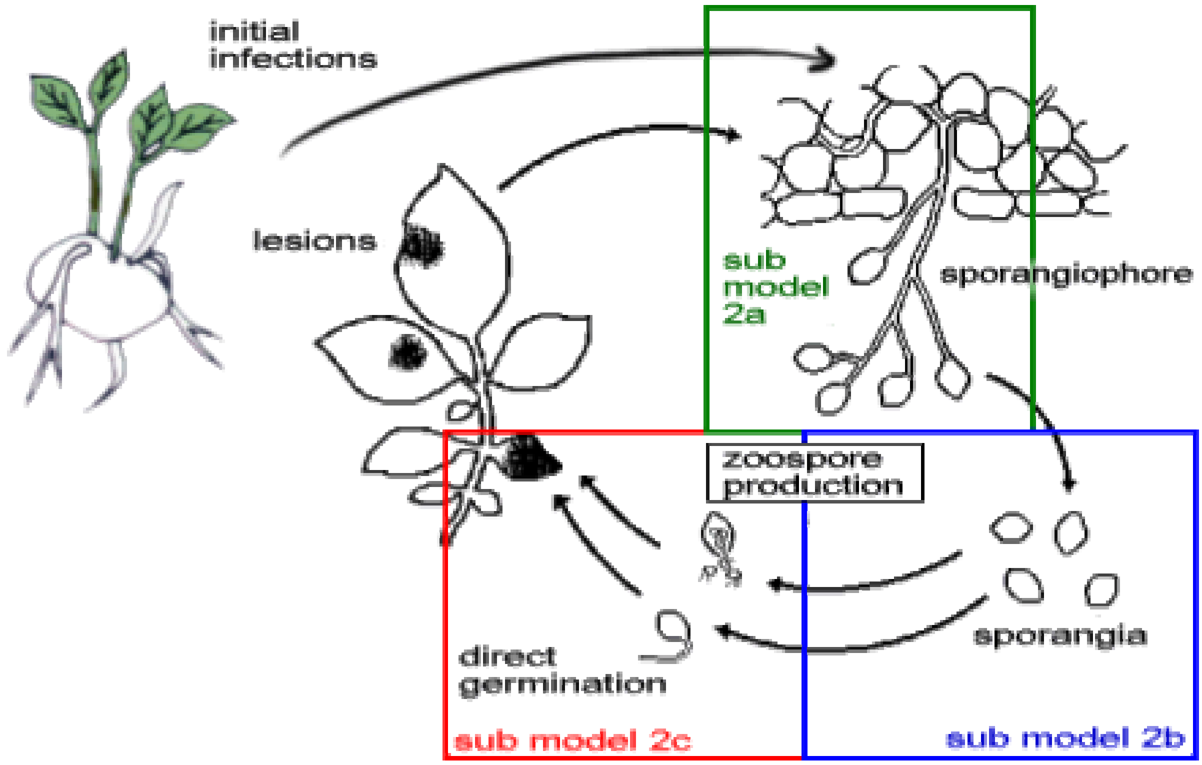


Figure 1: Fungus life cycle and PLANT-Plus sub-models

Ad sub model 2a: Formation of spores on each infected leaf

Sub model 2a calculates the number of viable spores on an imaginary lesion using temperature and relative humidity ranges for growing and dying of. The source of the lesion can either be infected debris or a secondary leaf infection.

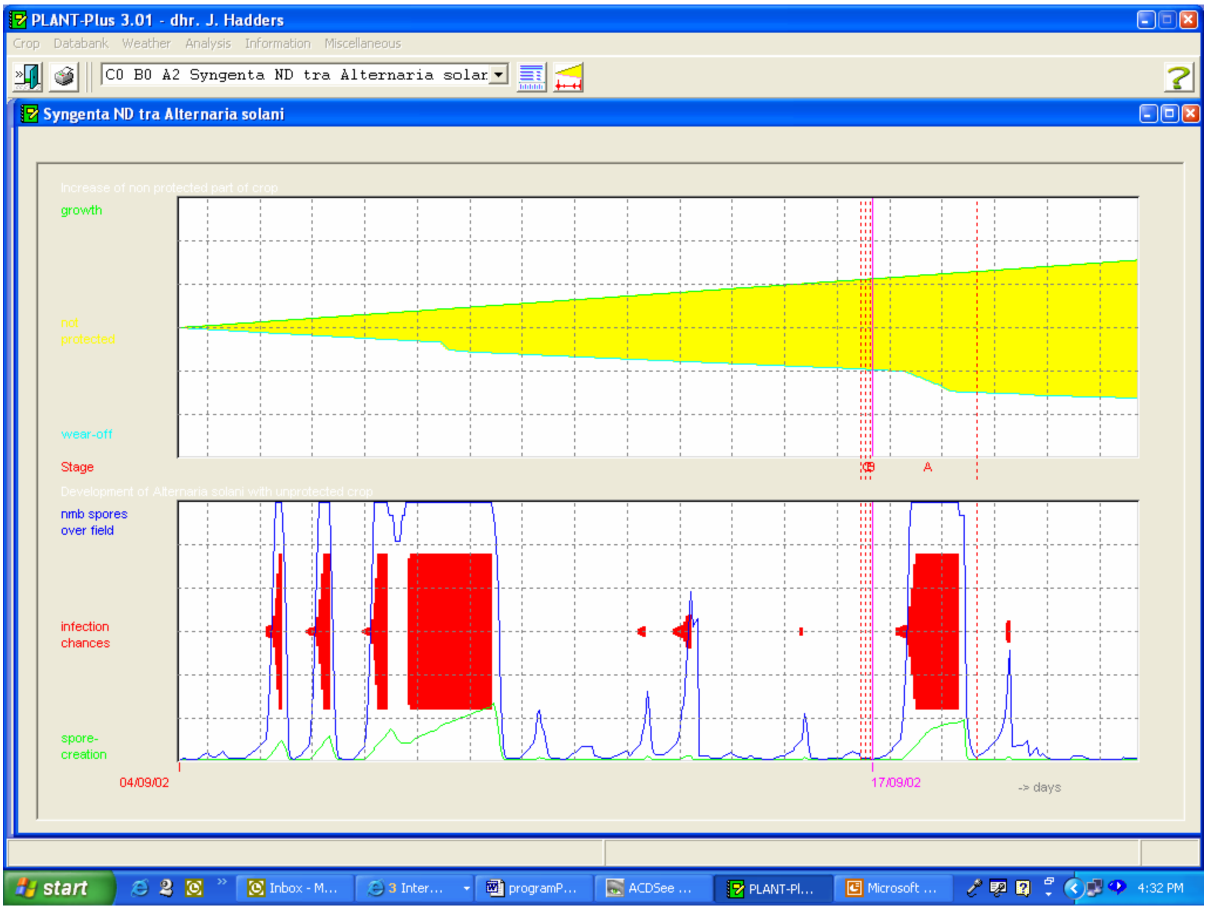


Figure 4: Example of PLANT-Plus disease model output

Ad sub model 2b: Eject and dispersal of spores into the air

After formation the spores can be dispersed into the air. Either climatic conditions like a drop in the relative humidity, wind or rain can cause this. The inputs for this model are the fictitious output from sub model 2a and the presence of the disease in the vicinity of the field, provided by field scouts (Hinds, 2000) or a disease mapping system (Hendriks, 1999; Hadders, 2002). This sub model has been evaluated with spore traps.

It might be obvious that the information about the presence of the disease is vital for an accurate calculation. Although the model will calculate spore flights anyway based on a very low standard figure, but not at accurate levels.

Sub model 2b results in a fictitious number of spores that fly above and land onto the field.

Ad sub model 2c: Germination of spores into unprotected leaves

The next step in the life cycle is to calculate the germination of the spores into a leaf and it completes the infection event. This part is based on temperature, leaf wetness, growth stage and variety resistance. Specific for Alternaria, the crop stage is an important factor for the infection efficiency. Leaf wetness enables the spores to germinate. PLANT-Plus has a specific model that calculates the leaf wetness of the crop, based on climatic conditions and the latest observation for crop density. Temperature and variety resistance influence the speed of germination. Sub model 2c results in the fictitious number of spores that can actually penetrate an unprotected leaf.

The outputs of model 1 and 2 are combined into one simple graph (Fig. 4) that reveals all the necessary information. The model run always starts with the date of crop emerge or the last chemical treatment (left of the graph) and uses station data until the current point of time (purple line) and continues with five days of forecast data.

Ad sub model 3: Combination of un-protected leaf area and infection events into advice
Sub model 3 interprets the unprotected leaf area and the infection event and provides a recommendation if and what type of chemical to use. The choice of the chemical is left up to the grower or his advisor. Within the recommendation the system also specifies the need for a treatment: 1) not needed, 2) to be considered and 3) necessary. The following recommendations for chemical types are feasible:

- no treatment needed;
- treatment with contact fungicide to be considered / necessary;
- treatment with translaminar fungicide to be considered / necessary;
- treatment with systemic fungicide to be considered / necessary.

This recommendation is influenced by the timing of the infection event related to the current point of time. An infection ***in the last 12*** or coming 24 hours will have to be treated with a contact fungicide. Unfortunately no curative acting chemicals are available for Alternaria. The active ingredient azoxystrobis has systemic action but no curative acition.

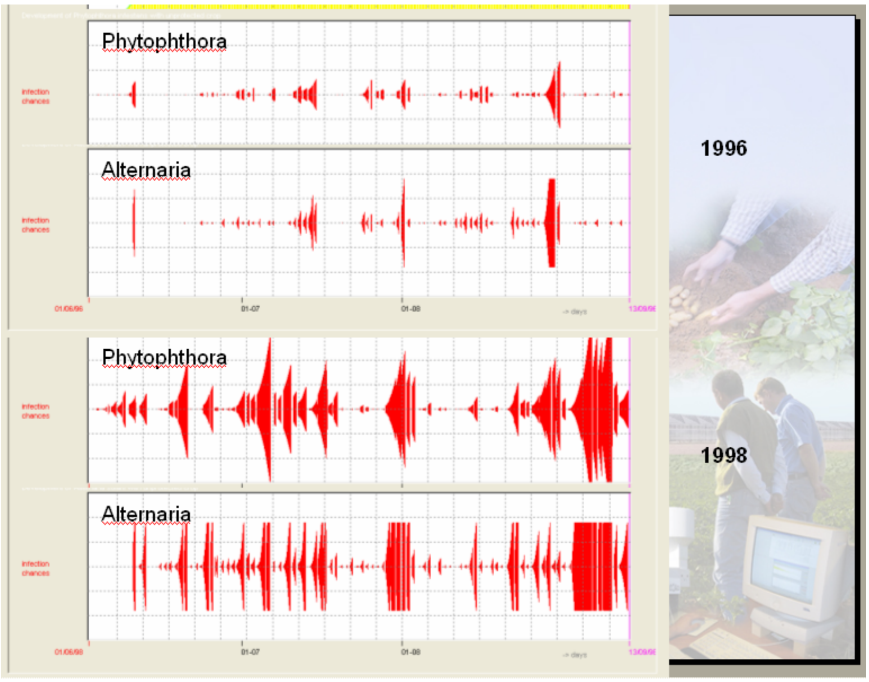
Occurrence of Alternaria

From 1993 – 2002 in Emmen, Netherlands

In the Netherlands, Alternaria is not considered as a big problem. Because of the fungicide treatments for Phytophthora, crop is normally well protected for an Alternaria infection event.

In 2002, Mancozep was not allowed in the Netherlands. In the Emmen region, 5 infection events were recorded. Because the crops had no protection for Alternaria, this resulted in heavy infected fields in the second half of the season. Note: in 2003, Mancozeb is allowed again in NL.

The average temperatures in the Netherlands are always within the band width of the activity of Alternaria and Phytophthora. The graph shows per year the cumulative infection events of both diseases and the cumulative rainfall and radiation during the season. Although operational decision can't be made on averages and summed data, this approach indicate the type of season. The graph shows that 1996 was a year with very low disease pressure and 1998 with very high pressure. In other climates where the PP system was used, the high temperatures benefit the infection with Alternaria. This happened in locations as Egypt, South Africa, Ontario, Canada and North Dakota, USA.



Case studies

<u>Egypt</u>

In 1998 Dacom carried out a feasibility study for the suitability of the PLANT-Plus system in Egypt. It soon appeared that Alternaria was an important disease but can be controlled well. The growing season in Egypt is in general during the winter time, from December till March. All the crops are irrigated by a center pivot system. The climate during the 2000 and 2001

season was very different. The humid and warm winter in 2000 resulted in a great number of infection events, resulting in 7 application and a high pressure from the outside. In 2001, only 4 applications were needed. This information also shows that infection events are caused by outside weather and not by the irrigation system. The irrigation will not sustain conditions for an infection event long enough to cause an infection. In both years, the control of Alternaria was excellent. In 2000, the advantage of using PLANT-Plus had to be gained by a better control of Alternaria while in 2001, the advantage was in using considerable less chemicals.
Case studies in other countries have also clearly shown the advantage of timed sprayings as advice by the PLANT-Plus system.

Conclusions

Occurrence of Alternaria in potatoes

- can cause great yield losses
- depends on weather conditions
- *Often* in line with Phytophthora infection events:
  - Therefore often unnoticed
  - Same humidity, prefers more heat
  - Depends on plant conditions:
    - Growth stage
    - Plant stress
- Survival on debris
- No curative products available
- Protection based on forecast, not on schedules

Control strategy

- Timed sprayings before infection event
- Uninterrupted plant growth (irrigation, fertilizer)

Control strategy with DSS:

- Improved control of Alternaria
- Dependency of weather forecast
- DSS's fail to warn in advance
- Spraying schemes fail under heavy pressure

PLANT-Plus model is based on scientific research and practical use has proven to be an excellent tool to control Alternaria.

Spatially interpolated Smith Periods and blight outbreak dates in the UK, 1998-2002

M.C. TAYLOR[1], N.V. HARDWICK[1] AND N.J. BRADSHAW[2]

[1]Crop Disease Research, Central Science Laboratory, Sand Hutton, York, YO41 1LZ, UK.
[2]ADAS Consulting Ltd., Henstaff Court Business Centre, Groesfaen, Cardiff, CF72 8NG, UK.

Summary

During 1998 to 2002, weather data from around 50 stations across England and Wales was used to generate interpolated maps of the date of the first Smith Period occurring for all locations where potatoes were grown on a 2 km x 2 km grid. These maps were subtracted from similar maps generated from scouting reports of the date of the first confirmed blight outbreak in maincrops. The resulting images represented the warning accuracy of the Smith Period forecasting scheme scaled by the number of days between warning and actual/interpolated infection. Using data on the number of hectares of potatoes typically grown within each 2km x 2km grid square the area of potatoes each year receiving a warning either too early, too late or ideal could be calculated. In years described as "severe" for late blight the Smith Period scheme gave larger areas of potatoes an ideal or too early warning than in years when the disease was "not severe". Averaging the extent of the warnings over all five years showed that only two potato growing localities typically received warnings on the too early side of ideal. The amount of potatoes grown within 20 km of the weather stations was very variable with regions such as Wales being very poorly represented. Some weather stations gave a date for the first Smith Period warning which was atypical for stations intended to represent a region. It is intended to repeat the exercise using a second, much denser, network of weather stations with more modern forecasting schemes.

Keywords: potato area comparison, spline interpolation, infection warning accuracy

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Introduction

On a national scale forecasting for late blight across England and Wales is achieved using the Smith Period scheme (Smith, 1956), which was introduced in the 1970's. The system uses about 50 of the UK Meteorological Office's synoptic stations, divided into six regions, which are not located with any particular reference to potato growing areas (Figure 1). This study made an attempt to evaluate how accurate the schemes' warnings were with regard to the first reported blight outbreaks by calculating what area of potatoes was covered by each of three warning classifications.

The weather stations used by the scheme are not intended to act independently but as part of a regional network covering an area with broadly similar topography and/or cropping practices. The results from this project were able to distinguish whether any regions contained stations whose warnings were falling outside the normal range for the other stations within their region. In addition it would be possible to calculate what area of potatoes was cultivated within 20 km of each weather station for comparison with the regional total.

Materials and methods

Each of the years 1998 to 2002 was treated as an individual case. The date of the first Smith Period occurring at each weather station after 1 May was used as a base network of 50 points from which an entire surface could be interpolated. The surface was defined by pixels representing 4 square kilometres on the ground and was constrained by using only grid squares where potatoes had been grown in the 1994 season, some 20246 locations. The tension spline method of spatial interpolation used to generate the surface was suited to the relatively sparse dataset and the fact that the extreme values of the surface may lie outside those recorded at the weather stations (Lam, 1983). Dates were coded as climatological days (Seem & Eisensmith, 1986) where days are counted from 1 March so that each day of the year has a unique value, including leap years. Following this convention 1 June is always day 93 and 31 August is always day 184.

A second image for each year was produced using the same method but using the locations and dates of confirmed outbreaks of late blight reported from around the regions during the course of the season. The number of sample locations varied from a minimum of 15 in 2001 to a maximum of 24 in 2000, unfortunately there is no systematic scouting system in the UK, but only confirmed and reliable records were used.

Using the geographical information system ArcView (Environmental Systems Research Institute, Redlands, Cal., USA) the pixel values in the image of the first Smith Period outbreak was subtracted from the image of the first confirmed blight occurrence. This yielded a map where the pixel values represented the days passing between the first warning of infection and the eventual appearance of the disease. Low values would indicate a poor warning with the disease following very soon after the forecast, maybe even before for negative values. Very high pixel values meant that the warning had preceded the outbreak by some considerable time. To aid interpretation the subtracted images for each year were reclassified so that all pixels with values less than 10, those with values from 11 – 21 and those with values greater than 21 were grouped together. These three groups represented warnings that were too late, ideal or too early respectively, although the classification values chosen were arbitrarily based on grower requirements.

Using the potato density data (Figure 1) the total hectares of potatoes growing within each warning category could be calculated and compared. Similarly the area of potatoes growing within a 20 km radius of the weather stations was calculated to estimate if there were differences in how representative the weather stations were within each region. The weather stations were also compared by plotting the date of their first Smith Period with the other stations within their region to check the consistency of the initial warning of blight infection.

Results

The images of the accuracy of the Smith Period forecasting scheme (Figures 2 – 6) illustrate that there appears to be little consistency between years in where the scheme is working best or indifferently. It is possible to average the warning category for each pixel over the five years (Figure 7) to reveal that the only problem areas are southern East Anglia and the southern Pennines.

The area of potatoes grown within each warning category (Figure 8) show that in years regarded as severe for the disease (1998 and 2002) the Smith Period scheme was safer than non severe years. In 2000 the disease was of intermediate severity for most growers and this was the only year of the five when the scheme did not perform particularly well with more than half the total area of potatoes receiving a warning that was less than ideal.

The results for the area of potatoes lying within 20 km of a weather station and the dates of the initial Smith Period are presented as a box and whisker plot which are particularly useful for showing the distributional characteristics of data (Figures 9 and 11). The width of the box is proportional to the number of items (in this case weather stations) included in the plot, a line is drawn across the box at the median. The bottom of the box is at the first quartile (Q1), and the top is at the third quartile (Q3) value. The whiskers are the lines that extend from the top and bottom of the box to the adjacent values. The adjacent values are the lowest and highest observations that are still inside the region defined by the following limits:

Lower Limit: Q1 – 1.5 (Q3 – Q1)
Upper Limit: Q3 + 1.5 (Q3 – Q1)

Outliers are points outside of the lower and upper limits and are plotted with an asterisk (*).

The East Anglia (EA), Midlands & West (M&W) and Northern (N) regions had weather stations which were closer to potato growing areas than the other regions (Figure 9). The EA and N regions grow most potatoes and a reasonable proportion (30% – 40%) is within 20 km of a weather station (Figure 10). The range of dates of the first Smith Period (Figure 11) was greatest for the Northern region probably reflecting the comparatively large latitudinal extent. The South West (SW), an area favoured for production of early potatoes, had clearly earlier warnings than the other regions.

Discussion

The Smith Period forecasting scheme was never intended to be field specific and the resolution of 2 km x 2 km imposed by the available cropping data used in this project may be as high as practicable. The extent and position of the areas of potato cultivation falling under each of the warning categories is clearly variable from year to year (Figures 2 – 6) despite the fact that the disease follows a broadly predictable regional development, starting in the South West and progressing North Eastward. This may be partly due to sources of inoculum, the forecasting scheme is aimed at protecting field crops from infection by monitoring short term temperature and humidity conditions. Growers may have blight infected dumps of potatoes on their land generating their own microclimate and acting as an early source of sporangia and eroding the length of infection warnings given by any forecasting scheme. Using reports only of confirmed outbreaks of blight in field crops ensured a consistency on which to base the disease maps across years but not all crops are uniformly at risk.

Over the five years covered in this report the Smith Period provides good warnings (either in the Ideal or Too Early categories) for most potato crops for seasons generally regarded as severe for late blight (Figure 8). The warnings were also accurate for the less severe year of 2001 but in 1999, also a low severity year, over two thirds of the area received a warning in the Too Late category. As the situation was slightly improved in 2000, a moderately severe year, it appears that the scheme responds to the national situation regarding the risk of blight infection and works best in blight favourable years. Assigning years as either "severe" or "not severe" is clearly open to interpretation but is based mainly on whether significant numbers of growers across large parts of England and Wales were struggling to control blight in their crops despite intensive fungicide programmes.

Working against the accuracy of the forecasting scheme is the fact that some of the potato cropping areas are located a great distance from the nearest weather station. Although nearer is generally regarded as better, the distance for which a particular weather station can be representative for potato fields must depend on surrounding topography. The Smith Period has shown itself to be robust in terms of any alterations to warning accuracy as distance from weather station increases (Hardwick *et al.*, 2000) but is still reliant on the data being representative for large areas of land. Field based sensors may be prone to distortion in their readings due to local sheltering effects making forecasts applicable over a shorter range, particularly in areas of greater orographic relief. Sensors at airfields, a frequent location for the synoptic stations used for the Smith Period scheme, or on roadsides may be more exposed and gives a valid warning for larger areas but miss out particularly favourable localities. An ideal forecasting scheme for national coverage would need to strike a balance between the two extremes. Some of the stations used for Smith Period forecasts in the South West and Wales regions show warning dates as outliers on the box plots (Figure 11) and are therefore out of step with their neighbours.

The map of the average warning category (Figure 7) shows that the Smith Period scheme works less well for some regions over the five year study. Both the southern area of East Anglia and that around the south and east of the Pennine hills grow a reasonable amount of potatoes although neither a major centres of production. Cultivar choice or regional husbandry practices/attitudes may have an impact on the performance of the scheme in these areas and maybe the short term nature of the Smith Period criteria are less suited to the regional climate. The view that forecasting schemes for late blight will not be internationally applicable has been debated for some years (Zadoks, 1984) and over large geographical areas it would seem plausible that a single scheme may not be the best for all situations. It will be instructive to repeat the mapping exercise with a different forecasting scheme to ascertain whether it has comparable areas of difficulty. More modern schemes such as NegFry (Hansen, 1999) require a greater density of weather stations and some additional meteorological parameters but would be more suited to producing the 2 km x 2 km resolution forecast maps.

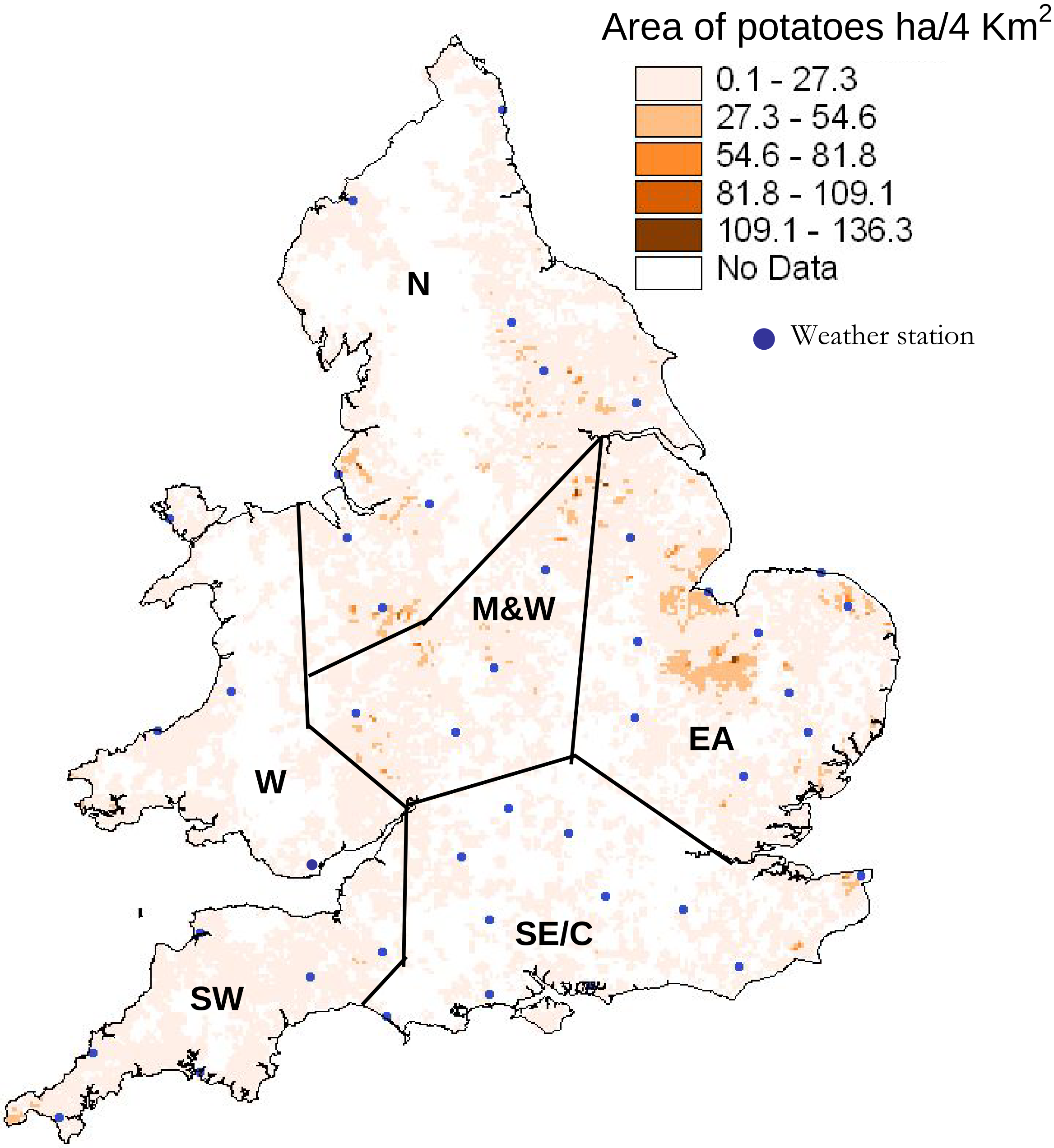

Figure 1. Areas of potato production across England and Wales, location of synoptic weather stations monitored for Smith Periods and regional divisions used to aid interpretation of blight forecast warnings.

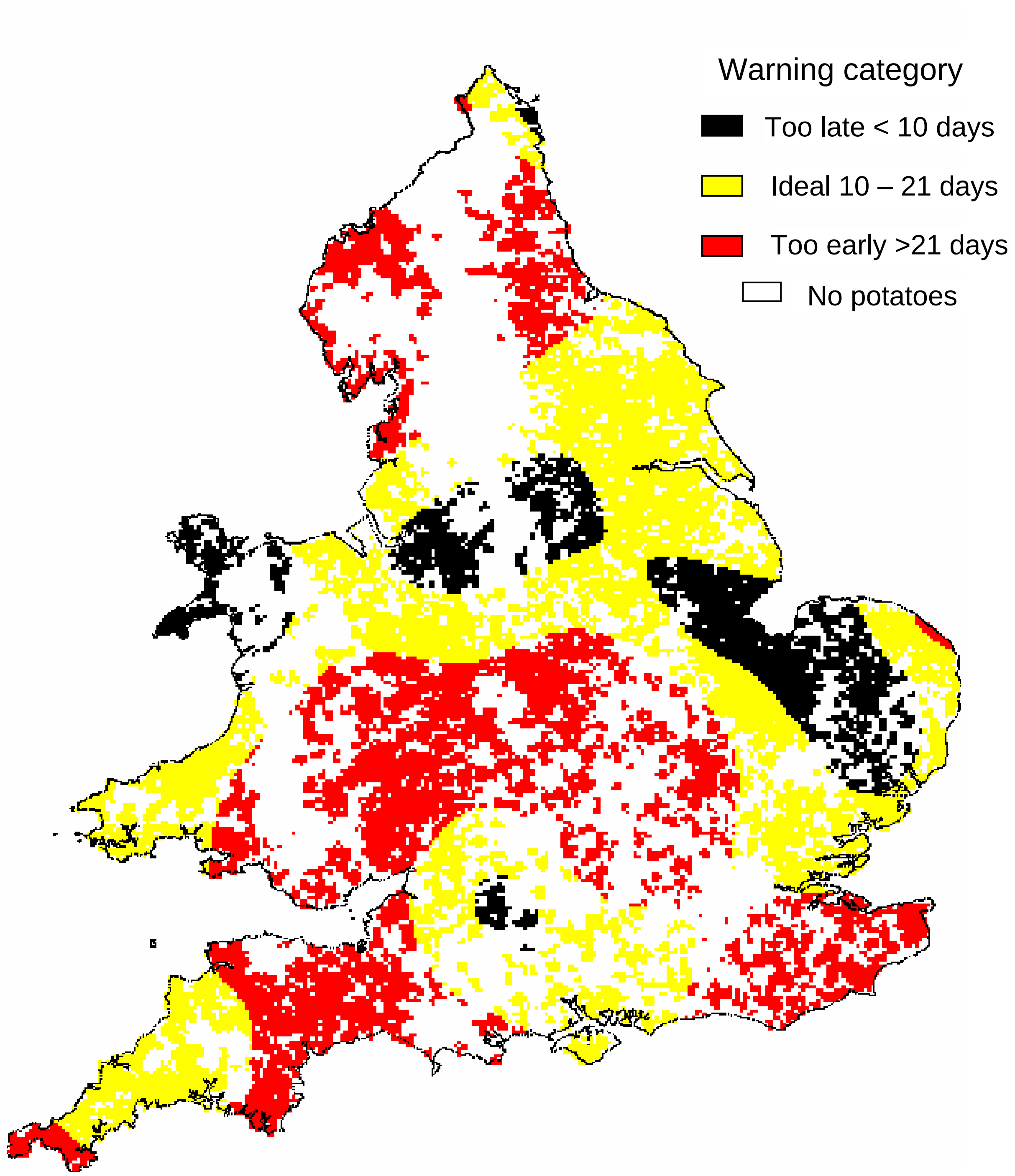

Figure 2. Extent of Smith Period accuracy categories 1998

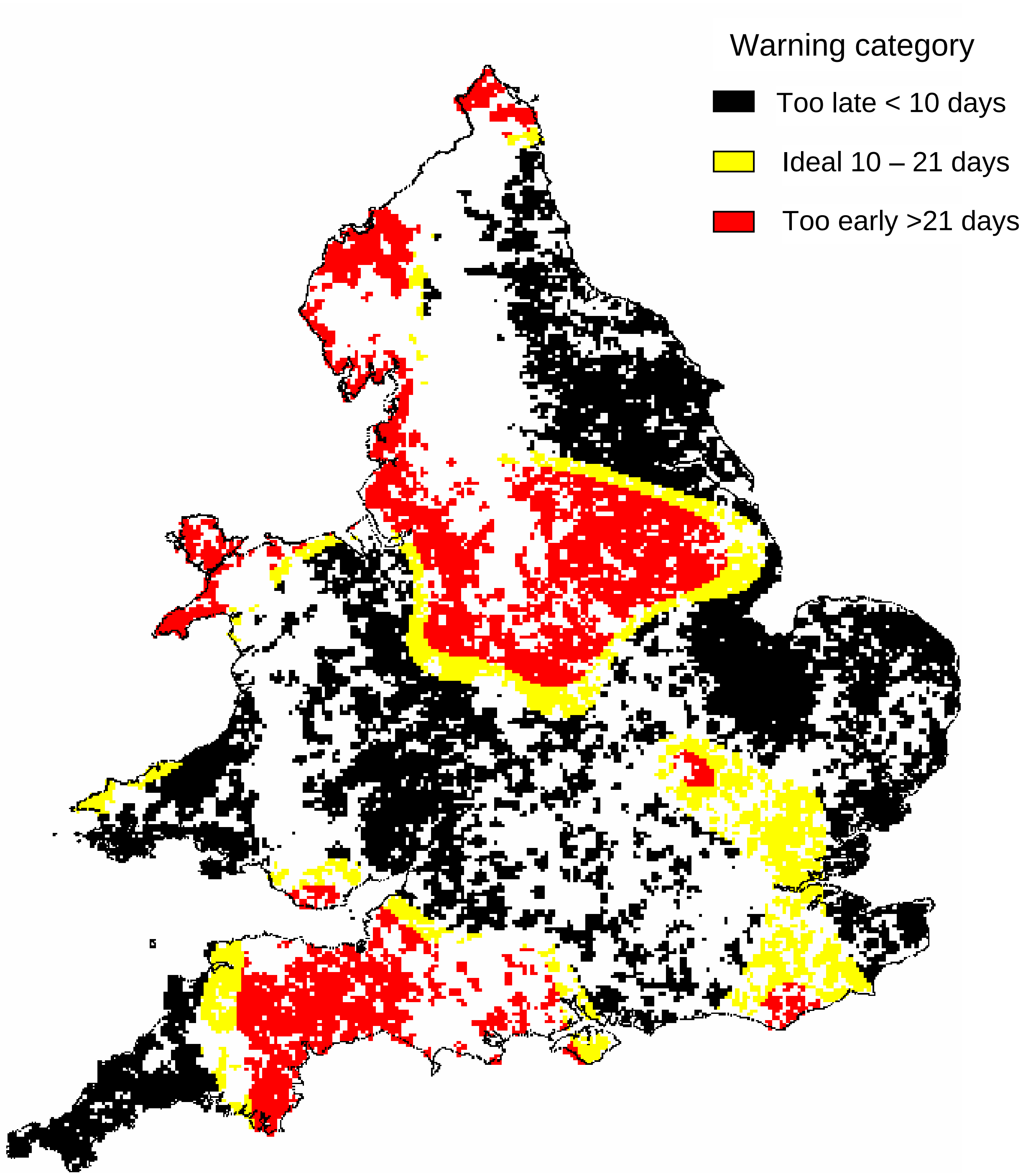

Figure 3. Extent of Smith Period accuracy categories 1999.

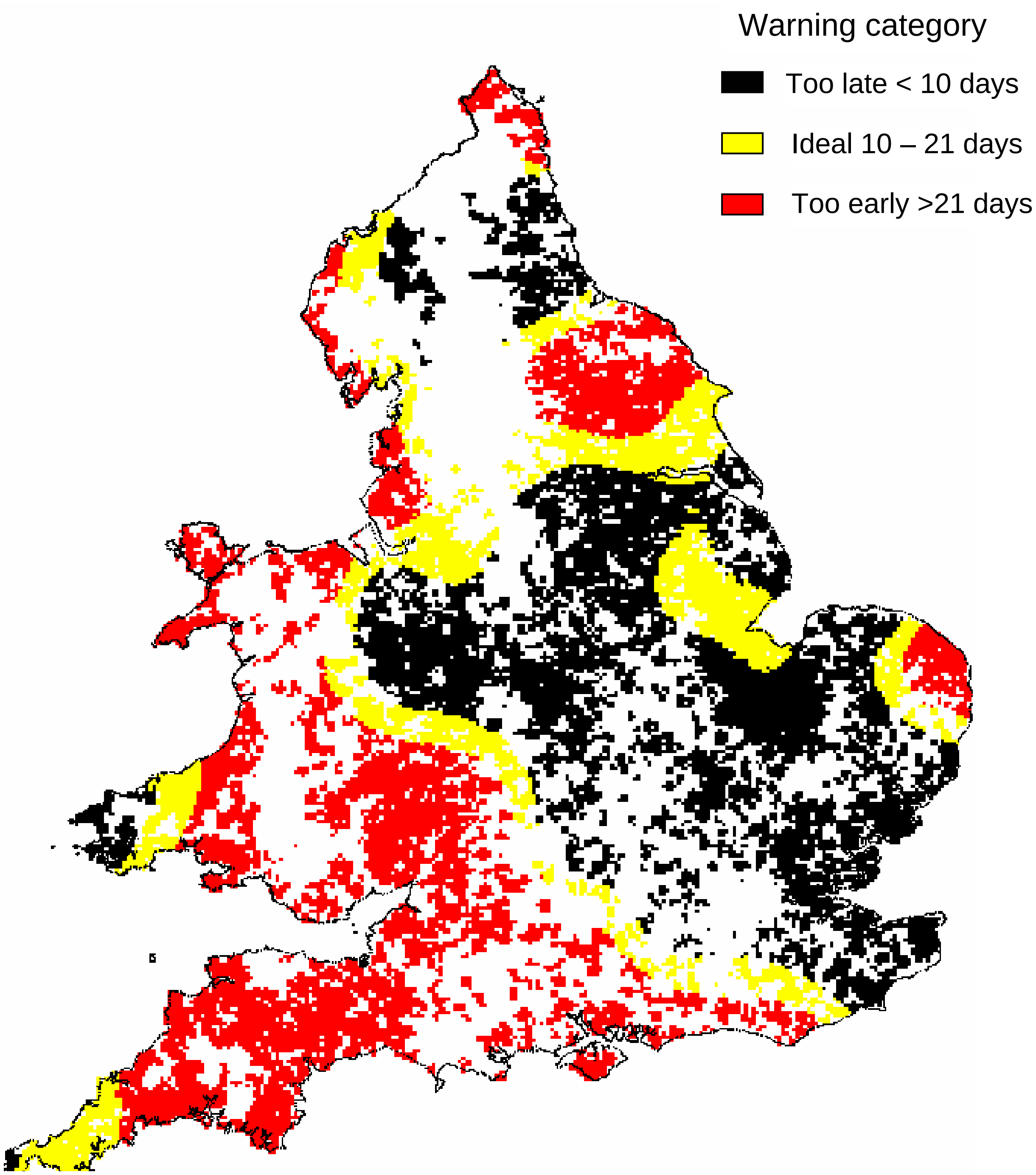

Figure 4. Extent of Smith Period accuracy categories 2000.

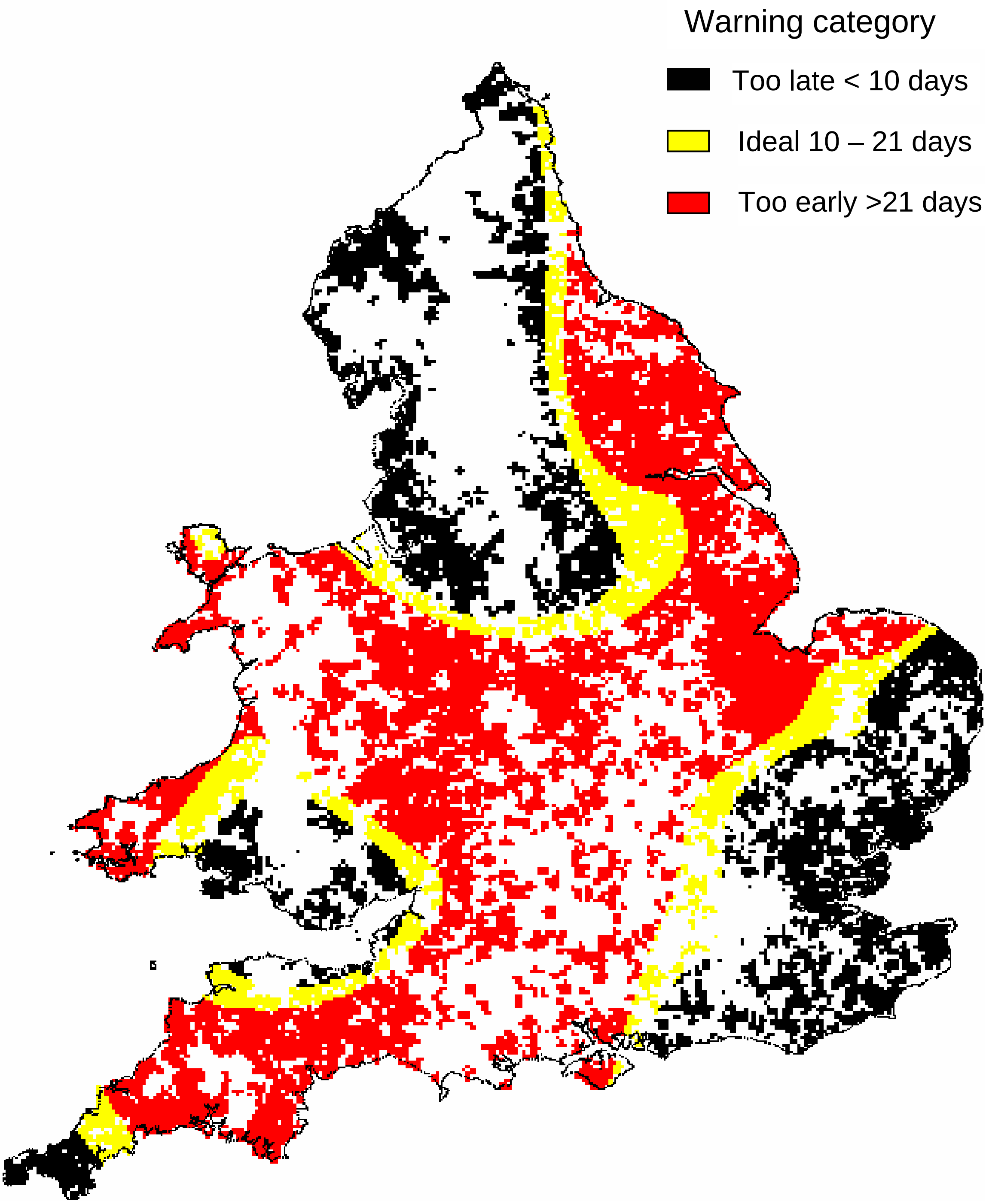

Figure 5. Extent of Smith Period accuracy categories 2001.

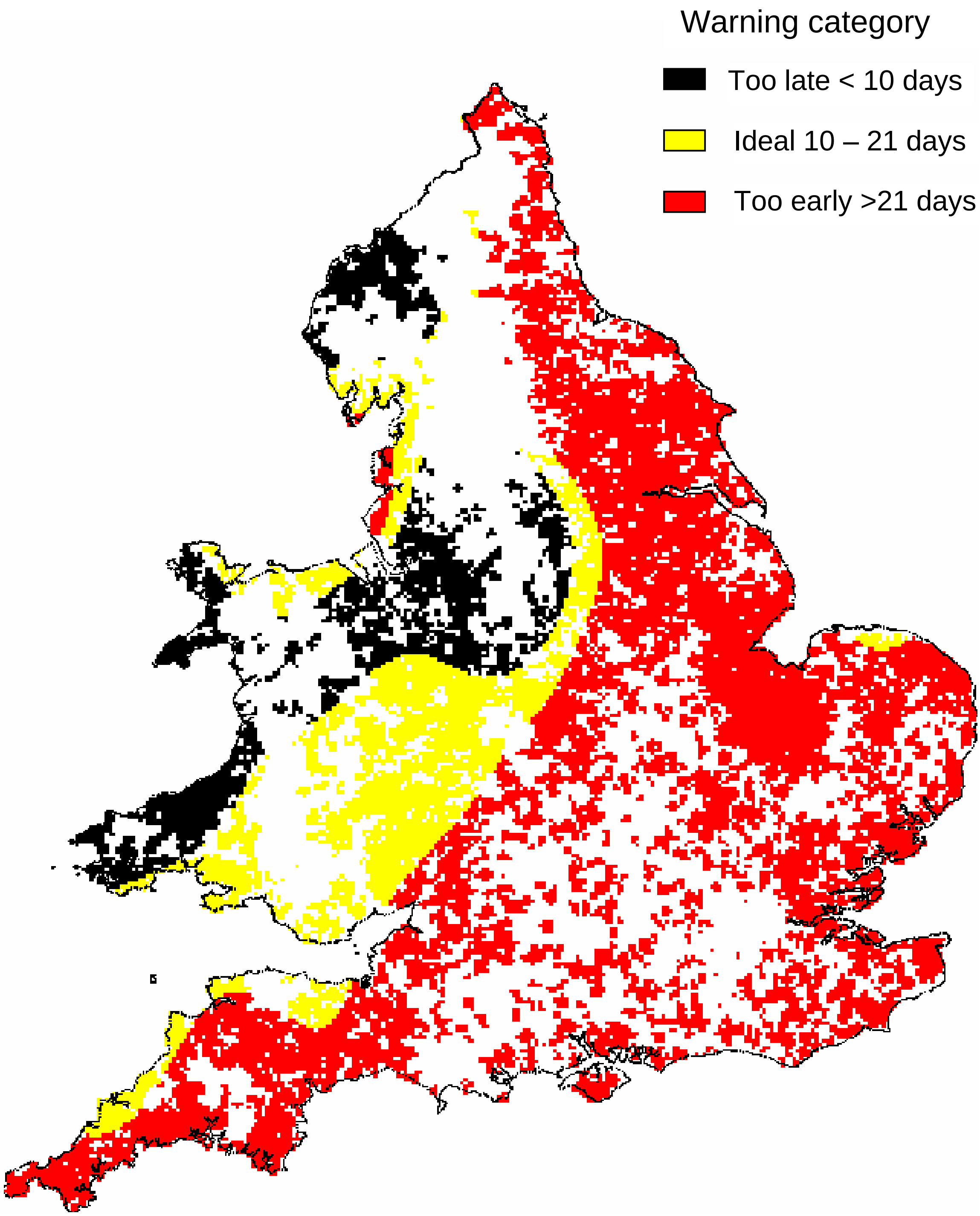

Figure 6. Extent of Smith Period accuracy categories 2002.

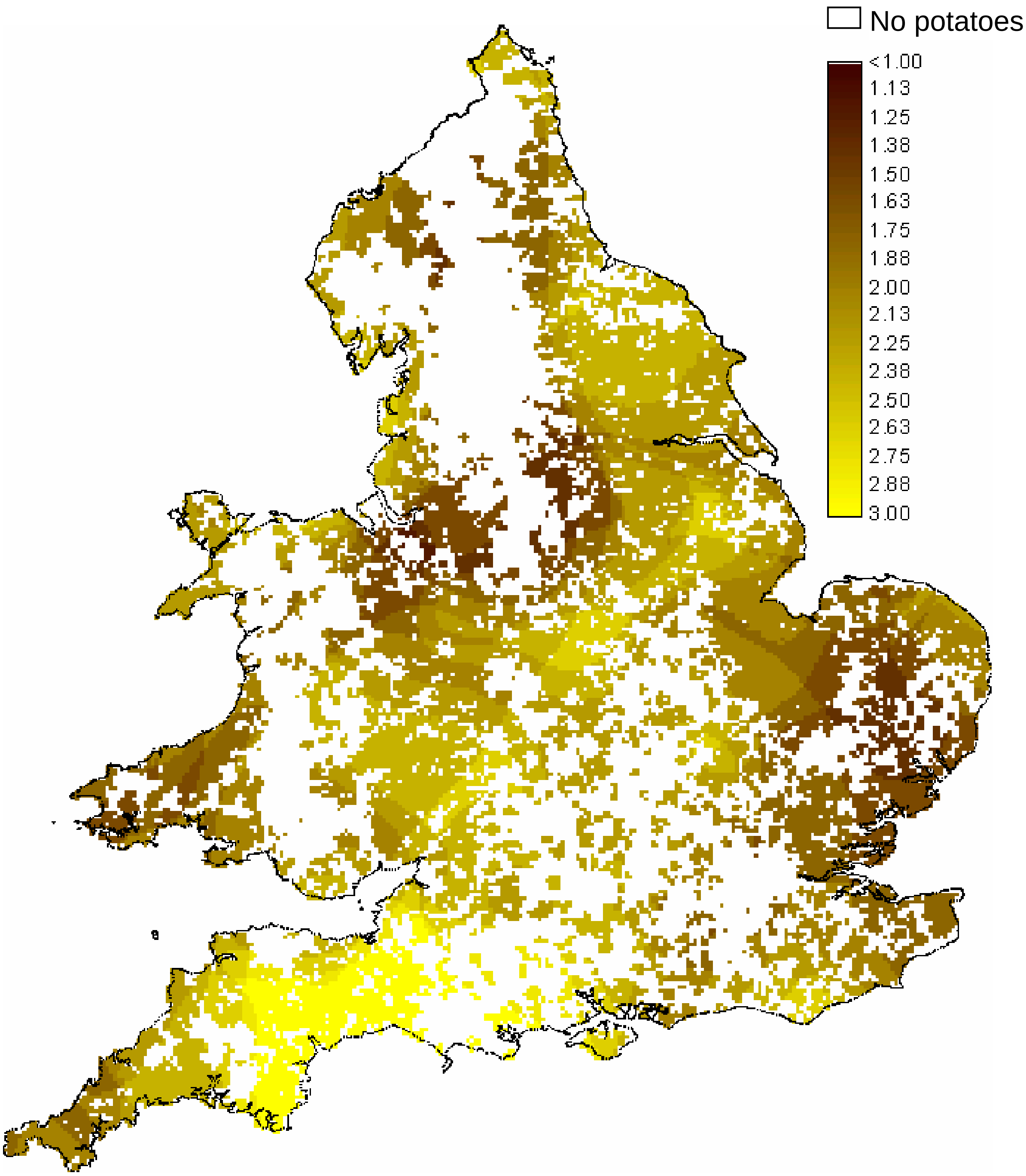

Figure 7. Smith Period average warning category, 1998 – 2002.

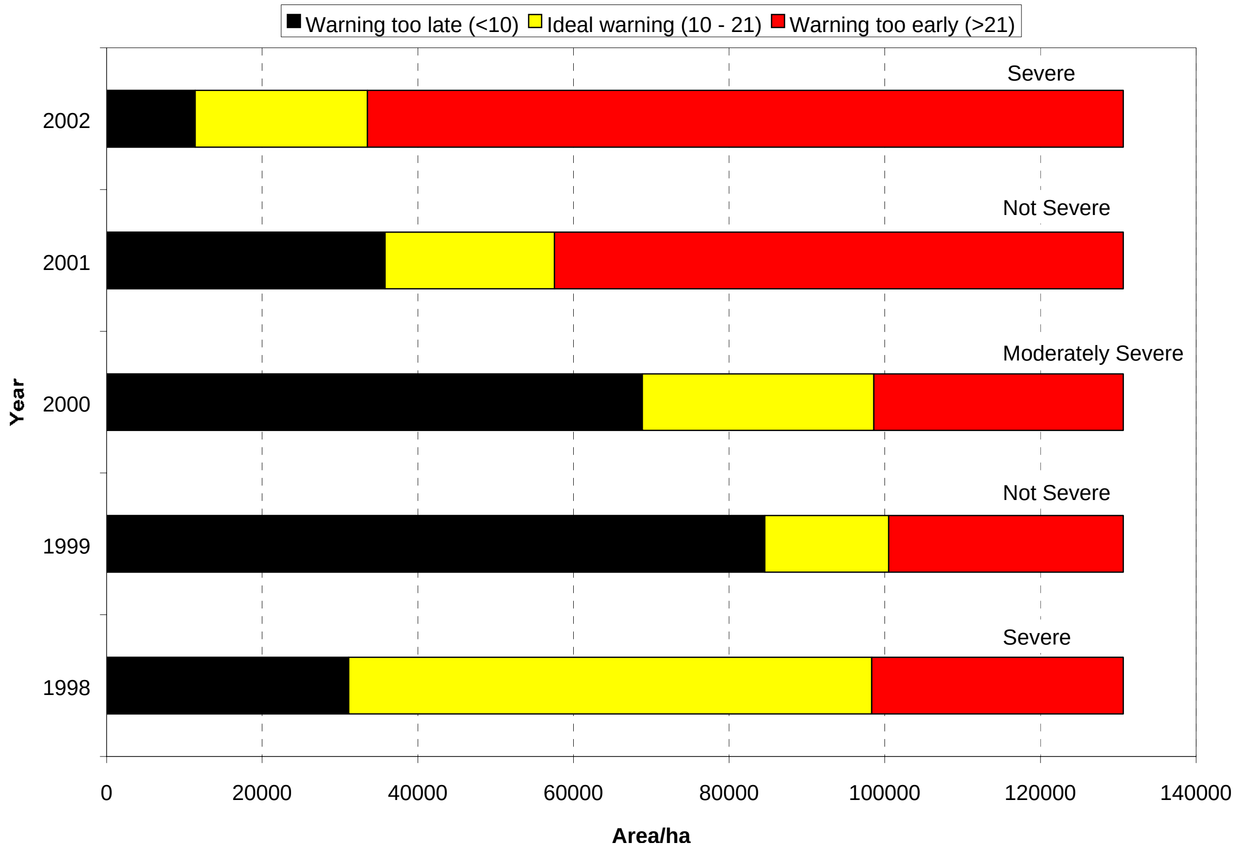

Figure 8. Potato area within Smith Period warning category.

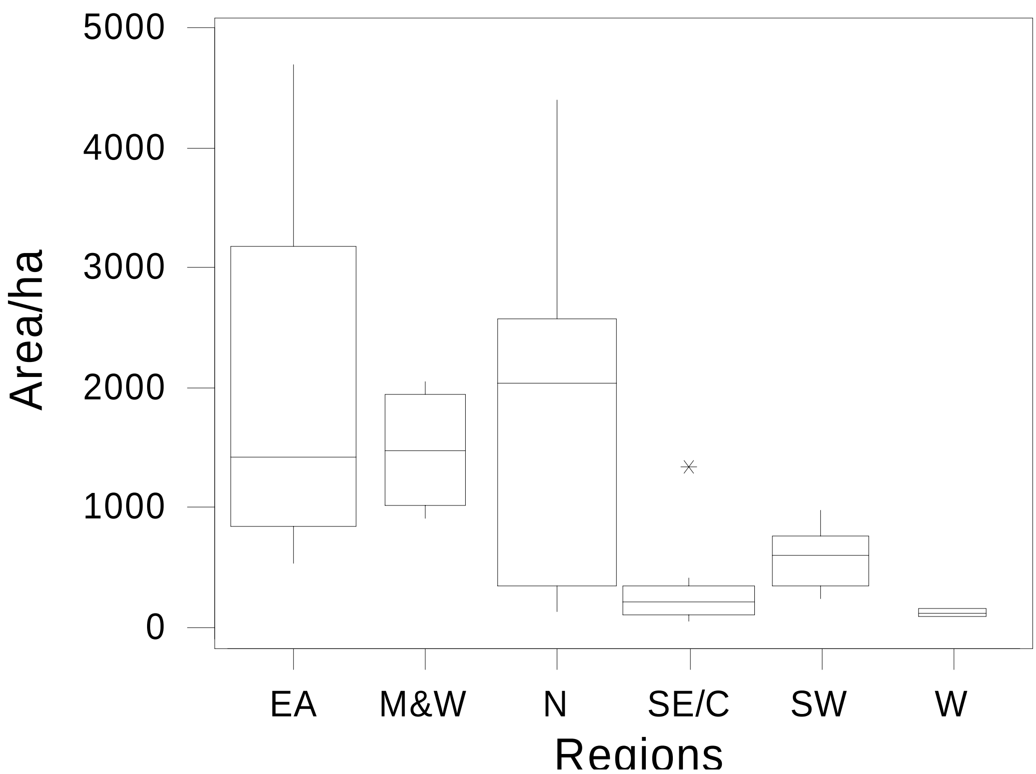

Figure 9. Area of potatoes found within 20 km of a weather station, arranged by region.

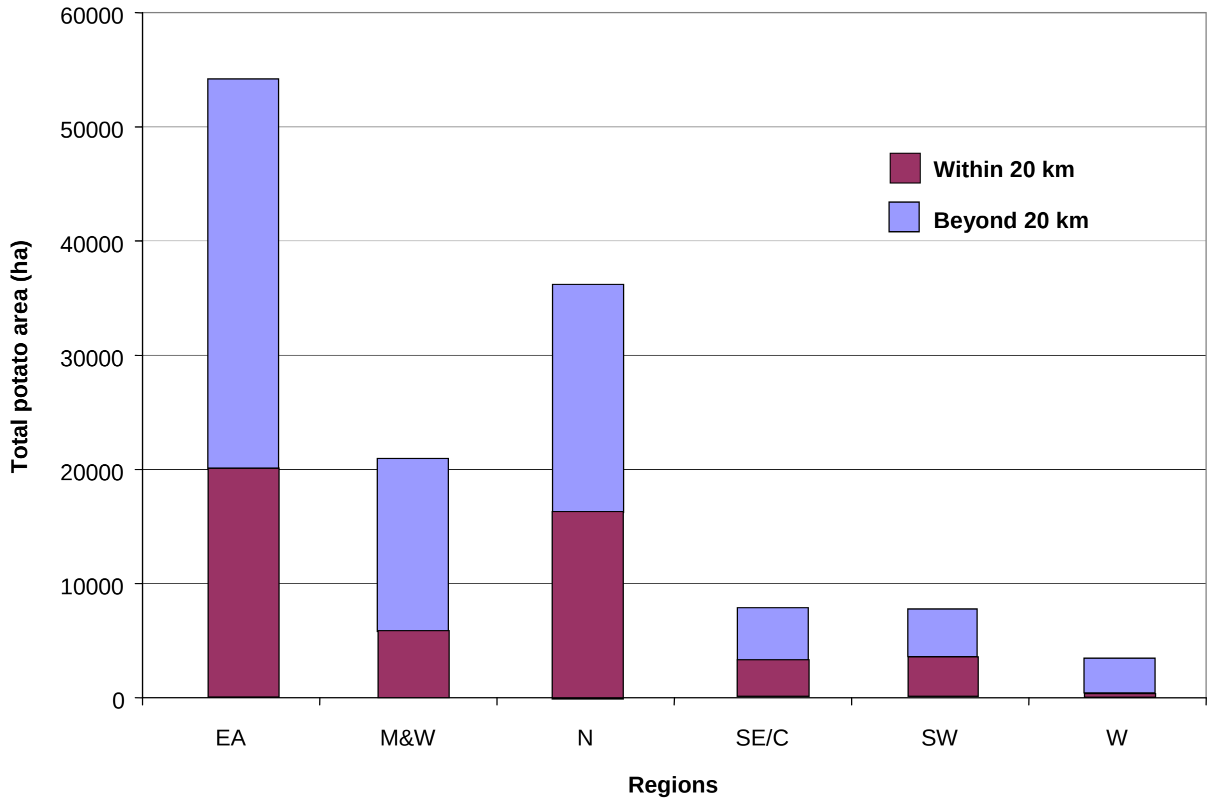

Figure 10. Proportion of regional potato crop within 20 km of a weather station.

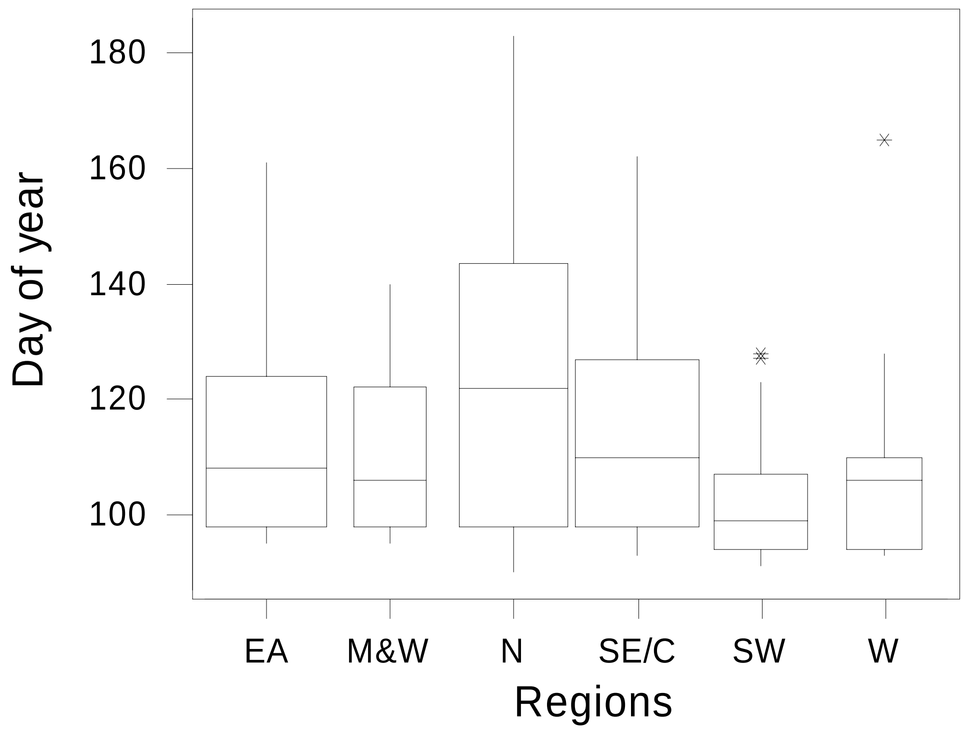

Figure 11. Range of first Smith Period dates arranged by region.

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DSS field evaluation focussed on variety resistance in The Netherlands, 2002

J.G.N. WANDER[1], H.G. SPITS[1] AND G.J.T. KESSEL[2]

[1]Applied Plant Research (PPO), P.O.Box 430, 8200 AK Lelystad, The Netherlands

[2]Plant Research International, P.O.Box 16, 6700 AA Wageningen, The Netherlands

Summary

DSS's in the Netherlands for management of potato late blight are of a very good quality, but the possibilities to improve recommendations by including data regarding variety resistance can probably be exploited in a better way. This could lead to a more efficient control of blight and possibly in a further reduction of fungicide input. With this objective the 2002 trials in the Netherlands were conducted. With the DSS's PLANT-Plus, ProPhy and the research tool WUR-Blight five varieties were tested.

Prophy and PLANT-Plus did hardly differentiate between the varieties in the number of sprays and the dose rate of Shirlan.

Degree of tuber blight infection seemed to depend on degree of leaf blight at the end of the growing season and the input of Shirlan sprayed in this period

Key words: *Phytophthora infestans*, variety resistance, decision support systems, tuber blight, fluazinam

Introduction

In the years 1999 until 2001 yearly 3 trials were conducted in the Netherlands to compare and validate Dutch and foreign Decision Support Systems (DSS). In 2002 the field evaluation of DSS focussed on variety resistance. How to use and exploit moderate and high resistance for *Phytophthora infestans* is a challenge to further improve DSS's.

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In 2002 two trials were conducted. The trial situated at Valthermond is not discussed in this paper because of very low infection levels, although the disease pressure in the surrounding fields was very high.

Materials and methods

Trial site, experimental set-up and weather data

The trial was set up on a loamy soil at Lelystad, The Netherlands. In the trial the DSS's Prophy and PLANT-Plus and the DSS research tool WUR-Blight (Kessel *et al.*, 2003) were tested on the varieties (late blight resistance foliage/tuber): Bintje (3/4.5), Santé (4.5/7), Agria (5.5/8), Remarka (6.5/8.5) and Aziza (7.5/8). Plot size was 10.5 x 10 m gross and 4.5 x 8 m net. Potatoes were planted on ridges on a distance of 75 cm and 32 cm in the ridge on April 25. Eighty percent of the plants were emerged on June 4. The trial was desiccated on August 29 and harvested on September 23.

When the development of Phytophthora in a plot clearly exceeded the average level of infection in the other plots, the crop on this plot was desiccated. All experiments were set up as randomised block treatments with three replications. The log-transformed data of the calculated infection percentages and percentages tuber blight were statistically analysed using ANOVA of GENSTAT 5, release 6.1.

Tuber blight was only estimated on plots, which were not early desiccated.

Fertilisation, insecticides and herbicides were applied according to good agricultural practice.

Distance to the automatic weather station of DACOM was less than 1 km. The Opticrop weather station was situated in the trial. 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 WUR-Blight. Hourly data as mentioned before and on temperature and relative humidity in the crop measured by Opticrop stations were used for ProPhy. PLANT-Plus and ProPhy both used 3-hourly successively hourly regional weather forecasts for five consecutive days.

The fungicides used were Shirlan Flow (50 % a.i. fluazinam), Aviso DF (4.8 % a.i. cymoxanil, 57 % a.i. metiram) and Tattoo C (375 g/l a.i. chlorothalonil, 375 g/l a.i. propamocarb hydrochloride) in a variable dose for Shirlan, 2.5 kg/ha for Aviso DF and 2,7 l/ha for Tattoo C.

Observations

Disease observations were carried out weekly. The first disease observation was carried out on June 18, the last on August 29. The number of diseased leaflets, petioles and stems on four ridges of net length of the plots were counted (Wander and Spits, 2002). Yield was not assessed. A tuber sample of 18 m^2 out of the net plot was stored for some weeks at 15 °C. In this sample the number of potatoes with a lesion or lesions of Phytophthora were counted.

Use of the DSS's

The systems were consulted daily (before 9:30 A.M.) except on Sundays. The farm manager decided how to interpret the recommendations made by Prophy and PLANT-Plus.

Prophy

The 2002 version of Prophy (CROP 2002, version 2.8) was used. ProPhy gives full recommendation (recommended type of fungicide, interval, dose) for individual varieties. Fungicide and dose were used according to the recommendation, however in this trial the recommendation interval of the less resistant variety dictated the interval for all varieties.

PLANT-Plus

The Windows version 3.3 of PLANT-Plus was used. The spraying interval and recommended type of fungicide were calculated for each variety independently. A recommendation was only used when the threshold of 200 was exceeded.

WUR-Blight

The WUR-Blight version 1.0 was used. The program only calculated the date of spraying for a sensitive variety using the model SIMCAST (Kessel *et al.*, 2003). The fungicide used was always Shirlan, irrespective whether a recommendation could be followed immediately or had to be postponed due to weather circumstances. The dose of Shirlan used was based on the level of resistance: Bintje 0.4 l/ha, Santé 0.32, Agria 0.24, Remarka 0.16 and Aziza 0.08.

Results

Spraying schedule and infection percentage

Spraying schedules and infection percentages are shown in the figures 1, 2 and 3. ProPhy and

WUR-Blight both gave the first recommendation on June 6. PLANT-Plus gave the first recommendation 15 days later on June 21. The total number of sprayings per system was 9 for PLANT-Plus, 15 for ProPhy and 11 for WUR-Blight.

In table 1 the real infection percentages shown in figures 1, 2 and 3 are shown including significant differences. Desiccated plots are included in the average of a system / variety combination until the date of desiccation.

From the beginning of the season until mid August the infection level of PLANT-Plus / Bintje was higher than the infection level of the other varieties. From the beginning of August the infection percentage of PLANT-Plus / Remarka was higher than of Santé, Agria and Aziza.

The infection percentage of ProPhy / Remarka was significantly higher than on the other varieties on August 16. On August 29 the infection percentage of ProPhy / Bintje was significantly higher than on Santé and Agria.

Average dose Shirlan

The average dose of Shirlan sprayed according to the recommendation of ProPhy was 0.30 l/ha for Bintje, Santé and Agria, 0.28 l/ha for Remarka and 0.25 l/ha for Aziza. On Remarka, 4 out of 12 sprayings with Shirlan were with a reduced dose and on Aziza 7 out of 12.

Early desiccation

Table 2 shows the dates on which plots had to be desiccated because the level of infection clearly exceeded the average level of infection in the other plots. In this way a high spore pressure on the surrounding plots was prevented. On June 18 one of the plots of PLANT-Plus / Bintje had quite a severe infection. On this date only on one other plot of ProPhy / Santé a light infection was observed (table 1).

On July 26 one of the WUR-Blight / Remarka plots had to be desiccated. The two remaining plots still had a very low level in spite of the very low dose of Shirlan (0,16 l/ha).

After the desiccation on August 16 of one of the ProPhy / Remarka plots the two remaining plots of ProPhy / Remarka and the three plots of ProPhy / Aziza were desiccated by mistake on August 19 due to a wrong interpretation of the recommendation given by ProPhy.

For all systems none of the Santé and Aziza plots had to be desiccated.

Table 1. Calculated infection percentages and marks for significant differences based on log-transformed data.

System	Variety	18-6		25-6		3-7		11-7		18-7		25-7	
PLANT-Plus	Bintje	0.133	b[1]	0.187	b	0.472	b	0.430	b	0.842	c	0.469	ab
	Santé	0.000	a	0.005	a	0.000	a	0.003	a	0.005	a	0.015	a
	Agria	0.000	a	0.052	a	0.068	a	0.067	a	0.225	ab	0.259	ab
	Remarka	0.000	a	0.005	a	0.018	a	0.016	a	0.073	ab	0.231	ab
	Aziza	0.000	a	0.000	a	0.000	a	0.000	a	0.003	a	0.001	a
ProPhy	Bintje	0.000	a	0.000	a	0.000	a	0.000	a	0.009	a	0.055	a
	Santé	0.005	a	0.000	a	0.001	a	0.012	a	0.036	a	0.070	a
	Agria	0.000	a	0.000	a	0.000	a	0.004	a	0.037	a	0.099	a
	Remarka	0.000	a	0.000	a	0.000	a	0.001	a	0.013	a	0.095	a
	Aziza	0.000	a	0.000	a	0.000	a	0.003	a	0.005	a	0.020	a
WUR-Blight	Bintje	0.000	a	0.001	a	0.029	a	0.045	a	0.124	ab	0.149	ab
	Santé	0.000	a	0.000	a	0.000	a	0.001	a	0.001	a	0.010	a
	Agria	0.000	a	0.000	a	0.049	a	0.049	a	0.197	ab	0.355	ab
	Remarka	0.000	a	0.000	a	0.001	a	0.045	a	0.563	bc	13447.00	b
	Aziza	0.000	a	0.001	a	0.000	a	0.003	a	0.035	a	0.131	ab

Table 1 continued

System	Variety	2-8		9-8		16-8		22-8		29-8	
PLANT-Plus	Bintje	0.233	d	0.337	d	1.222	cd	0.478	a	2.000	abcd
	Santé	0.007	a	0.075	ab	0.319	abc	1.081	ab	1.763	ab
	Agria	0.115	abcd	0.269	cd	0.908	abcd	0.670	a	0.400	ab
	Remarka	0.147	bcd	0.268	cd	1.346	cd	8.000	c	8.500	bcd
	Aziza	0.000	a	0.001	a	0.019	a	0.154	a	0.197	a
ProPhy	Bintje	0.029	ab	0.100	abc	0.268	abc	0.820	ab	9.333	cd
	Santé	0.027	ab	0.100	abc	0.199	abc	0.503	ab	0.733	ab
	Agria	0.055	abc	0.070	ab	0.372	abc	1.063	ab	1.733	ab
	Remarka	0.041	abc	0.093	abc	1.933	d	-		-	
	Aziza	0.000	a	0.001	a	0.083	ab	-		-	
WUR-Blight	Bintje	0.086	abc	0.224	bcd	1.459	bcd	0.205	a	0.850	ab
	Santé	0.007	a	0.042	ab	0.146	abc	0.297	a	0.800	ab
	Agria	0.158	cd	0.286	d	1.116	cd	0.830	ab	2.500	abc
	Remarka	0.023	a	0.186	abcd	2.500	d	6.000	b	30.000	d
	Aziza	0.021	ab	0.045	ab	0.310	abc	0.685	ab	16.000	cd

[1] *Values in columns followed by the same letter are not significantly different (a= 0.05)*

Table 2. Dates of necessary early desiccation per plot.

	Bintje	Agria	Remarka
PLANT-Plus	18-6, 16-8	16-8	22-8
ProPhy			16-8
WUR-Blight	16-8	16-8	26-7, 16-8

First observation

In table 3 the dates are shown on which blight was first observed in a specific system / variety combination. In Bintje blight was observed first in PLANT-Plus and last in ProPhy. In Santé, blight was observed first in ProPhy and last in WUR-Blight. In Aziza, blight was observed first in WUR-Blight and last in PLANT-Plus.

Table 3. Dates of first observation of potato late blight.

	Bintje	Santé	Agria	Remarka	Aziza
PLANT-Plus	18-6	25-6	25-6	25-6	18-7
ProPhy	18-7	18-6	11-7	11-7	11-7
WUR-Blight	25-6	11-7	3-7	3-7	25-6

Tuber blight

Percentages tuber blight are shown in table 4. In PLANT-Plus and ProPhy, Bintje had significantly more tuber blight compared to the other varieties. In WUR-Blight Aziza showed the highest percentage.

Table 4. Percentage tuber blight per system and variety.

	variety	% tuber blight	
PLANT-Plus	Bintje	7.4	d[1]
	Santé	0.7	ab
	Agria	0.3	ab
	Remarka	0.1	a
	Aziza	1.0	ab
ProPhy	Bintje	2.8	cd
	Santé	0.6	ab
	Agria	0.5	ab
	Remarka	-	
	Aziza	-	
WUR-Blight	Bintje	0.9	abc
	Santé	0.2	ab
	Agria	0.1	a
	Remarka	0.4	ab
	Aziza	1.3	bc

[1] *Values in columns followed by the same letter are not significantly different (a= 0.05)*

Discussion

In the 2002 trial in Lelystad, PLANT-Plus gave the first recommendation 15 days later than ProPhy. This trend was also seen in other years cq trials. PLANT-Plus recommended the first spray 6 to 24 days (with a mean of 11 days) later than Prophy (Wander and Spits, 2002; Spits and Wander, 2001; Visser and Meier, 2000). Only in the 2002 trial at Valthermond no difference occurred. In the 1999, 2000 and 2001 trials the late first recommendation of PLANT-Plus did not cause problems with blight severity.

In the 2002 trial at Lelystad in 1 out of 3 PLANT-Plus plots with the variety Bintje blight was observed three days before the first recommendation cq spray. In this plot a calculated infection percentage of 0.14 occurred. There might be two reasons for the occurrence of this infection: (1) the model calculated a too low infection risk or (2) there was an unknown infection source. This second reason seems to be the most plausible. On the other hand several times before the infection was observed a high infection risk was calculated but the threshold of 200 was not exceeded. Using a lower threshold for the first recommendation can reduce the risk for an early infection. When the threshold of 50 is exceeded the program gives the recommendation to consider a spray. Before the first spray was recommended (at 200) this situation had occurred several times.

Directly after this first observation of blight, this information was imported in the program. Because of a low infection risk PLANT-Plus did not give a spraying recommendation until three days after the observation. Because of the high infection level and because the crop was still untreated, the infected plot was desiccated on the day of the first observation of blight. On the two replicate plots of PLANT-Plus / Bintje, blight was observed 4 days after the spray. Probably an infection had occurred on these two plots also before the first spray.

The infection level on the two remaining plots of PLANT-Plus / Bintje was on a relatively high level during the rest of the growing season. Because also several other plots in the trial were infected, it was decided not to desiccate these two plots. The infection level remained high probably by the fact that the second, third and fourth spraying recommendations had to be postponed with one or two days because of the weather circumstances. Also the long intervals between recommendations in the period mid July mid August might have contributed to remaining a high infection level. Mid August several other plots including a second plot of PLANT-Plus / Bintje were desiccated.

First observation of blight in ProPhy was June 18 in Santé, July 11 in Agria and July 18 in Bintje. The spraying schedule (recommendation, spraying date, dose and fungicide) was exactly the same for these three varieties except the erroneously postponed spray on June 24 on Santé. The late occurrence in Bintje is especially remarkable while this is the most susceptible variety.

The figures 1, 2 and 3 show a remarkable increase of the infection in all varieties and especially in Remarka after the observation on August 9. On all systems spray recommendations of August 3, 5 or 6 had to be postponed to August 7. So, in this period infections have occurred. The increase of the severity on Remarka (late blight resistance 6.5) and Agria (5.5) were about the same as on Bintje (3). Probably the ageing of the plants had a stronger effect on the decrease of the resistance on Remarka and Agria than on the other varieties.

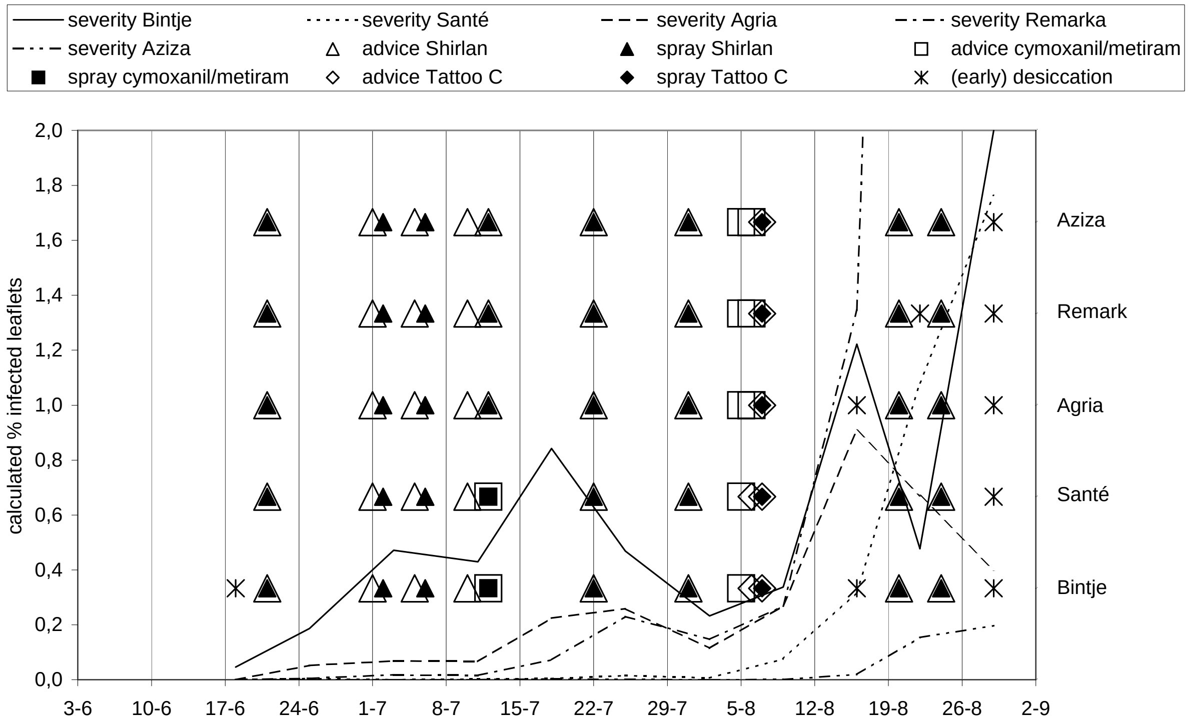

Figure 1. Advises, spraying schedule and calculated percentage infected leaflets for PLANT-Plus.

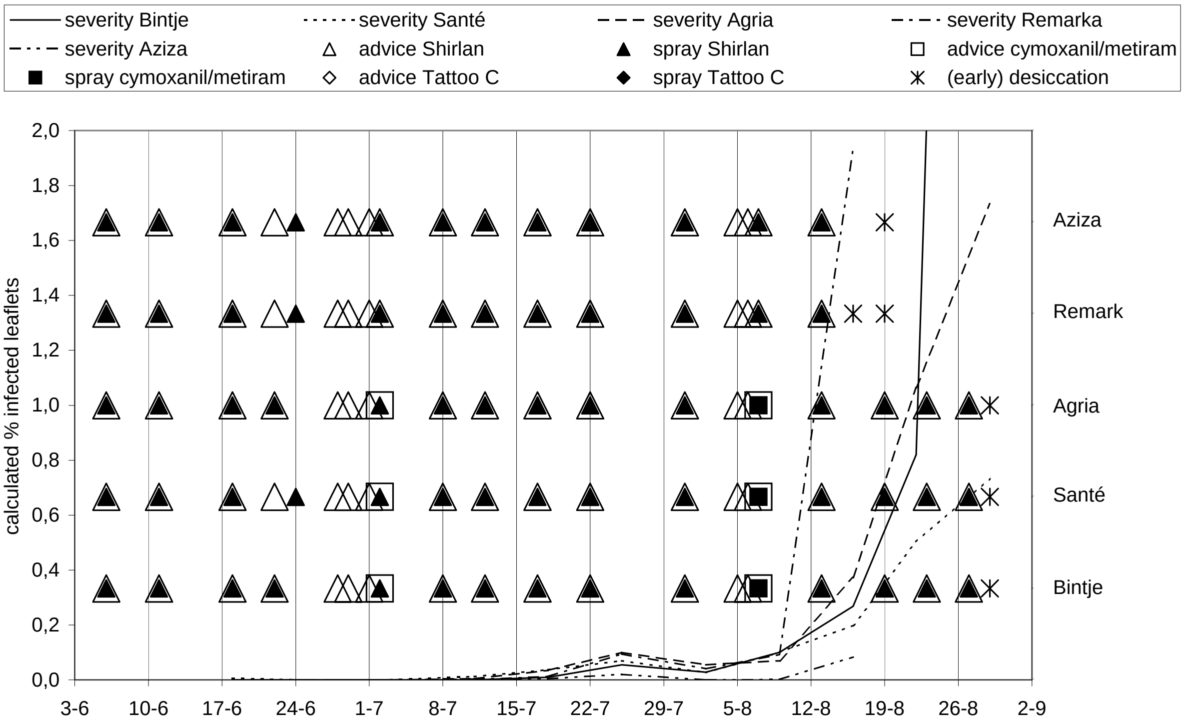

Figure 2. Advises, spraying schedule and calculated percentage infected leaflets for ProPhy.

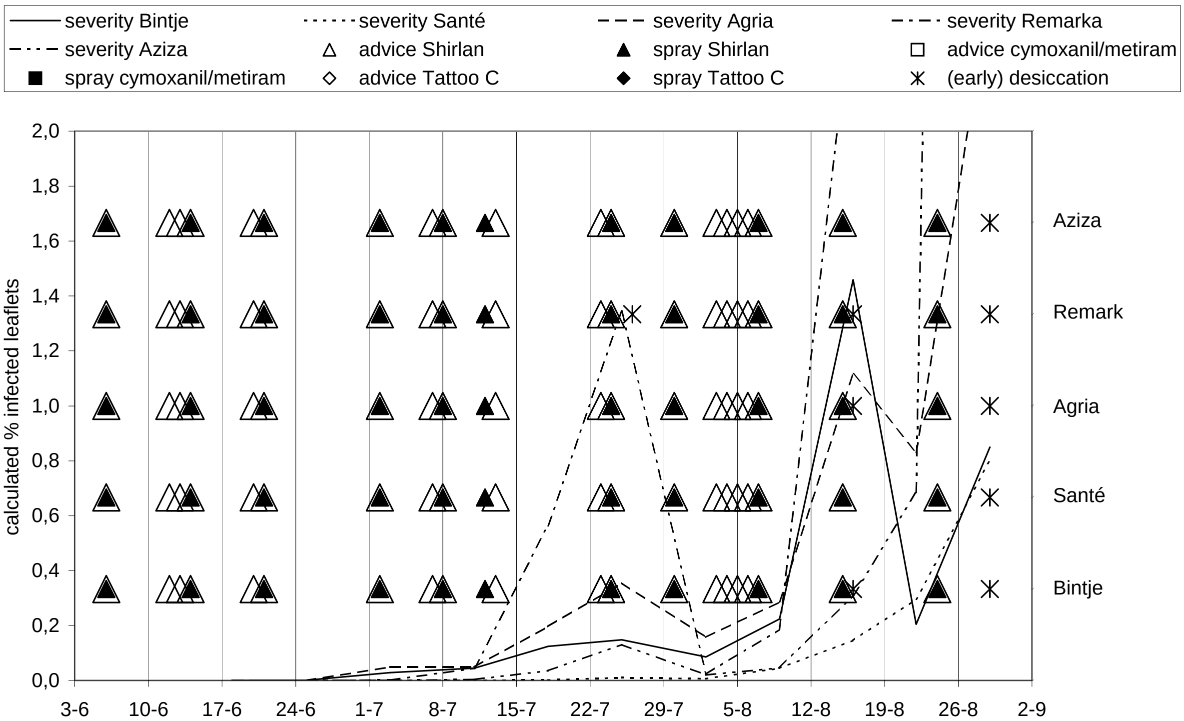

Figure 3. Advises, spraying schedule and calculated percentage infected leaflets for WUR-Blight.

ProPhy system recommendations led to an overall better performance (based on fungicide input, first appearance of blight, early desiccation and severity of leaf blight) of Aziza than of Bintje thanks to the lower fungicide input and lower severity. Bintje performed better than Santé due to the earlier first symptoms on Santé, although the severity on Bintje was higher. Bintje performed a little better than Agria thanks to the later first symptoms. Bintje performed better than Remarka thanks to the later first symptoms, no early desiccation and the lower severity although the fungicide input on Remarka was a little lower.

PLANT-Plus system recommendations led to an overall performance of all varieties better than Bintje due to mainly the early desiccation of Bintje and the earlier first symptoms. Also on Agria, Remarka and Aziza the fungicide input was lower than on Bintje. Severity was much less on Aziza, less on Santé and a little less on Agria compared with Bintje.

Over all three systems Santé performed better than should be expected based on the low potato late blight resistance (4.5). Nevertheless Gans (2003) showed that Santé could in some years act as a more susceptible variety and sometimes as a more resistant variety.

Tuber blight, leaf blight and dose of Shirlan

In WUR-Blight, Aziza showed the highest percentage tuber blight in spite of the high tuber resistance. A severe leaf infection at the end of the season in combination with the very low dose of Shirlan (0.08 l/ha) were probably more important than the tuber resistance.

Like last year (Wander and Spits, 2002) the percentage tuber blight was quite high. This provided again the possibility to look at the correlation between the input of Shirlan and the infection rate. For Bintje correlations between tuber blight and dose of Shirlan in the period from August 7, 13 or 19 to August 15, 20, 24 and 27 were compared. Of this 12 periods the period between August 7 and 20 gave the highest correlation. Apparently the strong increase of the epidemic shortly after August 7 played an important role. Precipitation in this period was only 25 mm. Nevertheless including 25 mm extra precipitation by prolonging the period until August 24 did not increase the correlation.

For the mentioned periods also the correlations between tuber blight and cumulative leaf blight were calculated. The period of August 7 until 20 showed the highest correlation.

In figure 4 the relationship between leaf blight for the period August 7 until 20, dose of

Shirlan in this period and tuber blight is shown. Regression analysis showed that the dose of Shirlan had a significant effect on tuber blight (F-prob. 0.049). Accumulated leaf blight did not have a significant effect.

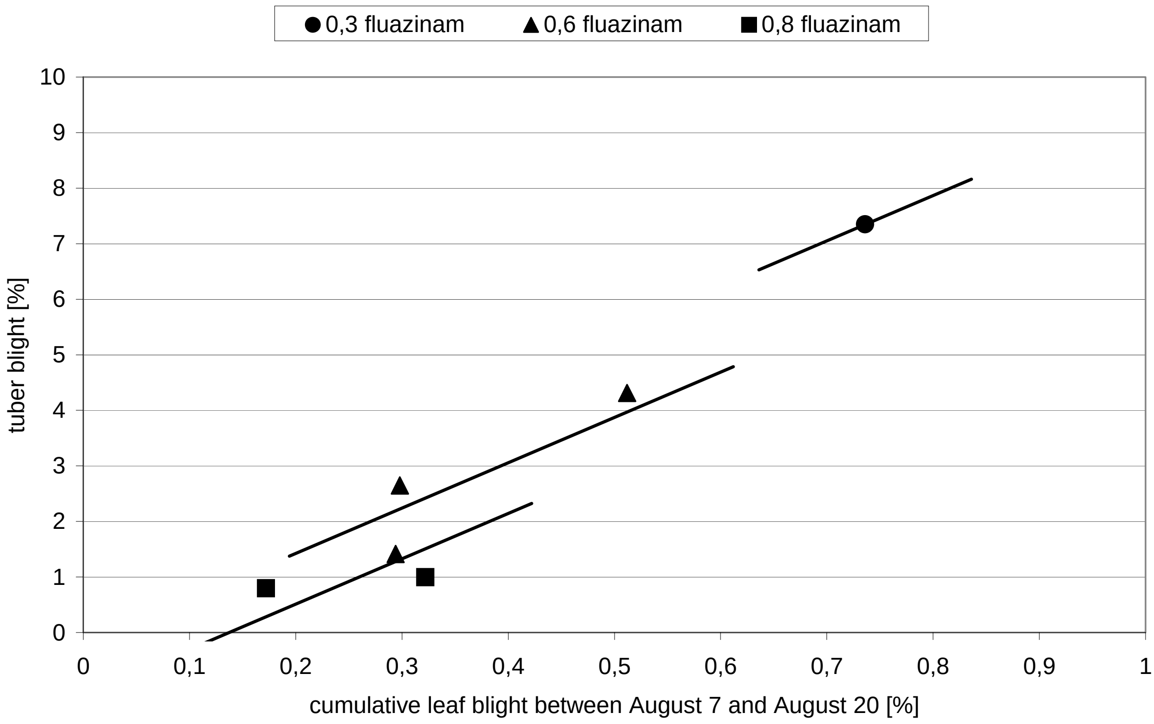

Figure 4. Effect on tuber blight by leaf blight on Bintje cumulated for the period of August 7 and 20 and the dose of Shirlan sprayed in this period (R^2 adj. = 89 %).

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LINBAL, Light INterception By Active Leaflayers: Description and application of a Late Blight limited potato growth model for the Andean Ecoregion

R.J.F. VAN HAREN[1] AND D.M. JANSEN[2]

[1] Avebe b.a., P.O.Box 15, 9640 AA Veendam, The Netherlands
[2] Plant Research International, P.O Box 16, 6700 AA Wageningen, The Netherlands

Summary

The objective of this study is to apply a potato model for the Andean Ecoregion and extend this model with Late Blight epidemiology and fungicide spray scheduling in order to evaluate effects (trade-offs) of fungicide applications on potato yield.

The LINTUL potato model is applied in the Andean Ecoregion. The model is extended with:

- late blight epidemiology and its effects on potato yield;
- fungicide spraying and its effect on Late Blight.

Data from the Andean Ecoregion calibrated the developed model in which potato growth, late blight epidemiology and fungicide applications were combined. Major difficulties were encountered at calibration of the model on the available data. Cause of the difficulties were:

- application of the LINTUL water-limited potato model to the local conditions specific for the Andean Ecoregion;
- quantity and quality of the available data on potato development, Late Blight epidemiology and Late Blight control by fungicides.

Roeland (1996) and Korva (in prep) supplied the data: two experiments in 1994 in Ecuador, site St. Catalina.

New procedures were developed for model calibration: non-linear multivariate regression techniques and calibration with genetic algorithms of the *complete* simulation model.

PPO-Special Report no.9 (2003), 133-178

With these new techniques the model could be calibrated within reasonable margins. Therefore, it was not needed to modify the structure of the LINTUL model specifically for the Andean Ecoregion. This is in contrast with the approach of Korva (in prep). Korva modified the original LINTUL model by extending it with a two-dimensional plant architecture model. This was not necessary in our study since by modifying the light extinction coefficient of the canopy, the different planting patterns in the Andean Ecoregion were matched.

The model is not validated because of a lack of reliable crop and Late Blight data.

Scenario studies with Late Blight and its control by spraying or resistant cultivars are performed for demonstrating model possibilities. These results should be treated with care since model validation is lacking. The scenario studies showed three major application possibilities of the model:

- evaluate spraying regimes and optimise these;
- evaluate interaction components of potato cultivars and Late Blight populations in combination with different spray regimes in order to:
    - ideotype new potato cultivars;
    - prototype new Late Blight management strategies;
    - risk assessment new Late Blight populations;
- evaluate trade-offs between amount of fungicide applications and potato yield formation for different (partial resistant) potato cultivars.

As result from these trade-off studies it is argued that breeding new cultivars should incorporate optimal spraying regimes specific to the potato cultivar.

The calibrated model is applicable for scenario-studies where qualitative aspects are important. The genetic algorithms can be used here for optimisation of scenarios even when constraints on for example spray frequency and amounts are applied. The model is not yet completely reliable for quantitative evaluations. When more data become available the model can be calibrated and validated by which the reliability and the prediction confidence of the model might increase.

Introduction

This report is a contribution to the project 'Regional scaling of field-level, Economic-Biophysical models' (DME-NOR) which is developed by International Potato Centre (CIP), AB-DLO (now Plant Research International) and Wageningen Agricultural University (now Wageningen University and Research). The project is approved and financed by the Ecoregional Fund to support methodological Initiatives. The Dutch Ministry of Agriculture, Nature and Fisheries, North South research programme co-finances the AB-DLO contribution.

The objective of the project is to develop a methodology which allows aggregation of field level simulation models to a regional scale in order to evaluate policy decisions, affecting field-level management and asses its effects on a regional scale.

The objective of this part of the project is to develop and apply a field-level water-nitrogen-Late Blight limited potato production model to the Andean Ecoregion and evaluate effects of different management strategies of Late Blight on field-level potato production. Therefore, trade-off relations between fungicide applications, resistance-virulence components and potato production have to be established.

Approach

The existing LINTUL-potato simulation model (Spitters & Schapendonk, 1991, Kooman & Haverkort, 1995) is extended with processes describing effects of: water and nitrogen on potato growth and development, Late Blight epidemiology, chemical control of Late Blight and Late blight effects on potato production. Effects of weather and microclimate on Late Blight epidemiology are not incorporated in this version of the model since these interactions are treated elsewhere extensively (see e.g. Fry *et al.* 1983 & Hijmans *et al.* in prep).

The extended model is then calibrated on experimental field data. For the calibration two procedures are applied: non-linear regression techniques and genetic algorithms. The procedure with genetic algorithms is especially developed for this purpose.

The calibrated model is subsequently applied for generating trade-off curves between fungicide application (frequency and amount), resistance-virulence components and potato production.

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Potential potato development and tuber production

Introduction

Potential growth of a crop is the dry matter accumulation under ample supply of water and nutrients in pest-, disease and weed free environment, under the prevailing weather conditions. The potential production is a hypothetical growth in optimal water and nutrients supply conditions. The rate of potential dry matter accumulation under optimal growth conditions is a function of irradiation, temperature and crop characteristics. The potential growth model makes use of the common observation that the crop growth under favourable conditions is proportional to the amount of intercepted light see e.g. Haxeltine & Prentice, 1996, Dewar *et al.*, 1998. This relation has been shown to be valid for agricultural and forest systems. The ratio of net primary production and the absorbed photosynthetically active radiation has been called the PAR utilisation efficiency or Light Use Efficiency. Dry matter production is therefore modelled as the product of light interception and a constant light use efficiency in the LINTUL-type of models, (Spitters & Schapendonk, 1991). The dry matter produced is partitioned among the various plant organs, using partitioning rules, which depend upon phenological development stage of the crop. The dry weights of the plant organs are obtained by integration of their growth rates over time. LINTUL-potential growth requires as input physiological properties of the crop and the actual weather conditions at the site, characterised by its geographical latitude, i.e. daily maximum and minimum temperatures and irradiation for each day of the year during the cropping season.

Modification of the Light Use Efficiency by environmental factors such as water and nitrogen supply is discussed in following chapters about water and nitrogen limitation respectively. Figure 1 gives an outline of the major relations within LINTUL-potato and an overview of relations at process level.

Dry matter production

The dry matter production is proportional to the amount of intercepted radiation. The ratio of dry matter production and the absorbed photosynthetically active radiation has been shown to be constant in several environments and with different conditions. The potential carbon production, SourcePot, (weight.area^{-1}.time^{-1}) is proportional to the amount of radiation, PAR, (energy.area^{-1}.time^{-1}) and the groundcover FINT, (area$_{leaf}$.area$_{soil}$$^{-1}$):

$$SourcePot = PAR\ FINT\ LUE\ TMEffGrowth$$

with

$$PAR = PARFraction\ RDD$$

$$FINT = 1.- \exp\{-ECPDF\ LAI\}$$

Where LUE is the Light Use Efficiency (weight.energy^{-1}), TMEffGrowth a function describing the temperature dependence of the photosynthesis (dimensionless), PARFraction is the fraction photosynthetically active radiation (dimensionless), RDD is the daily radiation (energy.area^{-1}.time^{-1}), LAI is the green leaf area index (area$_{leaf}$.area$_{soil}$$^{-1}$) and ECPDF is the light extinction coefficient in the canopy (area$_{soil}$ area$_{leaf}$$^{-1}$).

The carbon production is first used for leaf, and stem root growth. Carbon is partitioned according to fixed ratios between leaf and stem. Root growth is in this model version only modelled as increase of rooting depth. When the amount of produced carbon is more then necessary for maintaining leaf and stem growth, the surplus is partitioned to the tubers.

Leaf area dynamics

The leaf area dynamics is based upon temperature sum rules of leaf development. Leaf area is still growing when the temperature sum, TMSum, (temperature.time^{-1}) is lower then the maximum temperature sum for leaf development of the specific potato cultivar, TMSumLeafGrowth, (temperature.time^{-1}). The daily effective temperature for leaf growth, TMEff (temperature) is determined as the positive difference of the daily average temperature, TMDA, (temperature) and a specific base temperature below which leaf growth has stopped (temperature).

$$TMEff = TMDA - TMBase\,|_{TMEff>0}$$

The temperature sum, TMSum is consequently the total sum of daily effective temperatures:

$$TMSum = \Sigma_{t0}^{t} TMEff$$

where t0 is the day of emergence and t the current day.

Leaf area growth is now described by two growth processes for exponential and linear growth respectively:

$$LeafArGrowthPl1 = LeafArPl\ (\exp\ (RGRL\ TmEff\ Delt) - 1)$$

or

$$LeafArGrowthPl2 = LeafArGrowthRef\ Tmeff\ (1 - (TMSum\ /\ TMSumLeafGrowth)^{LeafPar})$$

Where LeafArGrowthPl1 is the exponential leaf area growth ($area_{leaf}.plant^{-1}.time^{-1}$), LeafArGrowthPl2 is the linear leaf area growth ($area_{leaf}.plant^{-1}.time^{-1}$), LeafArPl is the total leaf area per individual plant ($area_{leaf}.plant^{-1}.time^{-1}$), RGRL is the relative leaf growth rate during exponential growth ($(temperature.\ ture.time^{-1})^{-1}$), Delt is the integration time step (time), LeafArGrowthRef is the linear leaf area growth rate ($area_{leaf}.plant^{-1}.temperature^{-1}.\ time^{-1}$) and LeafPar is shape factor determining the relative decrease of leaf growth during the linear leaf growth phase (dimensionless). Leaf area growth per plant LeafArGrowthPl ($area_{leaf}.plant^{-1}.time^{-1}$), is the minimum value of either exponential or either linear leaf growth. Leaf area growth per plant is converted into the total leaf area growth of the canopy, LeafArGrowth, ($area_{leaf}.area_{soil}^{-1}.time^{-1}$), by multiplication with the planting density, NPL, (number plants. $area_{soil}^{-1}$). Leaf weight growth per area, LeafWtGrowth, ($weight.area_{soil}^{-1}.time^{-1}$) is now obtained by dividing the LeafArGrowth with the specific leaf area, SLA, ($area_{leaf}.weight_{leaf}^{-1}$). Stem weight growth is taken as a fixed fraction, LeafStemRatio, (dimensionless) of the leaf weight growth, LeafWtGrowth. The total growth of the above ground part of the plant, AboveDryWtGrowth, ($weight.area_{soil}^{-1}.time^{-1}$) is the sum leaf and stem weight growth.

However, the AboveDryWtGrowth has to be equal or less then the calculated total dry matter production, SourcePot. If SourcePot is lower then the AboveDryWtGrowth then the leaf area growth per plant, LeafArGrowthPl, is reduced in order to match the total dry matter production:

```
if (SourcePot < AboveDryWtGrowth) then
    LeafArGrowthPl      = LeafArGrowthPl SourcePot / AboveDryWtGrowth
    LeafArGrowth        = LeafArGrowthPl NPL
    LeafWtGrowth        = (LeafArGrowth/10000.)/SLA
    StemWtGrowth        = LeafWtGrowth*(1.-LeafStemRatio)
    AboveDryWtGrowth= SourcePot
end if
```

Leaf Age cohorts

Leaves on a potato stem are discrete units. A typical potato main stem can have 15 - 20 leaves at normal Dutch conditions with sufficient water and nitrogen. Most crop growth models do not distinguish between different leaf classes of leaf cohorts in a canopy. This version of the LINTUL-potato model applies leaf age cohort modelling for several reasons. It is assumed that leaf age cohort modelling give a better description of:

1. Leaf developmental ageing
2. Leaf accelerated ageing due to light damage accumulation
3. Leaf senescence due to self-shading
4. Leaf nitrogen (re)distribution due to leaf self-shading (optimal leaf-N content for leaf intercepted radiation)
5. Fungicide spraying scheduling due to weathering of fungicides on leaves and the formation of unsprayed new leaf layers.

Leaf layers are formed from emergence to the end of the growing period. A new leaf layer is formed each time step. The lowest leaf layer has cohort number 1, while the newest formed leaf layer has the greatest cohort number, see Figure 2. Each leaf cohort is characterised by five attributes:

1. Leaf class number
2. Leaf area
3. Leaf weight
4. Leaf age
5. Leaf class is alive or leaf class is death

The attributes of the new leaf layer are determined during the particular time step delt. So the attributes of the newest leaf class formed at time interval Δt are :

```
LeafArCl(LeafClCnt)      =   LeafArGrowth*delt
LeafWtCl(LeafClCnt)      =   LeafWtGrowth*delt
LeafAgeCl(LeafClCnt)     =   0.
LeafAliveCl(LeafClCnt)   =   .true.
```

With LeafClCnt is the leaf class counter, the leaf area (LeafArCl, $area_{leaf}.area_{soil}^{-1}$) and leaf weight (LeafWtCl, $weight.area_{soil}^{-1}$) of the newest leaf class and leaf class weight are the growth rates of leaf area and leaf weight respectively during time interval delt. LeafAgeCL is the leaf age of the leaf class expressed as degree-days ($temperature.time^{-1}$).

Leaves age due to the developmental ageing as function of temperature. It is also assumed that leaf age due to an accumulation of light damage on leaf tissue. Leaf senescence due to self- shading is not considered in this model version.

Leaves age as function of temperature. It is assumed that leaves have a maximum leaf age, LeafAgeMx, (temperature.time). Leaf age increase daily with the daily effective temperature, TMEff, and the amount of intercepted radiation. The rationale behind is that metabolic damage, like free radicals, damaged DNA etc., accumulates relative faster when metabolic rates increase. Metabolic rates increase with increasing temperatures and with increasing light intensity, which speeds up photosynthesis. So the leaf age increase is:

$$LeafAgeCl(i,t+dt) = LeafAgeCl(i,t) + (3.-2.*PARTrans(i) / 15.e6)*TmEff*delt$$

where

$$PARTrans(i) = PARFraction*RDD*exp(-ECPDF*LAI_{above})$$

and

$$LAI_{above} = \Sigma_{i+1}^{n} LeafAr(k)$$

The amount of transmitted radiation inside the canopy PARTrans(i) at depth (i) inside the canopy is calculated by summing the leaf area index LAIabove, above leaf layer (i), from (i+1) to (n), and substitute this in Lamberts-Beer law.

Leaf senescence

It is assumed that leaves senesce when they exceed the maximum leaf age, LeafAgeMx. So, leaf age of leaf class (i), LeafAgeCl(i) (temperature. time) is each time step compared with the maximum age a leaf can attain. When the leaf age is larger then the maximum leaf age, it is determined that the whole leaf layer is dead.

The total leaf area, LeafAr, leaf weight, LeafWt, and leaf dead weight, LeafDeadWt, is now recalculated as:

$$LeafAr = \Sigma_{1}^{n} LeafArCl(i)|_{alive}$$

$$LeafWt = \Sigma_{1}^{n} LeafWtCl(i)|_{alive}$$

$$LeafDeadWt = \Sigma_{1}^{n} LeafDeadWtCl(i)|_{death}$$

Root growth

Root growth is modelled as rooting depth. The rooting depth is an important feature for the soil water and soil nitrogen and organic matter model. The rooting depth determines the access to water and nitrogen resources. It is assumed that rooting depth of potato does not exceed the maximum rooting depth of potato, RootDepthCropMx (length), or the maximum rooting depth the potato can attain due to soil profile characteristics RootDepthSoilMx, (length). When the volumetric soil water content in a specific soil layer(i), wclqt(i) ($volume_{water}.volume_{soil}^{-1}$), is lower then the volumetric water content at wilting point, wcwp(i) ($volume_{water}.volume_{soil}^{-1}$), in that soil layer, then root growth is stopped. Root growth only occurs when there is leaf growth. Roots are assumed to have a maximum daily growth rate, RootDepthGrowthPar ($length.time^{-1}$). The daily increase in rooting depth is minimised between the maximum daily root growth rate and the difference between actual root depth and the maximum root depth:

RootDepthChange = min (RootDepthGrowthPar,
max (RootDepthMx - RootDepth,0.))

Tuber growth

The tuber weight growth, TuberWtGrowth, ($weight.area_{soil}^{-1}.time^{-1}$) is now the surplus of the total dry matter production, SourcePot, and the AboveDryWtGrowth:

$$\text{TuberWtGrowth} = \text{SourcePot} - \text{AboveDryWtGrowth}\,|_{>0}$$

Tuber initiation is at the moment when the first assimilates are allocated tot the tuber.

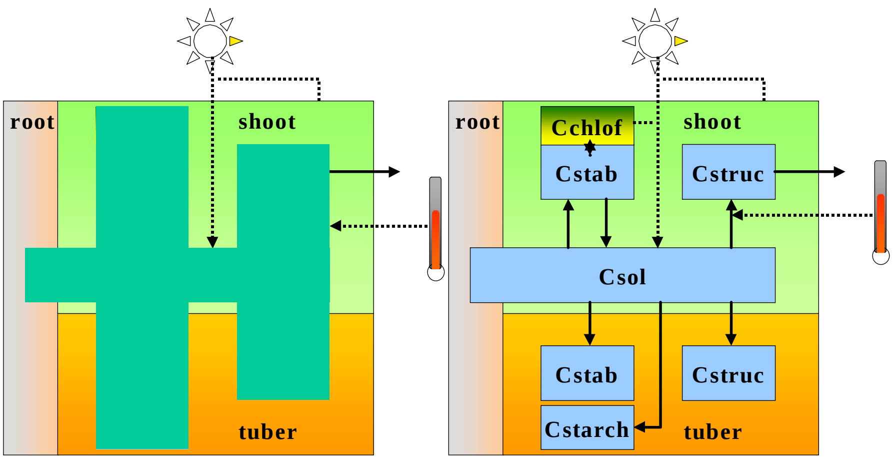

Figure 1. Outline of major relations in LINTUL potato and an overview of relations at process level.

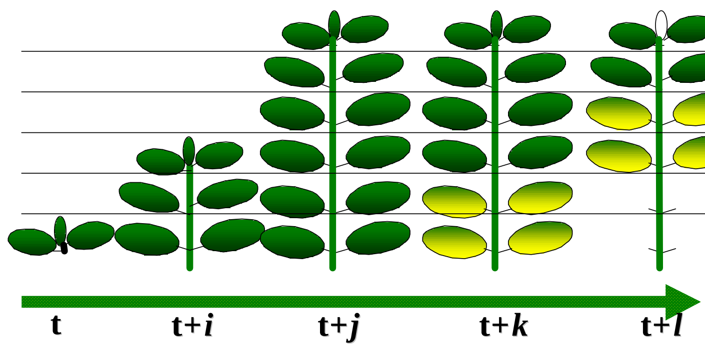

Figure 2. Leaf cohorts, each time step a new leaf layer is formed.

Table 1. Variables and parameters of the LINTUL-potato model.

Name	Type	Description	Units
AboveDryWt	R	Leaf and stem weight together	$kg.ha^{-1}$
AboveDryWtGrowth	R	Rate of change of AboveDryWt	kg $DM.d^{-1}$
CNames	R	Array with cultivar names	
DELT	R	Time interval of integration	D
Doy	R	Day of year	D
ECPDF	R	Extinction coefficient of leaves for PAR and for diffuse light	ha $ground.ha^{-1}$ leaf
ETAE	R	Dryness driven part of potential evapotranspiration	$mm.d^{-1}$
ETRD	R	Radiation driven part of potential evapotranspiration	$mm.d^{-1}$
FINT	R	Intercepted fraction of photosynthetically active radiation	-
HarvestIndex	R	Harvest index	$kg.kg^{-1}$
I	R	Do loop counter	-
KDF	R	Extinction coefficient	-
LAI	R	Green leaf area index	m^2 $leaf.m^{-2}$ ground
LAIMx	R	Maximum LAI obtained during simulation	m^2 $leaf.m^2$ $ground^{-1}$
LeafAgeCl	R	Array with temperature sum ages for different leaf classes	degrees C.d
LeafAgeMx	R	Required maximum effective temperature sum for a leaf to die	degrees C.d
LeafAgeMxs	R	Cultivar array with LeafAgeMx values	-
LeafAliveCl	R	Flag whether leaf class is alive or not	-
LeafAr	R	Total leaf area of canopy per hectare	m^2 $leaf.ha^{-1}$ ground
LeafArCl	R	Array with leaf areas for different leaf classes	$m^2.ha^{-1}$
LeafArGrowth	R	Rate of change in LeafAr	
LeafArGrowthPl	R	Rate of change of LeafArPl	m^2 $leaf.plant^{-1}.d^{-1}$
LeafArGrowthPl1	R	Change in leaf area per plant following exponential growth	m^2 $leaf.plant^{-1}.d^{-1}$
LeafArGrowthPl2	R	Change in leaf area per plant following linear growth	m^2 $leaf.plant^{-1}.d^{-1}$
LeafArGrowthRef	R	Reference leaf area increase per plant	$m^2.plant^{-1}$.degree C
LeafArGrowthRefs	R	Cultivar array with leaf area growths of individual plant	$m^2.plant^{-1}$.degree $Celsius.d^{-1}$
LeafArPl	R	Total leaf area of individual plant	$m^2.plant^{-1}$
LeafArPlI	R	Initial value of LeafArPl	$m^2.plant^{-1}$
LeafClCnt	I	Number of used leaf classes	-
LeafDeadWt	R	Dry weight of dead leaves	kg $DM.ha^{-1}$
LeafPar	R	Leaf dry matter partitioning parameter	-
LeafStemRatio	R	Ratio between new leaf and stem dry matter	-
LeafWt	R	Dry weight of green leaves	kg leaf $DM.ha^{-1}$
LeafWtCl	R	Array with leaf weights for different leaf classes	kg $DM.ha^{-1}$
LeafWtGrowth	R	Rate of change of LeafWt	kg leaf $DM.ha^{-1}.d^{-1}$
LogFileUnit	R	Open unit for log file output	-
LUE	R	Light Use Efficiency	g $DM.MJ^{-1}$
Module	R	Name of model	-
NewTask	R	Task that the model should carry out	-
Nl	R	Number of layers used in soil water balance	-

Table 1. Continued.

Name	Type	Description	Units
NPL	R	Planting density	#plants.ha^{-1}
OldTask	R	Previous task that the model carried out	-
PAR	R	Photosynthetically active radiation	$J.m^{-2}.d^{-1}$
PARFraction	R	Fraction of RDD that is photosynthetically active	-
PARTrans	R	Level of PAR at a particular depth in the canopy	$J.m^{-2}.d^{-1}$
Rain	R	Amount of rainfall	mm rain.d^{-1}
RainInt	R	Amount of rainfall that is intercepted by the crop	mm rain.d^{-1}
RainIntPar	R	Amount of rainfall intercepted per unit of leaf area index	mm rain.ha $leaf^{-1}$.ha $leaf^{-1}$
RDD	R	Daily short-wave radiation	$J.m^{-2}.d$
RGRL	R	Relative growth rate of leaf area during exponential growth	(degrees C $d)^{-1}$
RootDepth	R	Rooted depth	m
RootDepthChange	R	Rate of root elongation	$mm.d^{-1}$
RootDepthCropMx	R	Maximum rooting depth of the crop	m
RootDepthGrowthPar	R	Maximum daily increase in rooting depth	$m.d^{-1}$
RootDepthI	R	Initial rooting depth	m
RootDepthMx	R	Maximum value for rooted depth	m
RootDepthSoilMx	R	Maximum value for rooted depth as soil characteristic	m
RootGrowthFlag	R	Flag that indicates whether conditions at the tip of the root are suitable for growth	-
RootLayerNo	R	Water balance layer number where root tips are growing	-
SLA	R	Specific leaf area	ha leaf.kg $leaf^{-1}$
SourcePot	R	Available dry matter for growth	kg DM.$ha^{-1}.d^{-1}$
StemWt	R	Dry weight of the stems	kg DM.ha^{-1}
StemWtGrowth	R	Rate of change of StemWt	kg DM.$ha^{-1}.d^{-1}$
StemWtI	R	Initial dry weight of stems	kg DM.ha^{-1}
TKL	R	Thicknesses of soil compartments	m
TMBase	R	Base temperature below which leaf area growth does not take place	degrees C
TMDA	R	24 hour average temperature	degrees C
TMEff	R	Daily effective temperature for leaf growth	degrees C
TMEffGrowth	R	Effect of temperature on leaf growth	-
TMEffGrowthTb	R	Table with effect of temperature on light use efficiency	
TMEffGrowthTBL	I	Length of array TMEffGrowthTb	-
tmpi1	I	Temporary integer	-
TMSum	R	Temperature sum of TMEff	degree C.d
TMSumLeafGrowth	R	Temperature sum during which leaf growth takes place	degree C.d
TMSumLeafGrowths	R	Cultivar array with temperature sums during which leaf growth takes place	degree Celsius.d^{-1}
TotalAboveDryWt	R	Total aboveground dry weight (including dead leaves)	kg.ha^{-1}
TotalDryWt	R	Total dry weight (including dead leaves)	kg.ha^{-1}
TransAct	R	Total actual transpiration rate of the canopy	$mm.d^{-1}$
TransPot	R	Potential transpiration rate	$mm.d^{-1}$
TRWL	R	Array with transpiration rates per soil compartment	$mm.d^{-1}$
TuberFreshDryRatio	R	Tuber dry matter content as a fresh/dry ratio	-
TuberFreshWt	R	Fresh weight of tubers	kg fresh.ha^{-1}
TuberWt	R	Dry weight of tubers	kg DM.ha^{-1}
TuberWtGrowth	R	Rate of change of TuberWt	kg DM.$ha^{-1}.d^{-1}$
TuberWtI	R	Initial value for dry weight of tubers	kg DM.ha^{-1}
WaterExtrPar	R	Amount of water that the plant can potentially transpire	d^{-1}
WaterStressIndex	R	Degree of water stress on a particular day	-
WCAD	R	Volumetric water content at air dryness in each soil layer	cm^3 $H_2O.cm^{-3}$ soil
WCFC	R	Volumetric water content at field capacity in each soil layer	cm^3 $H_2O.cm^{-3}$ soil
WCLQT	R	Volumetric water content in soil compartments	cm^3 $H_2O.cm^{-3}$ soil
WCREL	R	Relative water content, between field capacity and wilting point	-
WCST	R	Volumetric water content at saturation	cm^3 $H_2O.cm^{-3}$ soil
WCWP	R	Volumetric water content at wilting point	cm^3 $H_2O.cm^{-3}$ soil

Late Blight epidemiology

Introduction

Late Blight is a serious disease of the potato crop and can, if not managed properly, completely destroy the potato crop. Late Blight is caused by phytopathogenic fungus, *Phytophthora infestans* that infects, and kills leaves, stems and tubers of the potato plant. Late Blight control is by frequent applications of fungicides, or more recently the combination of resistant potato cultivars in combination with fungicides. Fungicides are sprayed with a frequency of 7-14 days in the developed countries and with a frequency of none to 1-2 during the crop cycle in some developing countries.

The life cycle of *P. infestans* consists of an asexual and a sexual cycle. The asexual cycle has the following phases:

1. production of sporangia and sporulation
2. dispersion
3. direct germination
4. hyphae production
5. indirect germination: zoospores formation
6. encystement and germination
7. hyphae production
8. production of sporangia and sporulation

The sexual cycle requires the presence of both the A1 and A2 mating types. Both of the mating types were for a long time localised to South America. More recent, both mating types are found globally. Genetic recombination occurring during the sexual reproduction causes an increase in genotypic variability of P. infestans which might lead eventually to an increased fungicide tolerance or overcoming host resistance. The sexual cycle has the following phases:

1. hyphae production of A1 and A2 mating types (antheridium and oogonium)
2. fusion of gametes
3. germination of oospores
4. sporangia formation

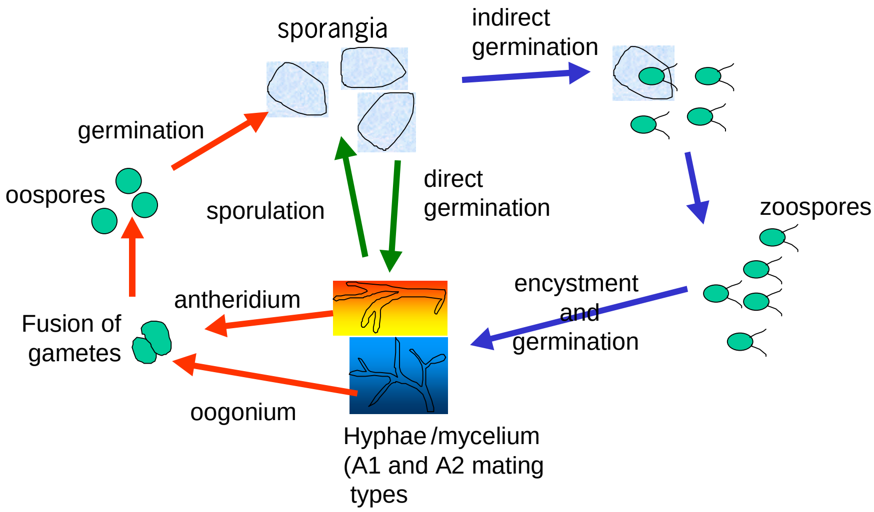

Figure 4. Asexual and sexual lifecycles of P.infestans (after Harrison, 1995).

The disease cycle reflects the life cycle of the pathogen as it occurs on the host with leaf infection, lesion expansion, sporulation, spore dispersal and spore survival. (Harrison, 1995). Figure 5 shows the disease cycle of P. infestans on potato. The asexual cycle is further described for the purpose of this report. The factors that affect the epidemiology of Late Blight can be divided in: 1) abiotic factors; 2) biotic factors and 3) fungicides. Weather conditions determine mainly the onset and the disease progress of Late Blight Since weather conditions are not considered yet in the epidemiological model, its effects on disease progress is not discussed, see e.g. Harrison (1995) for a review. The effect of biotic factors and fungicides are discussed in the next section on epidemiology and fungicides respectively. Table 2 gives an overview of different factors affecting the different stages of the Late Blight development.

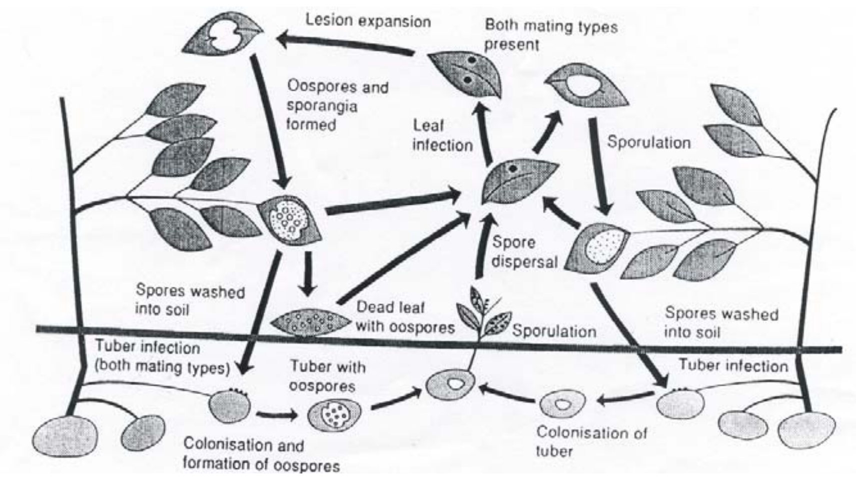

Figure 5. Disease cycle of P. infestans on potato (after Harrison, 1995).

Table 2. Biotic and abiotic factors influencing stages of Late Blight development and the corresponding model parameters. The effects of abiotic factors on Late Blight development are not considered in this paper.

Stage of pathogen	Model parameters	Description	Biotic	Abiotic	Management
Spore production	SR	Sporulation rate	Cultivar	Temperature, relative humidity	Curative fungicide
Dispersal	DPSEFF	Deposition efficiency	Proportion susceptible tissue	Leaf wetness, rainfall	
Germination	IE, LP	Infection efficiency		Temperature, leaf wetness	
Infection	IE	Infection efficiency	Cultivar	Temperature, leaf wetness	Protective fungicide
Lesion expansion	LG, IP	Radial lesion growth rate, infectious period	Cultivar proportion susceptible tissue	Temperature	Curative fungicide

Late Blight Epidemics

The Late Blight Epidemics and Damage model presented here is the model developed by van Oijen (1989,1991a,1991b,1995). The basic principles of van Oijens models are based upon the epidemiological models for human infectious diseases. Next follows an outline of the general approach taken by van Oijen (1989).

General Epidemic Model (GEM)

The basic principles of most of the human epidemiological models are based upon the distinction into three classes of individuals:

1. Susceptible individuals (S), still uninfected;
2. Infective individuals (I);
3. Removed individuals (R) because of death, immunisation or isolation.

The total population size (S+I+R) is assumed to be constant. Infection of susceptibles is assumed to be proportional to the contact rate between susceptibles and infectives. This assumption is based upon complete mixing of the two populations, like the mixing of chemicals in a chemical reactor. So the infection rate dS/dt is proportional to the product of the two reactants S and I: (S * I). Removal of infectives, i.e. the ending of their infectious period is assumed to be independent of the length of the infectious period, they experienced. This lead to a constant relative removal rate from I to the R group. Above mentioned assumptions completely define, together with estimates of the initial conditions, the General Epidemic Model (Kermack and McKendrick, 1927) with two proportionality constants k1 (number^{-1} time^{-1}) and k2 (time^{-1}):

$$dS/dt = -k1\,S\,I$$

$$dI/dt = k1\,S\,I - k2\,I$$

$$dR/dt = k2\,I$$

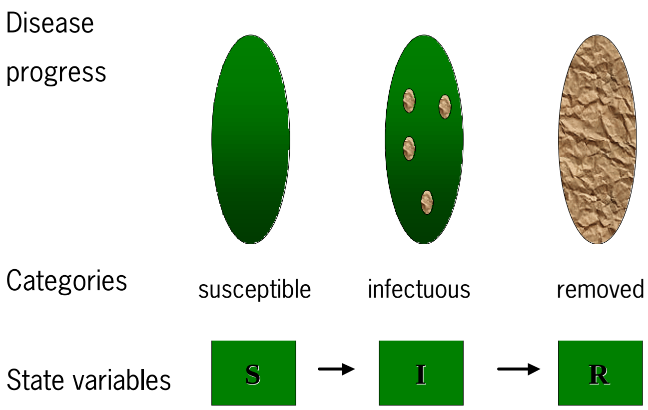

Figure 6. Disease progress of different categories: susceptible, infective, removed in the General Epidemic Model.

A SIR model for Late Blight

The natural unit of disease in the GEM's is the individual with one infection. The natural unit for plant diseases is the individual lesion. Plant diseases, like leaf rust of wheat, have determinate lesion growth a while plant disease like Late Blight has indeterminate lesion growth. The group of susceptibles can be identified as the potential number of infection spots. This number can be assumed to be proportional to the uninfected leaf area divided by the average lesion area. The description of the Late Blight model is based upon van Oijen (1989).

The state variables LAI_{green}, DIS and R represent green leaf area, sporulating leaf area and dead leaf area respectively ($area_{leaf}.area_{soil}^{-1}$). The total leaf area index LAItot is consequently:

$$LAItot = LAI_{GREEN} + DIS + R$$

The total lesion density n_T is sum of the density of latent lesions, Nlat, and the density of visible infectious lesions Ninf. ($number.area^{-1}$). The latent lesions are considered to be without area, growth and sporulation. Lesions become visible after latency, when they are assumed to grow and sporulate.

The increase rate of latent lesions is proportional to the area of infected leaves and susceptible (green) leaves. The proportionality factor can be decomposed in three processes:

1. SR: Sporulation rate, number of spores per sporulating area per day. ($number_{spores}.area_{infected}^{-1}$ $time^{-1}$).
2. DPSEFF: Deposition efficiency, fraction of landed spores on susceptible plant tissue relative to total number of landed spores per area, ($number_{spores}.area_{leaf}^{-1}$)/($number_{spores}$ $area_{soil}^{-1}$).
3. IE: Infection efficiency, fraction of spores landed on susceptible tissue that leads to (latent) lesion formation ($number_{lesions}^{-1}.number_{spores}^{-1}$).

These processes are in reality strongly dependent on environmental conditions like temperature, wind speed, relative humidity, rainfall and duration of leaf wetness. These dependencies are not covered in this paper because some other models treat them very extensively (see e.g. Bruhn and Fry 1981 and Hijmans *et al.* in prep.). The formation rate of infectious lesions is proportional to the density of the latent lesions and inversely proportional to the time they remain invisible, the latent period, LP (time). With these assumptions the density dynamics of latent (Nlat) and infectious (Ninf) lesions can be described:

$$dNlat/dt = LAIgreen\ DIS\ SR\ DPSEFF\ IE - Nlat/LP$$
$$dNinf/dt = Nlat/LP$$

Late Blight lesions sporulate at the edges, the lesion parts most recently formed. The density of visible lesions and their average growth rate determines the transition of infectious leaf area to removed leaf area. The average lesion growth rate is proportional to the area susceptible leaf tissue and the distribution of lesions on the leaves and in the canopy. The numbers of lesions per leaf are assumed to follow a Poisson distribution, which eventually leads to:

$$LAIles = LAItot\ (1 - \exp\{-Ninf/NLFlt\})$$

with

$$NLFlt = LAItot/LFLtar$$

Where LAIles is total area of infected leaflets where at least one lesion is present ($area_{leaf}.area_{soil}^{-1}$), LAItot the total leaf area ($area_{leaf}.area_{soil}^{-1}$), NLFlt the total number of leaflets per area soil (number. $area_{soil}^{-1}$) and LFLtar the average area per leaflet (area), see van Oijen 1989 for an extensive discussion of the Poisson distribution).

Visible lesions have a constant radial lesion growth rate, LG (length.time^{-1}) in the absence of space limitation. When space limitation occurs, the radial lesion growth is assumed to be proportional to the disappearance rate of the green area fraction of diseased leaflets which equals the relative formation rate of visible lesions. The growth of the average lesion radius, INFrad (length) is now:

$$dINFrad/dt = LG\,(1-(DIS + R) / LAIles) - INFrad\,(dNinf/dt) / Ninf$$

The average area of infectious lesions can be calculated when it is assumed that

1. lesions are circular and
2. lesion radii are distributed according to a power function between zero and the radius of the largest lesion, INFrdm (length). The radius of the largest lesion can be found by integrating the growth rate over the time elapsed since the first appearance of lesions.

$$dINFrdm/dt = LG\,(1-(DIS + R) / LAIles)$$

The average lesion area, INFar, (area) can now be derived, see van Oijen (1989) for more details:

$$INFar = \pi\, INFrad\, INFrdm / (2 - INFrad / INFrdm)$$

The total sporulating leaf area equals:

$$DIS = Ninf\ INFar.$$

Sporulating leaf area stops sporulating when it becomes necrotic. The time a lesion remains sporulating is assumed to be constant, i.e. infectious period, IP (time). The rate of change of sporulating leaf area can now be derived as:

$$dDIS/dt = Ninf\, dINFar/dt + INFar\, dNinf/dt - DIS/IP$$

The structure of the Late blight model is given with the equations above. The parameters SR, IE, LP, LG and IP describe the host – parasite interaction. Results of a preliminary survey by van Oijen (1989) about typical ranges of these 'interaction components' are given in Table 3. An outline of the Late Blight model is given in Figure 7.

Table 3. Variables and parameters of the Late Blight model.

Name	Type	Dimension	Description
LAIgreen	State variable	Area leaf.area soil^{-1}	Green leaf area index
DIS	State variable	Area leaf.area soil^{-1}	Sporulating leaf area index
R	State variable	Area leaf.area soil^{-1}	Dead leaf area index
LAItot	Variable	Area leaf.area soil^{-1}	Total leaf area index
LAIles	Variable	Area leaf.area soil^{-1}	Leaf area index with at least one lesion
Nlat	State variable	Number.area^{-1}	Density of latent lesions
Ninf	State variable	Number.area^{-1}	Density of visible infectious lesions
INFrad	State variable	Length	Average lesion radius
INFrdm	State variable	Length	Maximal lesion radius
INFar	Variable	Area	Average lesion area
NLFlt	Variable	Number.area soil^{-1}	Number leaflets per area soil
SR	Parameter	Number.area infected^{-1}.time^{-1}	Sporulation rate
DPSEFF	Parameter	(Number.area leaf^{-1})/ Number.area soil^{-1})	Deposition efficiency
IE	Parameter	Number lesions. number spores^{-1}	Infection efficiency
LP	Parameter	Time	Latent Period
LG		Length.time^{-1}	Lesion growth rate
IP	Parameter	Time	Infectious period
LFLtar	Parameter	Area	Area per leaflet

Interaction component	Dimension	Value			Description
SR	#.m^{-2}.d^{-1}	6.4	-	8.5 E8	Sporulation rate
IE	#.# $^{-1}$	0.0026	-	0.0240	Infection efficiency
LP	d	4	-	5	Latent period
LG	m.d^{-1}	0.001	-	0.003	Lesion growth
IP	d	0.75	-	1.00	Infectious period

Late Blight damage effects and yield reduction

The Late Blight model interacts with the LINTUL-potato model. The major input of the Late Blight model is the green leaf area. The green leaf area, LAIgreen, is calculated in the LINTUL model as function of light, temperature, water and nitrogen. See Chapters 'Potential potato development and tuber production', 'Late Blight epidemiology' and 'Late Blight Control' for an extensive discussion on the LINTUL intrinsic processes (pages 136 to 156).

The damage effect of Late Blight is assumed to be an increase in dead leaf area, so a decrease in green leaf area. A decrease of green leaf area means a reduced light interception, which leads eventually to a reduced tuber yield.

The additional leaf dead due to Late Blight is communicated to the LINTUL crop growth model and there incorporated in the Leaf Area dynamics of the model, see Figure 7 and 8.

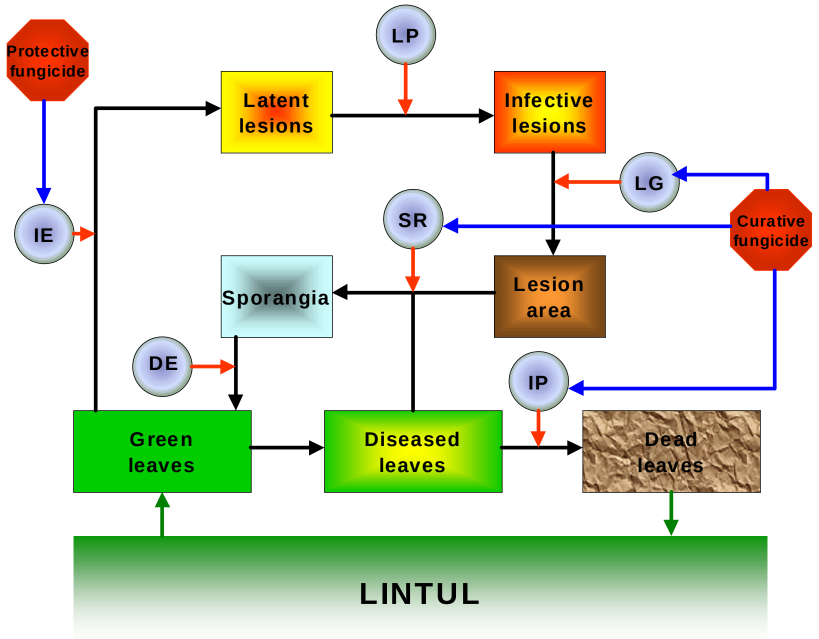

Figure 7. An outline of the major interaction in the Late Blight model and its interaction with the physiological LINTUL potato model.

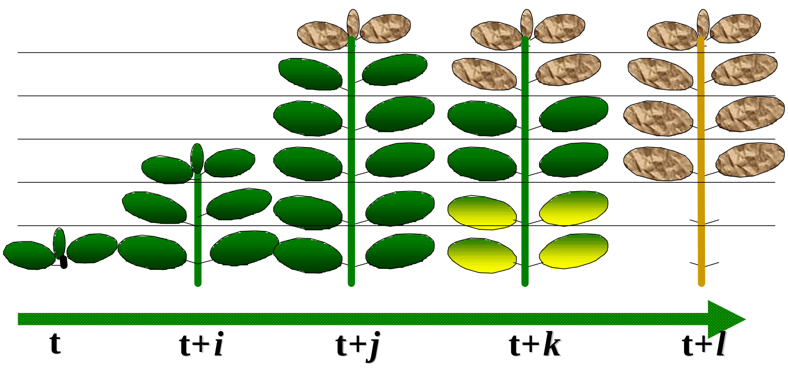

Figure 8. Damage effects of Late Blight incorporated in the multi-layer leaf-cohort model of LINTUL-potato

Late Blight Control

Late Blight can be controlled with protective and curative fungicides. Protective fungicides affect in general the infection efficiency, IE, of the sporangia. Curative fungicides affect in general the growth and extension of already established infections. Curative fungicides can affect the lesion growth rate, LG, the sporulation rate, SR and the infectious period IP. It is assumed that the reduction of these interaction components is proportional to the concentration of the active ingredient on the leaves. Therefore a Weibull distribution is assumed which is frequently applied in toxico-kinetic studies:

$$\text{InterCom} = \text{InterCom}_{max} / (1 + (c / c_{E50})^{1/\beta})$$

Where InterCom is the interaction component, IE, LG, SR or IP, InterCom_{max} is the value of this interaction component without fungicides, c is the areal concentration of the active ingredient on the leaf ($\text{weight.area}_{leaf}^{-1}$), c_{E50} is the concentration of the active ingredient where InterCom is half of its maximal value ($\text{weight.area}_{leaf}^{-1}$) and β is a shape factor of the Weibull curve.

The concentration c is per definition:

$$C = c \text{ LeafArPl}$$

Where C is the amount of active ingredients per plant (weight), c is the areal concentration of the active ingredient ($\text{weight.area}_{leaf}^{-1}$) and LeafArPl is the area leaves per plant ($\text{area}_{leaf}.\text{plant}^{-1}$). By taking the derivatives of both sides:

$$dC/dt = dc/dt \text{ LeafArPl} + c \text{ dLeafArPl}/dt$$

By assuming that the amount of fungicides remains constant, $dC/dt = 0$, the areal concentration of the fungicides change through the formation of new leaf tissue:

$$dc/dt = - c/\text{LeafArPl dLeafArPl}/dt$$

A complete control of Late Blight by fungicides is only direct after application. Weathering processes and the formation of new leaf tissue leads to a reduced protection in time.

Persistence of the fungicide on the leaves is important for calculating the period with sufficient protection. Normally, the concentration of the active ingredient decreases due to weather conditions and other transformations. Two main processes for the concentration decrease of the active ingredients are considered:

1. natural weathering (biotransformation, transformation, decay etc.)
2. wash-off by incidental rain

The weathering of the fungicide is assumed to be proportional to the concentration, c, of the active ingredient on the leaf:

$$dc/dt = -k_{decay}\,c$$

Where k_{decay} is the decay rate of the fungicide ($time^{-1}$) and c the areal concentration of the fungicide ($weight.area^{-1}$). Fungicides are washed of by rain. It is assumed that the wash of rate of fungicides is proportional to the amount of precipitation (mm) and the concentration of the active ingredient:

$$dc/dt = -k_{rain}\,c\,RAIN$$

Where RAIN is the amount of precipitation (mm) and k_{rain} is the wash off rate constant, ($mm^{-1}.time^{-1}$).

The total decrease rate of the fungicide concentration on the leaves is then:

$$dc/dt = -c\,(k_{rain}\,RAIN + k_{decay})$$

Formation of new leaf area after spraying leads to an increase of unprotected leaf area relative to the protected leaf area. Environmental variables such as light, temperature, water and nitrogen fertilisation determine the growth rate of new leaf tissue. The calculations of new leaf tissue are performed in the LINTUL submodel. The LINTUL submodel calculates the leaf area since the last spray. Two leaf categories are now distinguished LeafArProt and LeafArNotProt, which are respectively protected and unprotected leaf area by fungicide spraying ($area_{leaf}.area_{soil}^{-1}$).

When the concentration of the active ingredient on the leaf exceeds a threshold, leaf protection is assumed. This threshold is defined as an acceptable risk level for Late Blight infection. The risk level can be given by a farmer or extension service and is expressed as reduction of the Infection Efficiency, IE. For example acceptable risk levels are 10%, 5%, 1% or 0.1% of the IE probability. This corresponds with a specific concentration of active ingredient on the leaf. Leaves which have a lower concentration than the corresponding risk level are considered to be unprotected and leaves with a higher concentration of active ingredient are considered to be protected (LeafArNotProt and LeafArProt respectively).

$$LeafArNotProt = \Sigma\, LeafAr(i) \mid c(i) < c_{crit}$$

and consequently

$$LeafArProt = \Sigma\, LeafAr(i) \mid c(i) \geq c_{crit}$$

Where c(i) is the concentration of active ingredient on leafclass(i), (weight.$area_{leaf}^{-1}$) and c_{crit} is the critical concentration of the active ingredient corresponding to a specified reduction of the interaction component (weight.$area_{leaf}^{-1}$) corresponding to a given risk level. The area protected leaves relative to unprotected leaves is evaluated each time step. The leaf areas change due to new leaf formation during the timestep and the weathering and/or wash-off of the fungicide, see Figure 9. The critical concentration c_{crit} can be derived and is:

$$c_{crit} = c_{E50} \, (1 - r_l / r_l)^{\beta}$$

with

$$r_l = \text{InterCom}/\text{InterCom}_{max}$$

Where r_l is the risk level preferred by the farmer (dimensionless) ranging from 0 no risk to 1 (maximal risk).

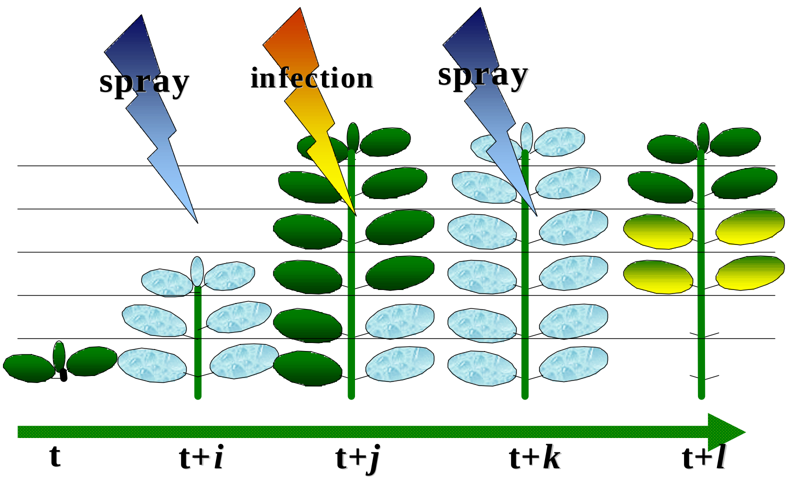

Figure 9. Effects of spraying on protection of foliage to Late Blight infections. Effects of spraying decrease due to weathering and wash-off of the fungicide and the formation of new leaf layers, as is shown in time steps t+I and t+j.

The decision to spray or not to spray is based upon the ratio of protected leaves relative to unprotected leaves, the disease pressure in the environment and the weather conditions and forecast. This is decision is covered in other models and consequently not considered here.

Fungicide spraying is meant to increase the concentration of the active ingredient on the leaf above the risk level concentration. The amount of fungicides applied per area must be sufficient to exceed this risk level concentration and to last at least a few days on the leaf surface. So the rate of change of the active ingredient concentration on the leaves is:

$$dc/dt = c_{bottle} \, spray \, / \, LAI$$

Where c is the concentration active ingredient on the leaves, (weight.area^{-1}), c_{bottle} is the concentration active ingredient in the bottle (weight.volume-1), spray is the amount of commercial product applied per area soil per day (volume.area$_{soil}^{-1}$.time^{-1}) and LAI the leaf area index (area$_{leaf}$.area$_{soil}^{-1}$).

The concentration change of the fungicide is now:

$$dc/dt \quad = \qquad c_{bottle}\ spray\ /\ LAI - c\ (k_{rain}\ RAIN + k_{decay}) - c/LeafArPl\ dLeafArPl/dt$$

see Figure 11.

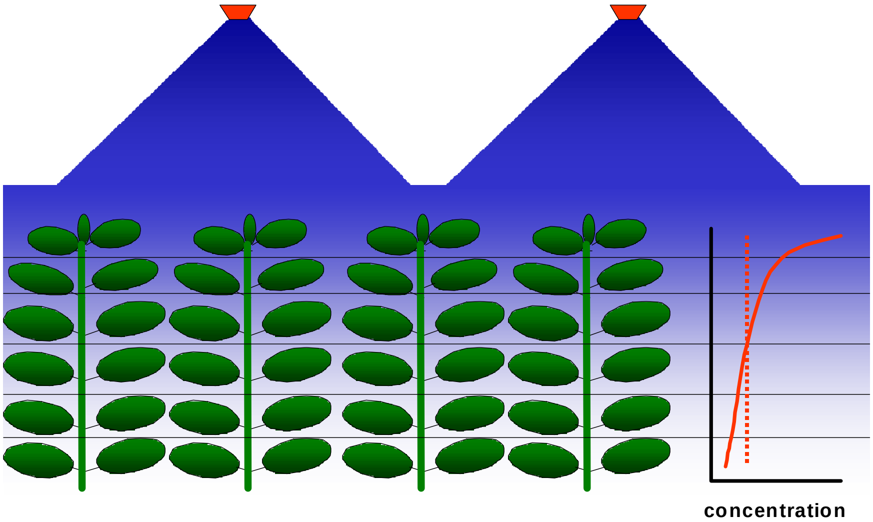

Figure 10. Vertical distribution of sprayed fungicides in a closed canopy. The lower leaf layers receive less fungicide then the upper leaf layers. On the right is the concentration profile of the fungicide in the canopy and the critical fungicide concentration where protection is insufficient.

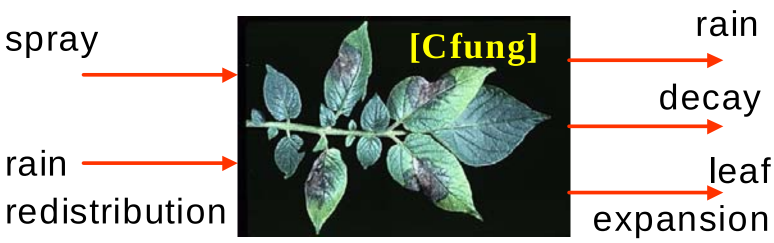

Figure 11. Schematic representation of the fungicide concentration model.

A homogenous application of the fungicide within the potato foliage is difficult to achieve. Manual fungicide spraying is the best application method since the atomiser allows for actual spraying within the canopy. Fungicide spraying with a tractor and machine driven atomiser has the risk of an inhomogeneous distribution of the fungicide within the canopy, especially when the canopy is closed, see Figure 10. The difference between the application methods is not considered for the Andean situation since manual spraying is common practice. Spray distribution in the canopy is therefore only considered for Western European conditions.

It is assumed that the effectiveness of the machine driven fungicide application decrease with the amount of leaf layers present. The decrease of effectiveness is assumed to be proportional to the light extinction in the canopy, since both processes are driven by the same mechanism i.e. hitting of a photon or fungicide molecule with a particle (leaf). Lamberts-Beer law describes light extinction in the canopy:

$$PARTrans(i) = PARFraction*RDD*\exp\{-ECPDF*LAIabove(i)\}$$

Where PARtrans is the amount of photosynthetic active radiation received at leaf layer (i), PARFraction is the fraction Photosynthetic active radiation of the total radiation, RDD is the total daily radiation, ECPDF is the light extinction coefficient of the canopy and LAIabove(i) is the LAI above leaf layer (i). As first approximation it is assumed that the extinction of fungicides in the canopy follows the extinction of light:

$$FungTrans(i) = c_{bottle}\ spray\ delt\ \exp\{-ECPDF\ LAIabove(i)\}$$

Where FungTrans(i) is the areal concentration of fungicides passed through leaf layers (n-i) ($weight.area_{soil}^{-1}$),c_{bottle} spray delt, is the concentration of totally applied fungicides ($weight.area_{soil}^{-1}$) per treatment, (n) is the upper youngest leaf class and (1) the lowest oldest leaf class. The areal concentration of fungicides which remains at leaf layer (i) is now:

$$c(i) = LAI(i)\ (Fungtrans(i) - Fungtrans(i-1))$$

with

$$c = \Sigma_1^n\ c(i)$$

For a complete canopy protection the concentrations of all leaf layers c(i) should exceed the critical concentration.

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Model calibration

The complete model is implemented in the simulation environment FSE 3.3+, which is not documented yet. (FSE Fortran Simulation Environment). The model is structured in modules with specific tasks.

The current version of the potential and water-limited LINTUL potato model is calibrated for Dutch conditions as is the Late Blight epidemiology model (van Oijen, 1991). For application in the Andean Ecoregion, the model has to be calibrated on the local conditions.

Method

Two methods of model calibration are combined here. First, data from literature are selected for specific processes that could not be calibrated on the available databases. Data from literature were either digitised by using a calibrated xy-tablet or directly taken form tables. Process parameters were estimated by using non-linear regression techniques. The derivatives of total sum of squares with respect to the parameters are approximated by the forward difference method. The roots of the normal equations are solved with the Gauss-Newton method for systems of non-linear equations. Standard deviations of the parameters are estimated according to the large sample theory of maximum likelihood estimators, where a normal distribution for the scatter around the deterministic model is assumed.

Genetic Algorithms

The second method is calibration by means of Genetic Algorithms. Genetic algorithms are a specific group out of the class of Evolutionary Computing. Evolutionary computing refers to the study of heuristic techniques based on the principles of natural evolution. An Evolutionary Algorithm is an iterative and stochastic process that operates on a set of individuals (population). Each individual (chromosome) represents a potential solution to the problem being solved. This solution is obtained by means of an encoding/decoding mechanism. The initial population is random generated. Every individual in the population is assigned by means of a fitness function, a measure of its goodness with respect to the problem under consideration. This value is the quantitative information the algorithm uses to guide the search (Evonet 2000). The selection is dependent upon the fitness, so highly fit individuals may reproduce several times, while the least fit may not reproduce at all.

The algorithm comprises three stages:

1. selection
2. reproduction
3. replacement

The Genetic Algorithms (GA's) rely on the use of selection, combination, crossover, mutation and replacement. GA's proceeds by creating successive generations of better and better individuals by applying very simple operations. The search is guided by the fitness value, which is used for ranking the individuals depending upon their suitability for the problem being solved, see Figure 12.

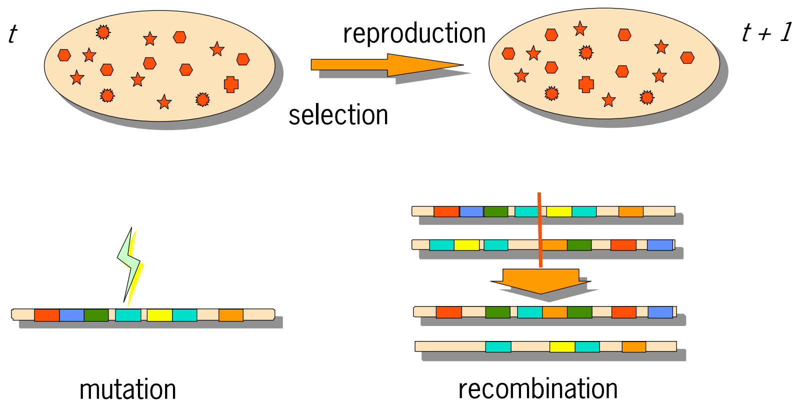

Figure 12. Different steps in the application of Genetic Algorithms (GA's)

For the calibration problem the most common type of chromosomes were used: fixed length strings of binary digits (eg …01100101001100….). Each string is a complete representation of the selected parameters of the simulation model. Each parameter consists of 64 digits. The digits represent binary the number of possible steps between the minimum and maximum value of the parameter. So the number of steps is in this case 2^{64} = 4096 steps. The number of parameters that can be used is large and sufficient for our purposes (more then 100). Populations of 50 individuals were used. Crossover and mutation are the reproduction processes considered. The mutation rate is 0.01 per digit per generation.

The fitness function is closely related to the objective function. The objective function has to be mapped to the fitness. Two common mappings are:

1. fitness scaling
2. fitness ranking

Fitness scaling applies a linear mapping to the objective function based upon population statistics. Fitness ranking sorts individuals according to their objective value. The mapping considered here is ranking.

The objective function is:

$$- \sum_{i}^{n_{treat}} \sum_{j}^{n_{obs}} (|\ Xobs_{i,j} - Xsim_{i,j}|) \,/\, (|\ Xobs_{i,j} + Xsim_{i,j}|)$$

This objective function is chosen because:

1. it provides a relative (scaled) measure which is independent of the size of the parameter value;
2. it is robust with respect for zero values of either observation or simulation.

Selection, reproduction and replacement

The first step in producing the new generation is to select the individuals for reproduction, that is to select the parameter values of the simulation model leads to the best fit with the observations. Two individuals from the population, the parents, are randomly chosen for the mating process (sampling with replacement). Two offspring individuals are generated where the fittest of these two is allowed to survive into the next generation t+1. This procedure ensures that the population size remains constant.

Application on the observed data

With the GA procedure it is possible to calibrate the model to several experiments, treatments within experiments and the individual observations for the different state variables at the same time. The procedure stops when the objective function is minimised to a certain value. The procedure never reached the stop value of the objective function when more experiments at the same time were optimised. Computer calculation time on a Pentium III, 300 MHz took many days for one experiment.

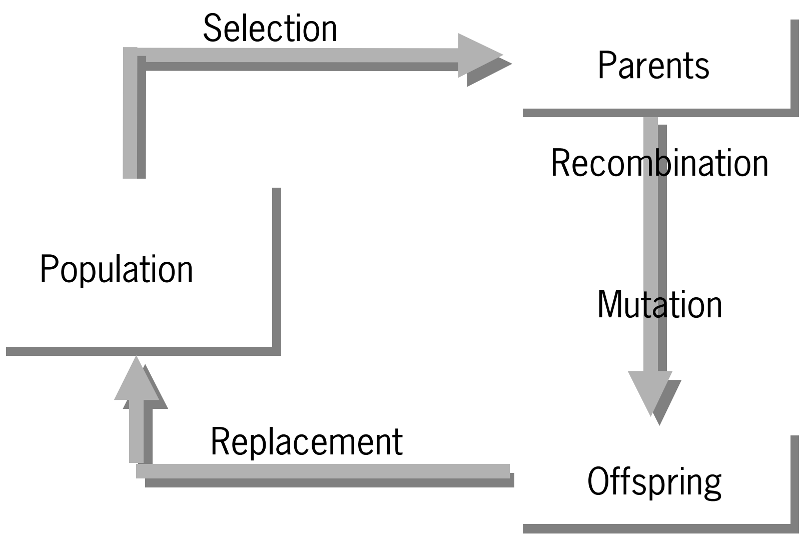

Figure 13. The evolutionary cycle.

Data

The model is developed for application in the Andean Ecoregion. Two databases are available for model calibration:

1. database from R. Roeland about potential and water limited potato production in Ecuador (autumn 1994);
2. database from J. Korva about Late Blight in potato in Ecuador (spring 1994).

Processes concerning the fungicide toxicity model are based upon data available in literature.

Results

Regression analysis at process level.

Light extinction in the canopy

The planting pattern in the Andean ecoregion is different from the planting pattern in the Netherlands. Differences in the planting pattern affect the light extinction coefficient ECPDF. Data from R. Roeland, cultivars Catalina, Gabriela, Super Chola and Yema de Huevo, are used for estimating the light extinction coefficient with equation:

$$FINT = 1.- \exp\{-ECPDF\ LAI\}$$

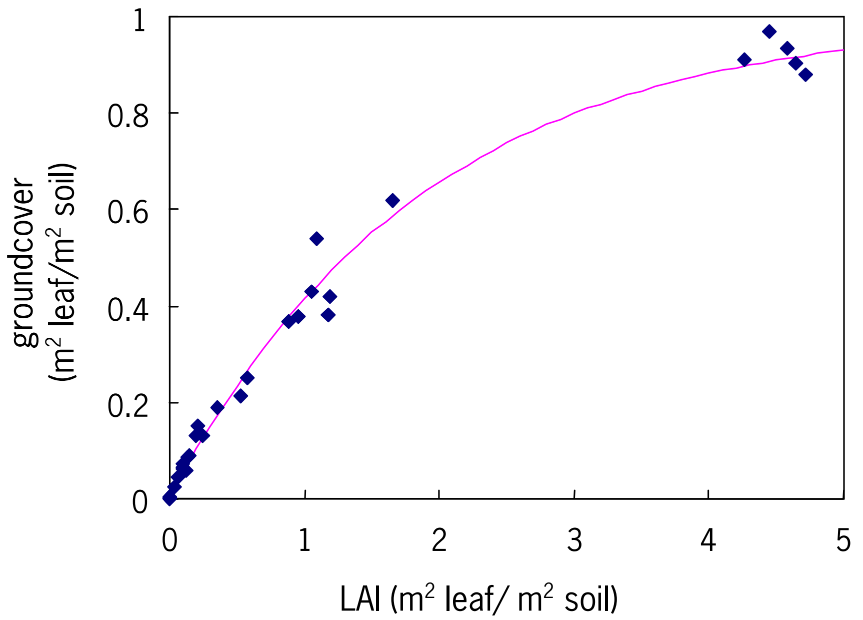

Figure 14. Relation between LAI and FINT according to equation. FINT = 1.- exp {-ECPDF LAI} where ECPDF = 0.535 (SD = 0.0144).

Fungicide toxicity for Late Blight

The toxicity of the fungicides Chlorothalonil and Mancozeb for different life-stages of the Late Blight has to be estimated. Figure 15 shows the effect of chlorothalonil and mancozeb on successful development of lesions induced by Late Blight on potato foliage when sporangia were applied (data from Bruck *et al.*, 1981). The Infection Efficiency, IE, was estimated according to the Weibull function:

$$IE \quad = \quad IE_{max} \;/\; (1 + (c \;/\; c_{E50})^{1/\beta})$$

The EC50 concentrations are 326.8 (SD=7.40, ug(ai)/ml) and 6.42 (SD=1.43E-5,ug(a.i)/ml) for chlorthalonil and mancozeb respectively. The potato plants in this experiment were sprayed to runoff with the fungicides. The leaves can attain about 0.0068 $cm^3_{water}/cm^2 l_{eaf}$ when sprayed to runoff (own observations). This means that the EC50 concentrations are 2.22 and 0.0437 ug (a.i.)/cm^2_{leaf} for chlorothalonil and mancozeb respectively.

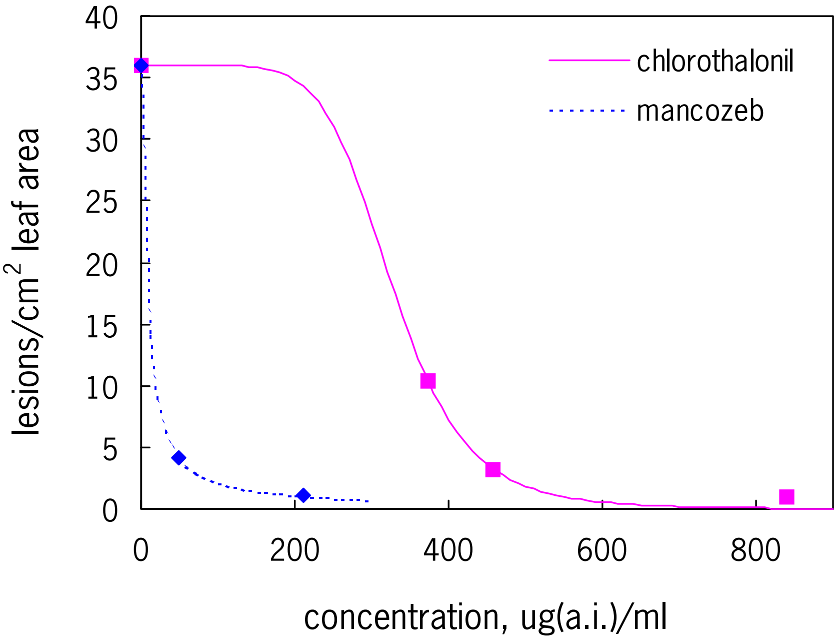

Figure 15. Effect of Chlorothalonil and Mancozeb on lesion formation induced by sporangia (data form Bruck et al 1981). The EC50 concentrations are 326.8 (SD=7.40, ug(ai)/ml) and 6.42 (SD=1.43E-5,ug(a.i)/ml) and β is 0.146 (SD=0.018) and 0.992 (SD=1.02E-6) for chlorothalonil and mancozeb respectively.

Fungicide weathering and wash-off

Due to effects of UV-radiation, temperature and other sources of inactivitation, fungicides loose their toxicity. Another source of fungicide loss is the wash-off of fungicides by rain or overhead sprinkler irrigation. Figure 16 shows the loss of activity of Chlorothalonil caused by either weathering or wash-off due to simulated rain (data are from Malthi and Jeyarajan, 1995). The dissipation rate was in the rain exposed situation twice as high as that in the rain protected situation. An amount of 8 mm rain was recorded after 1-3 days after spray. The estimated rate constants are 0.14 (d-1) for weathering and 0.02 (mm-1) per mm rain for the wash-off respectively. The fitted equation is:

{C} = {C0} exp{-kt}

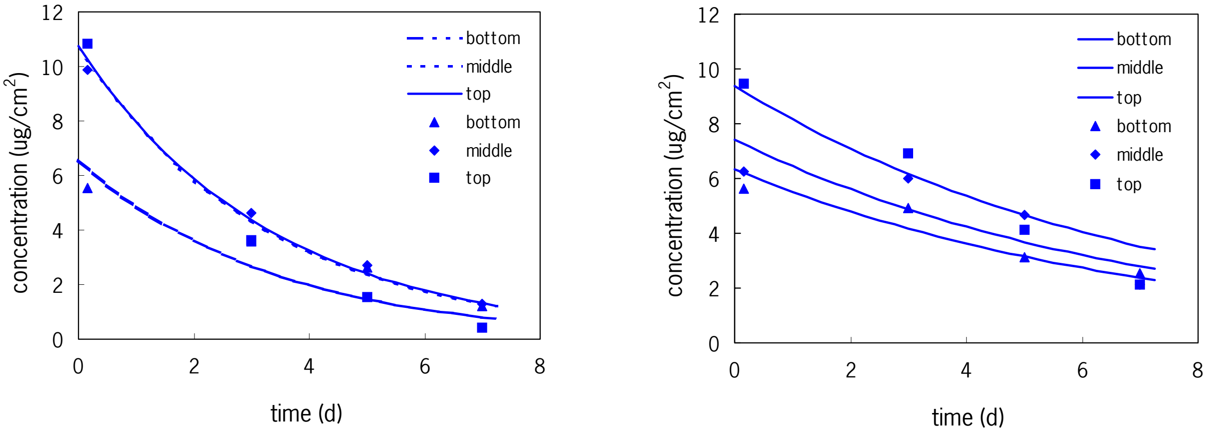

Figure 16. Persistence of Chlorothalonil in rain exposed (left) and rain protected situation (right) for the top, middle and bottom leaf layers (Malthi and Jeyaryan, 1995). The estimated rate constants are 0.30 (SD=0.026, d^{-1}) and 0.14 (SD=0.019, d^{-1}) for the rain exposed and protected respectively.

Calibration of integral simulation model with genetic algorithm

Water limited potato production

The model was first calibrated on data from R. Roeland (1996). The data form experimental site Estacion (Experimental Research Station CIP 'Santa Catalina' in Cutuglahua, Ecuador) were used. This potato trial started in June 1994 and was harvested in December 1994. It can be regarded as a water-limited potato trial since no irrigation was supplied. Other experimental details can be found in Roeland (1996). The weather data for 1994, site Estacion, are given in the appendix.

The calibrated model parameters are listed in Table 4. Results are shown in Figures 14 and 15 and are quite satisfactory.

Late Blight limited potato production

The model is calibrated on data obtained from J. Korva. The results are shown in Figure 16 for Catalina and in Figure 17 for Gabriela respectively. The calibration results are quite satisfactory. The trends between the different treatments are covered by the model. Tuber weight is either over estimated or under estimated between the treatments. The simulated tuber weights of the Roeland data set suit better the observed data. There is no explanation for the differences in model behaviour at the moment. The fraction disease of the potato crop is simulated fairly well for Catalina and Gabriela.

The calibrated parameter values for Gabriela and Catalina are given in Table 5. The start values for the parameters are also given. The start values are used as initial for the genetic algorithm.

The calibrated parameter values differ from the data set of Roeland. The differences are given in Table 3. There is no explanation for the differences at this moment.

Table 3. Differences between calibrated parameter values on data sets Roeland (1996) and Korva.

Parameter	Gabriela		Catalina	
	Data Roeland	Data Korva	Data Roeland	Data Korva
LUE	2.43	1.76	1.81	1.61
Rellossdeadleaves	0.74	0.86		
LeafArPll	1.24	1.55	1.49	1.42

Table 4. Estimated Parameter values for different potato cultivars on data set Roeland 1996, site Estacion, Ecuador 1994.

Parameter	Cultivars								
	Start value	Cap	Catalina	Cec	Desiree	Gabriela	Spunta	Super Chola	YemadeH uevo
Kstrslue	1.00E-02	9.10E-03	9.10E-03	9.10E-03	9.10E-03	9.10E-03	9.10E-03	9.10E-03	9.10E-03
Kstrsrgrl	0.1	0.110821	0.110821	0.110821	0.110821	0.110821	0.110821	0.110821	0.110821
Waterextrpar	1.67E-02	1.63E-02	1.63E-02	1.63E-02	1.63E-02	1.63E-02	1.63E-02	1.63E-02	1.63E-02
Lue	1.856	2.764053	1.819279	1.264383	0.970615	2.426268	1.626153	2.377802	2.385055
Rgrl	2.92E-02	2.43E-02	1.55E-02	3.26E-02	3.43E-02	1.12E-02	3.49E-02	2.20E-02	2.01E-02
Leafpar	3.2	2.125257	3.314502	3.944895	1.878261	3.0426	3.561896	4.706204	2.455105
Leafstemratio	0.757	0.567843	0.536185	0.734996	0.473171	0.351403	0.780853	0.852226	0.571541
Tmsumleafgrowth	751.6	424.6338	794.8994	884.3325	552.0423	666.3347	394.5257	700.3796	743.3386
Leafagemx	1693	1563.564	1860.916	2053.186	887.8532	1616.112	1143.416	1838.977	1305.521
Leafargrowthref	5.12E-03	4.69E-03	7.94E-03	3.04E-03	4.48E-03	5.56E-03	2.90E-03	5.33E-03	6.09E-03
RelLossdeadLeave	1	0.744993	0.744993	0.744993	0.744993	0.744993	0.744993	0.744993	0.744993
KstrsAge	0.76	0.499922	0.370337	0.499922	0.499922	0.609773	0.499922	0.499922	0.499922
Bage	2.8	4.019443	3.251442	4.019443	4.019443	2.655704	4.019443	4.019443	4.019443
LeafArPlI	1.55E-02	1.94E-02	1.49E-02	1.84E-02	1.61E-02	1.24E-02	1.57E-02	1.97E-02	2.04E-02
KageLUE	442.6	236.0029	379.0656	236.0029	236.0029	338.6689	236.0029	236.0029	236.0029
BageLUE	4.78E-02	5.74E-02	6.85E-02	5.74E-02	5.74E-02	5.73E-02	5.74E-02	5.74E-02	5.74E-02

Table 5. Start and calibrated parameter values for cultivars Gabriela and Catalina for the control, early inoculation and late inoculation respectively. site Estacion, Ecuador 1994 (data Korva).

Parname	Gabriela				Catalina			
	start	control	early	late	start	control	early	late
Lue	1.871	1.766345	1.766345	1.766345	1.856	1.608926	1.608926	1.608926
Sla	1.80E-03	1.14E-03	1.14E-03	1.14E-03				
RelLossdeadLeaves	1	0.860772	0.860772	0.860772	1	1	1	1
LeafArPlI	1.55E-02	2.00E-02	2.00E-02	2.00E-02	1.55E-02	1.42E-02	1.42E-02	1.42E-02
InocEffi					1.00E-05	1.51E-05	1.51E-05	1.51E-05
InocInEf	1.00E-02	2.59E-02	2.59E-02	2.59E-02	1.00E-02	5.76E-03	5.76E-03	5.76E-03
InocLeGr	3.00E-03	7.34E-04	7.34E-04	7.34E-04	3.00E-03	1.94E-03	1.94E-03	1.94E-03
InocSpRt	8500000	5331705	5331705	5331705	8500000	2.33E+07	2.33E+07	2.33E+07
BlightBeta	3	3.350269	3.350269	3.350269	3	4.480215	4.480215	4.480215
BlightDelta	0.5	0.59404	0.59404	0.59404	0.5	0.469956	0.469956	0.469956
BlightEps	0.5	0.334148	0.334148	0.334148	0.5	0.534196	0.534196	0.534196
Leafstemratio					0.82	0.8202	0.8202	0.8202
Leafargrowthref					6.07E-03	6.07E-03	6.07E-03	6.07E-03
Leafagemx					1643	1643.401	1643.401	1643.401
Tmsumleafgrowth					782.1	782.291	782.291	782.291
InocDate(2)	65	81.59135	43.29629	75.05007	65	63.04714	48.75794	70.15999
InocDens(2)	2.00E+09	3.27E+10	1.79E+11	1.66E+11	2.00E+09	1.72E+11	1.95E+11	8.75E+10

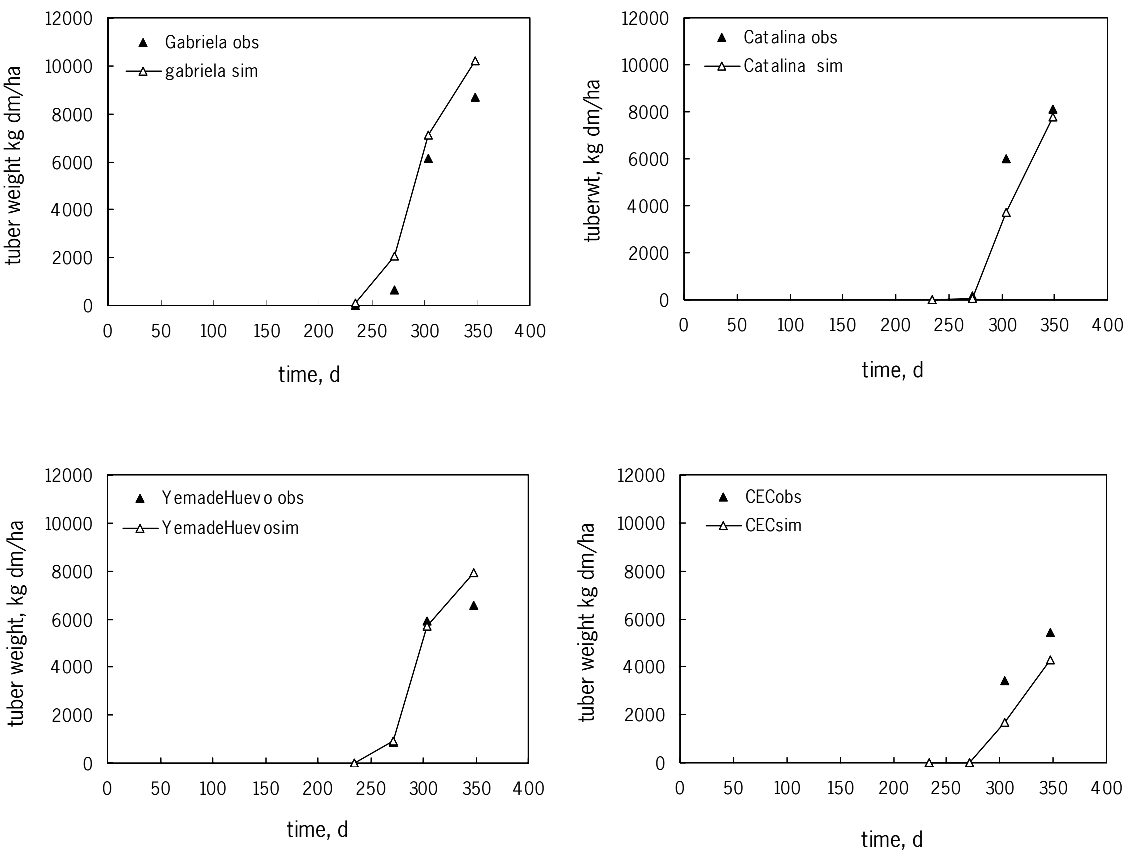

Figure 14. Simulated and observed tuber weights for cultivars Gabriela, Catalina, Yema de Huevo and Cec at site Estacion in Ecuador, 1994. Data are from Roeland 1996.

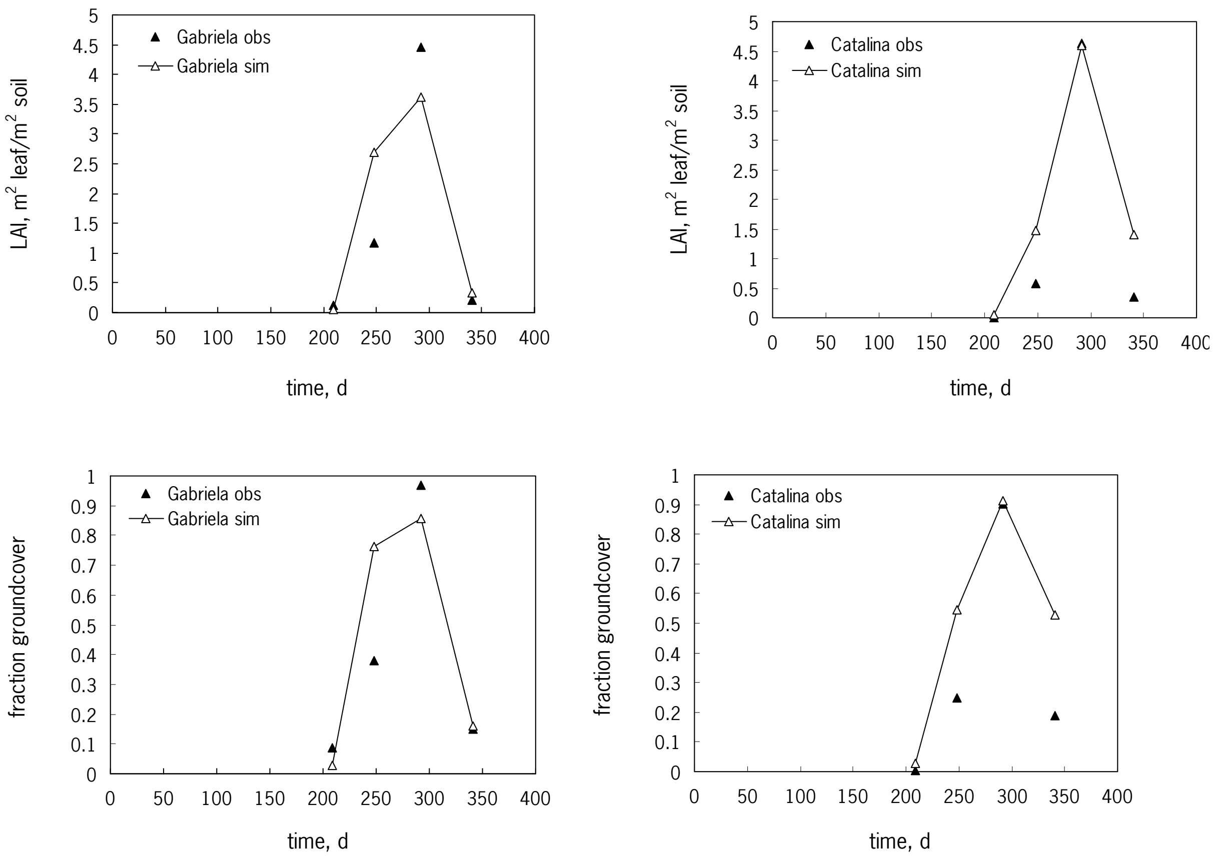

Figure 15. Observed and simulated LAI and fraction groundcover for potato cultivars Gabriela and Catalina at site Estacion in Ecuador, 1994. Data are from Roeland 1996

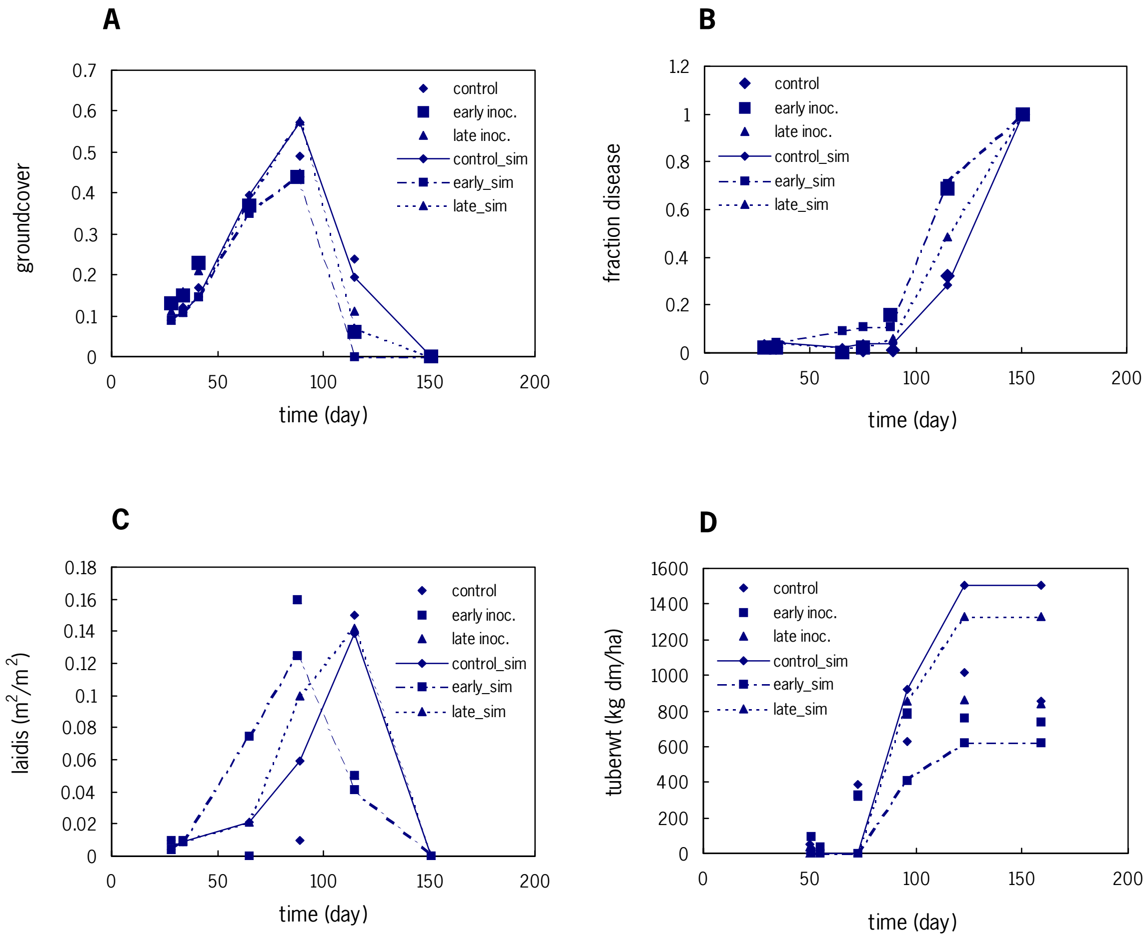

Figure 16. Calibration results for cultivar Catalina for a control treatment, early Late Blight inoculation and late Late Blight inoculation. Figure (a) Observed and simulated groundcover, Figure (b) observed and simulated fraction leaf area affected (necrotic and diseased) by Late Blight, Figure (c) observed and simulated diseased (sporulating) leaf area, Figure (d) observed and simulated tuber weight. Data are from Korva in prep.

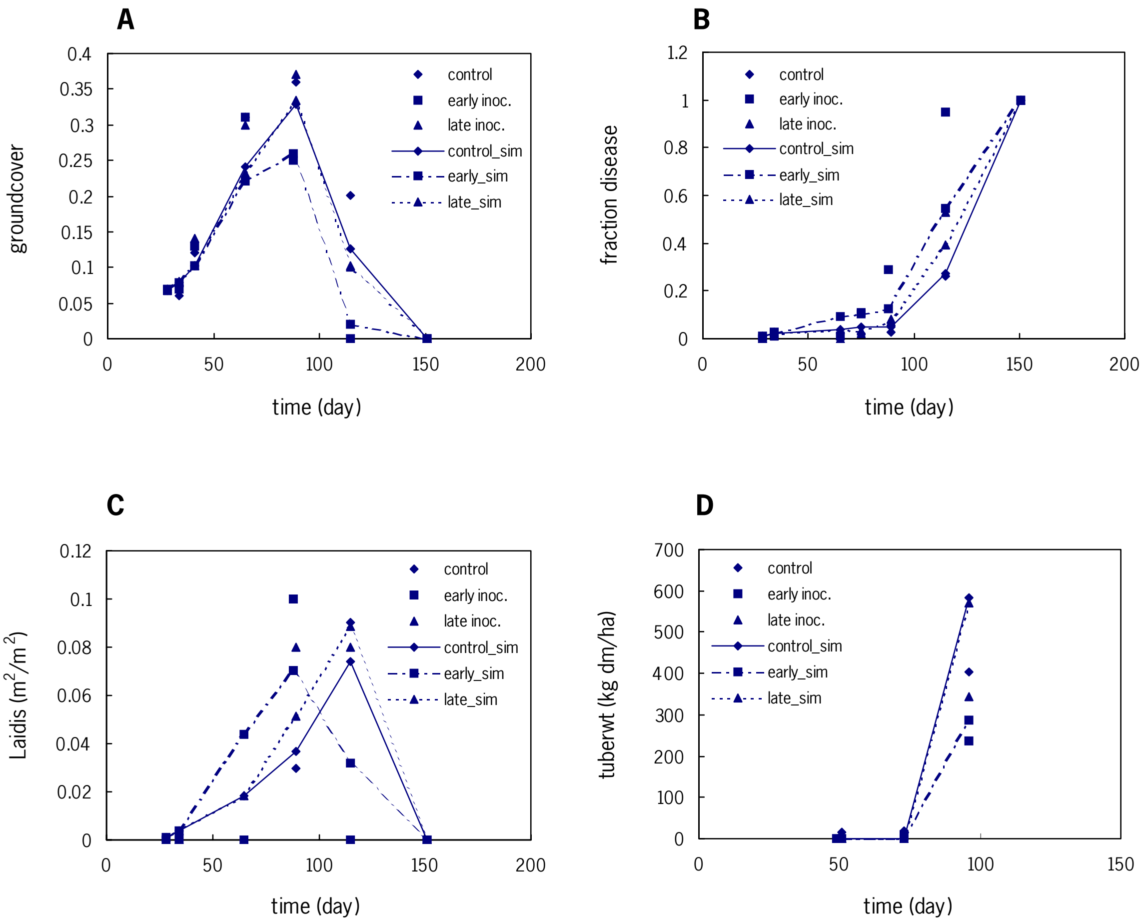

Figure 17. Calibration results for cultivar Gabriela for a control treatment, early Late Blight inoculation and late Late Blight inoculation. Figure (a) Observed and simulated groundcover, Figure (b) observed and simulated fraction leaf area affected (necrotic and diseased) by Late Blight, Figure (c) observed and simulated diseased (sporulating) leaf area, Figure (d) observed and simulated tuber weight. Data are from Korva in prep.

Scenarios

Effects of fungicide application on yield formation

The calibrated model can be applied for evaluation of fungicide application strategies with respect to yield formation. Four strategies are compared:

1. Each second day a chlorothalonil fungicide application of 0.3 kg a.i. /ha, a total amount of 20.7 kg a.i./ha during the cropping season;
2. Each second day a chlorothalonil fungicide application of 0.7 kg a.i. /ha, a total amount of 48.3 kg a.i./ha during the cropping season;
3. Each seventh day a chlorothalonil fungicide application of 1 kg a.i. /ha, a total amount of 20. kg a.i./ha during the cropping season;
4. Each seventh day a chlorothalonil fungicide application of 2.5 kg a.i. /ha, a total amount of 50. kg a.i./ha during the cropping season.

The weather, which is applied for evaluation of the strategies, is the weather of site St. Catalina, Ecuador in spring 1994 with a planting date late December 1993. The applied planting conditions are the same as in the experiments of Korva. The cultivar Gabriela is used.

The cumulative amount of applied fungicides during time is shown in Figure 18. The 2-daily and 7-daily application regimes can be clearly distinguished. The resulting tuber yields are shown in Figure 19. The difference between application strategies is negligible, when a total amount of about 20 kg a.i./ha chlorothalonil is applied. When the amounts are doubled, the effect of different application strategies is obvious. The 2-daily application regime results in a higher tuber yield then the 7-day application regime. So, the model can be applied for optimising the fungicide application regimes for the local conditions and cultivars.

The concentration of fungicides on leaves differs for a large extent when a 2 or 7 day application regime is applied. This is shown in Figure 20 and Figure 21 where the concentration kinetics for the 0.3 kg 2 day and 1.0 kg 7 day application regimes are compared. The effect of the fungicides on the infection efficiency (IEFUNG) of Late Blight is also shown. The large decrease in concentrations on the leaf is caused by the wash-off of the fungicide due to heavy rains. Heavy rains on day 30, 31 and 32 of respectively 32, 24.1 and 33.1 mm and on day 52 of 36.4 mm cause large wash-off effects.

The epidemiology (fraction diseased leaf area), and the fraction total groundcover of the leaves is shown in Figure 22. The differences in fraction groundcover and fraction disease between the 2 day and 7 day applications are small, as could be expected from the small differences in tuber yield. However, the crop dies when no fungicides are applied and consequently no yield is produced.

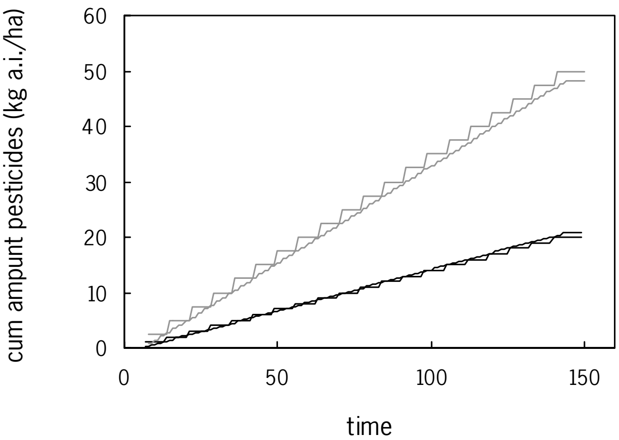

Figure 18. Cumulative amounts of applied chlorothalonil in 2-daily and 7-daily application regimes of respectively 2daily, 0.3 kgha; 2daily 0.7 kg/ha; 7daily 1 kg/ha and 7 daily 2.5 kg/ha. The final amounts are 20.7, 48.3, 20 and 50 kg ai/ha.

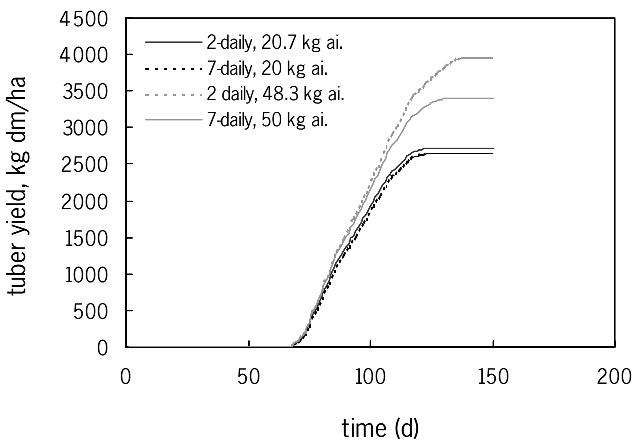

Figure 19. Simulated tuber yield for four different fungicide application regimes. The application regimes are respectively 2 and 7 daily with 0.3 , 0.7 , 1 and 2.5 kg a.i/ha/application.

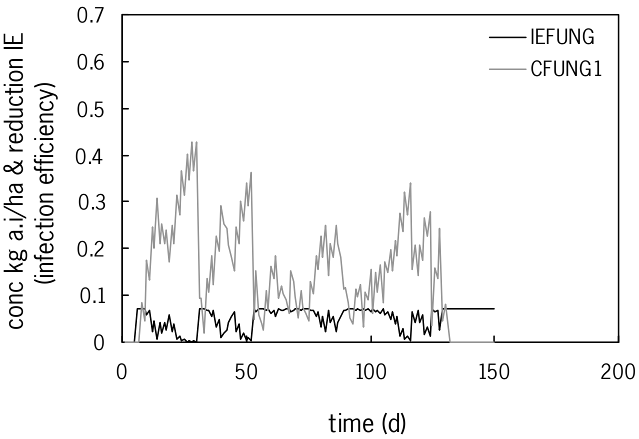

Figure 20. Concentration of chlorthalonil (kg a.i/ha leaf, CFUNG) with a 2-daily fungicide application regime of 0.3 kg a.i/ha and the reduction of Infection Efficiency (IEFUNG) of Late Blight due to the fungicide.

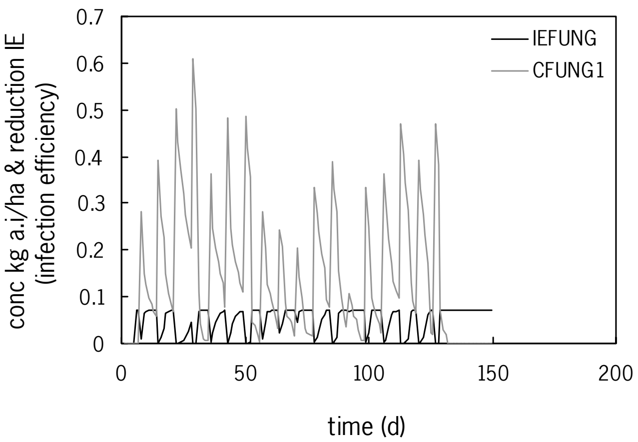

Figure 21. Concentration of chlorthalonil (kg a.i/ha leaf, CFUNG) with a 7-daily fungicide application regime of 1 kg a.i/ha and the reduction of Infection Efficiency (IEFUNG) of Late Blight due to the fungicide.

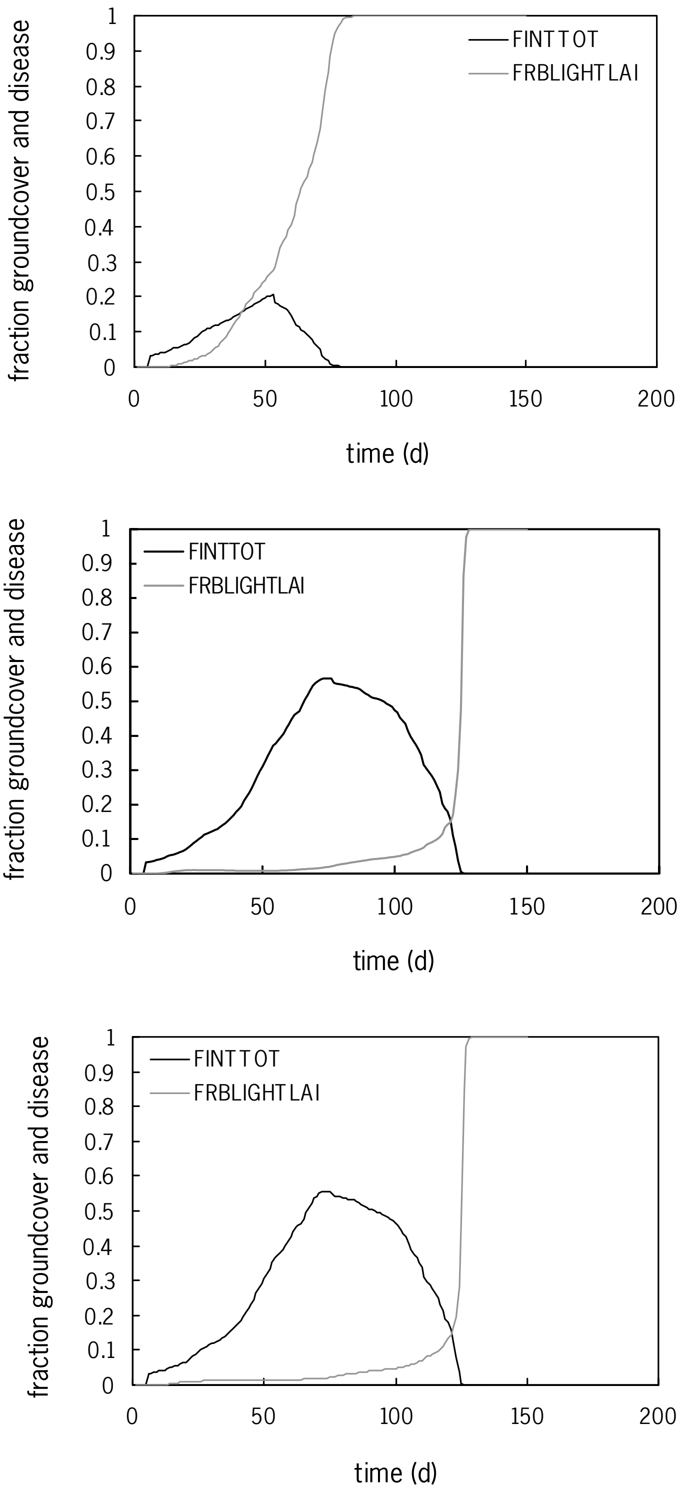

Figure 22. Fraction total groundcover and fraction disease (diseased leaf area) for (a) no fungicide application, (b) 2-daily 0.3 kg ai/ha application and (c) a 7-daily 1 kg ai/ha application.

Trade-offs between fungicide application and potato yield for cultivars differing in resistance.

The calibrated model can be applied for evaluating the trade-off between the amount and frequency of fungicide applications and potato tuber yield. Four different hypothetical cultivars are compared with four different spraying strategies:

1. Each second day a chlorothalonil fungicide application;
2. Each third day a chlorothalonil fungicide;
3. Each fifth day a chlorothalonil fungicide;
4. Each seventh day a chlorothalonil fungicide application.

The cultivars differ in their interaction components. Three interaction components were individually changed with respect to the default:

1. Infection efficiency, IE;
2. Lesion growth rate, LG;
3. Sporulation rate, SR.

The 50% values of the interaction components were taken in order to mimic a more resistant cultivar and/or a less virulent population of Late Blight.

The weather is from station St. Catalina in Ecuador in 1994

It is obvious from Figure 23 that the 2-day spray schedule has the largest impact on potato yield formation after passing a critical threshold of amount of applied fungicides. It can also be seen that the lesion growth rate and the infection efficiency have effects on potato yield formation in the middle range of fungicide applications only. It can therefore be concluded that breeding for new (partial) resistant cultivars should incorporate at the same time the optimal fungicide-spraying regime.

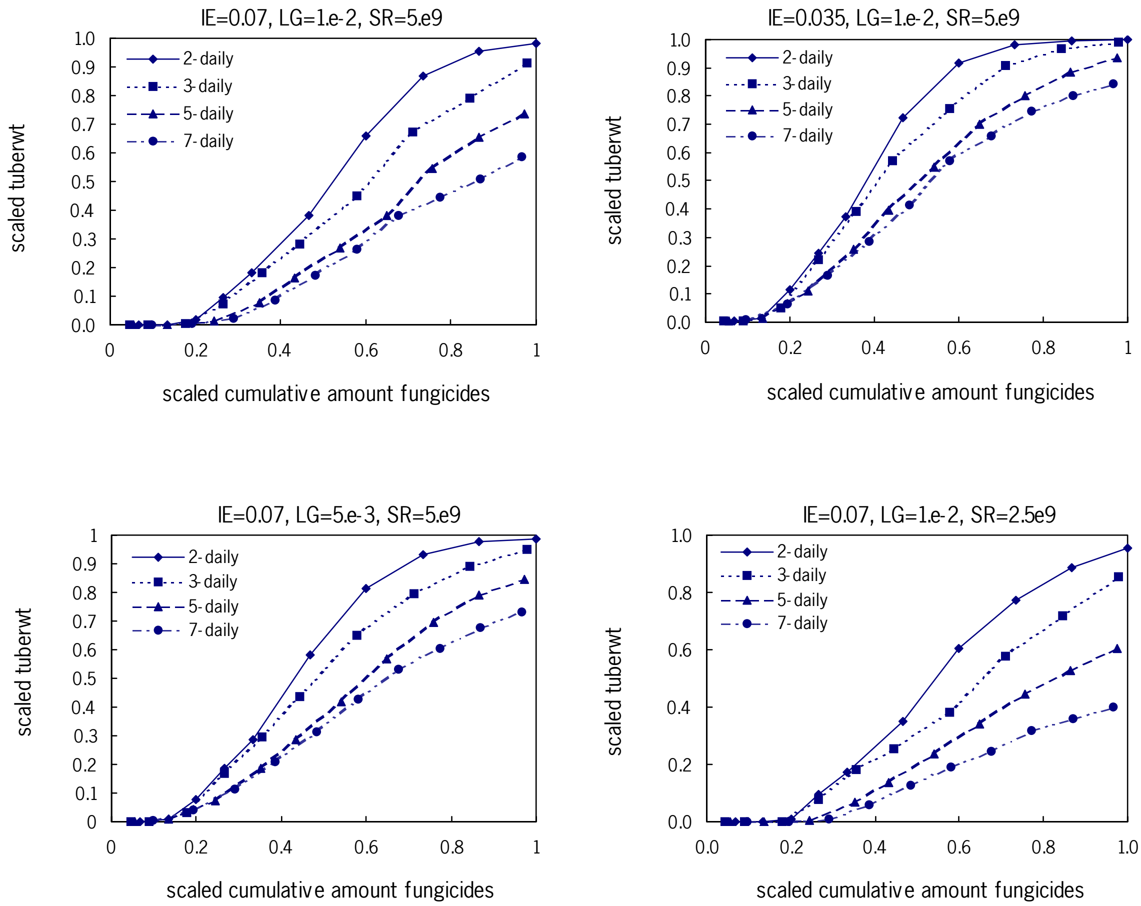

Figure 23. Trade-off curves between amount fungicide application and tuber weight for four different application regimes: 2-daily, 3-daily, 5-daily and 7-daily and four different hypothetical potato culitvars differing in their Interaction components IE (infection efficiency). LG (lesion growth rate) and SR (sporulation rate).

Discussion

The developed model where potato growth, soil water and nitrogen dynamics, late blight epidemiology and fungicide applications are combined is calibrated on data from the Andean Ecoregion. Major difficulties arose from calibration of the model on the available data. The available databases were from Roeland (1996) and Korva (in press). New techniques are applied for model calibration. These techniques, multi-variate nonlinear regression and Genetic Algorithms (GA's) can be applied with satisfactory results. Application of GA's allows for calibration of many parameters and initial values at the same time. As a consequence, the model-structure needs no change for calibration of the LINTUL model to the conditions specific for the Andean Ecoregion. So, the LINTUL model is applicable for the Andean Ecoregion. Because of the few available databases for calibration, the model can not be applied properly in the Andean Ecoregion. The developed procedure for calibrating models with the aid of genetic algorithms is promising. When more data becomes available, model calibration can be improved and hence model application.

Model validation could not be performed due to lack of data.

Nevertheless, scenario studies are performed for demonstrating model possibilities alone. These results can not be used for proper decision making since model calibration was poor on only two data sets and model validation lacking.

These scenario studies show two major application possibilities of the model:

1. Evaluate spraying regimes and optimizing these;
2. Evaluate interaction components of potato cultivars and Late Blight populations in combination with different spraying regimes.

When more data become available the model can be calibrated and validated by which the reliability and the prediction confidence of the model might increase.

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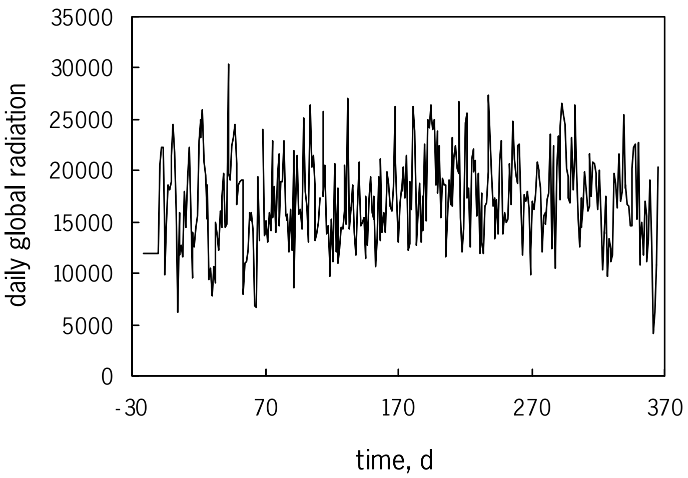
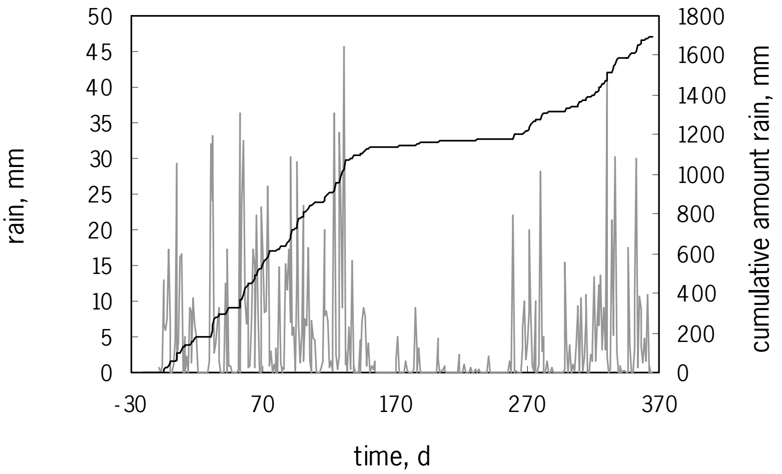
Weather data





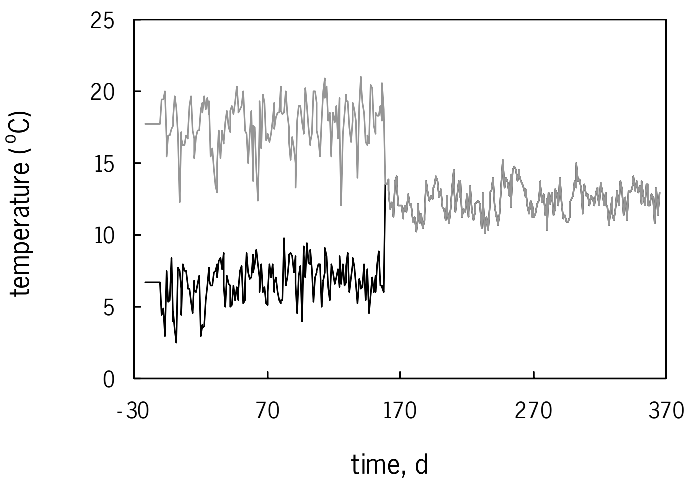


Figure 24. Weather data for year 1994 at site Estacion (Experimental Research Station, CIP, Ecuador).

Seventh Workshop of an European Network for development of an
Integrated Control Strategy of potato late blight
Poznan, Poland, 2-6 October 2002

Prevention of tuber blight in potatoes with Ranman

K. JILDERDA, H.C.M. KRUTS, R.E. SCHOLTENS AND T. SINNEMA

BASF Netherlands BV, Division Agro

Introduction

In 2002 the fungicide Ranman was introduced for the control of potato late blight, *Phytophthora infestans*, in Belgium, Germany, The Netherlands and The United Kingdom. D. Ebersold describes the features of this fungicide in 2001 during the Edinburgh workshop. At that time limited experience was available on the effect on tuber blight. Prevention of tuber blight deals with prevention of zoospore formation, immobilisation and killing of zoospores.

In 2001 a number of trials were carried out in which tuber blight occurred. In this paper the efficacy of Ranman on tuber blight in field trials will be demonstrated.

Materials and methods

Three series of field trials F2001/833, F2001/834 and F2001/836 were carried out with different objectives. In all trials, with the exception of one trial where Agria was used, the variety Bintje was planted by hand at a distance of 36 cm in a row. A plot consisted of 4 rows at a row distance of 75 cm. The plot length was 7 m. Unsprayed extra rows in some trials were to generate an evenly infection pressure in those trials. Fungicide treatments were randomised in four complete blocks. The applications were partly done by a knapsack sprayer with nozzletype XR 11002 VS or TJ 8002 VS and partly with a tractor mounted High Pressure sprayer with nozzletype XR 10-03. All trials were sprayed with a spray volume of 300-350 l/ha. In the trials the unsprayed rows served as untreated, just to show the presence of infections.

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The rating on the leaf infestation was done with the Dutch PD-scale and was later recalculated to % infected leaf surface.
After desiccation, the plots were harvested and the net yield was measured. The tuber blight was assessed as percentage of the net yield in weight, directly after harvesting and after 3 weeks storage. Both figures were totalled and herewith the %-infested tubers (w/w) was calculated.

Field trial series F2001/834: in this series 2 trials were carried out in which tuber blight occurred. Objective of the trials was to assess the efficacy on leaf and tuber blight of Ranman, Shirlan, Tanos and Acrobat, applied in a 7-day spray interval. The first spray was done at stage 31-32 and the last sprays in September during ripening.

In a second trial programme F2001/836 3 trials were carried out. These trials started later in the season after ending of the growth period of the potato crop. The intention was to assess the efficacy on leaf and tuber blight of a number of products in a 7-day spray interval under non-growing conditions. A total of 6-7 sprays were carried out.
In the third series F2001/833 5 different spray programmes were compared regarding leaf and tuber blight. In one trial heavy tuber infestation occurred, this trial is presented here. In table 1 the spray programmes are described.

Table 1. Spray programme in trial F 2001/833:

			Block			
Trt	prod. name	dose/ha	A	B	C	D
1	ACROBAT	1.5	1.5			
	RANMAN	0.2		0.2		0.2
	ACROBAT	2			2	
2	ACROBAT	1.5	1.5			
	RANMAN	0.2		0.2		0.2
	SHIRLAN FLOW	0.4			0.4	
3	AVISO DF	2.5	2.5			
	RANMAN	0.2		0.2		0.2
	MANTRILON FL	0.25		0.25	0.25	
	SHIRLAN FLOW	0.4			0.4	
4	TURBAT	2.25	2.25			
	SHIRLAN FLOW	0.4		0.4	0.4	0.4
5	RANMAN	0.15	0.15			
	MANTRILON FL	0.25	0.25			
	FORUM	0.9	0.9			
	SHIRLAN FLOW	0.4		0.4	0.4	0.4

A	APPLICATION 1-5	13-jun	20-jun	26-jun	03-jul	12-jul
B	APPLICATION 6-8	20-jul	27-jul	02-aug		
C	APPLICATION 9-11	10-aug	15-aug	21-aug		
D	APPLICATION 12-14	30-aug	05-sep	11-sep		

Results

F2001/834: from early August onwards many infections occurred, which could be seen in the untreated rows. Also in the trial the leaf attack was visible. The % infestation raised from 0 to 20-30 for Ranman,. Shirlan and Acrobat and to almost 60% for Tanos (figure 1). Dose response is visible for Ranman and Shirlan full and ¾ rate. The highest efficacy had Ranman full rate, followed by Shirlan full rate and Acrobat, followed by Ranman and Shirlan both ¾ rate.

At harvest the yield and the weight % of blighted tubers was measured.

In table 2 the results are presented. The yield level was round 60 tons/ha for Shirlan and Ranman, the other products were on a lower level. A heavy tuber infestation occurred. Ranman showed very good protection of the tubers even with 0.15 l/ha, Shirlan showed more infestation and a dose response. The tuber blight control with Acrobat and Tanos was insufficient.

Table 2. Yield and yield of healthy tubers in tons/ha and % of yield with tuber blight.

	F2001/834 (n=2)		
li, kg/ha	total yield	healthy yield	% tuberblight
Ranman 0.15	60.9	58.6	3.7
Ranman 0.2	61.6	60	2.6
Shirlan 0.3	59.3	50.2	15.3
Shirlan 0.4	62.4	58	7.1
Tanos 0.7	40	20.8	48.2
Acrobat 2.0	52.5	33.2	36.8

F2001/836: from 10^{th} of August onwards many infections occurred, which could be seen in the untreated rows. Also in the trial leaf attack was visible. The % infestation raised linear in the plots from 0 to 30 % for Ranman in both dose rates, to 50% for Shirlan, Tanos and Aviso DF, to 65% for Acrobat and Sereno and to 70% for Electis (figure 2). In these trials no dose response is visible for Ranman full and ¾ rate.

Figure 1: % infested leafsurface Phytin
F2001/834 (n=2)

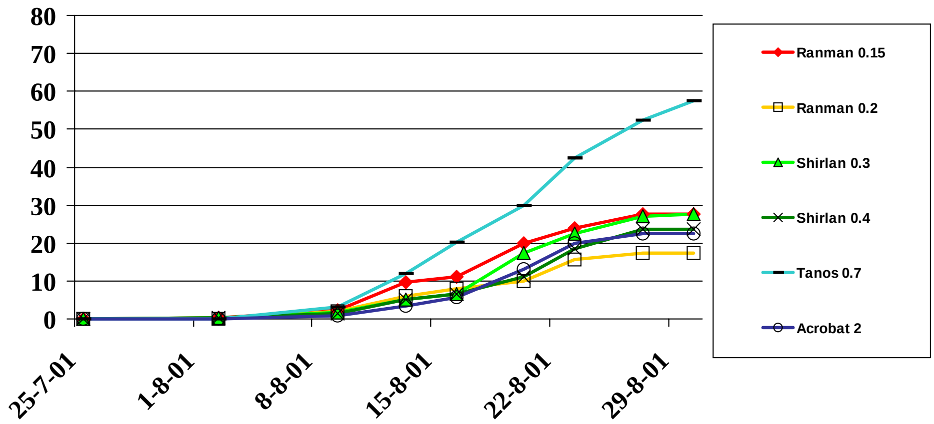
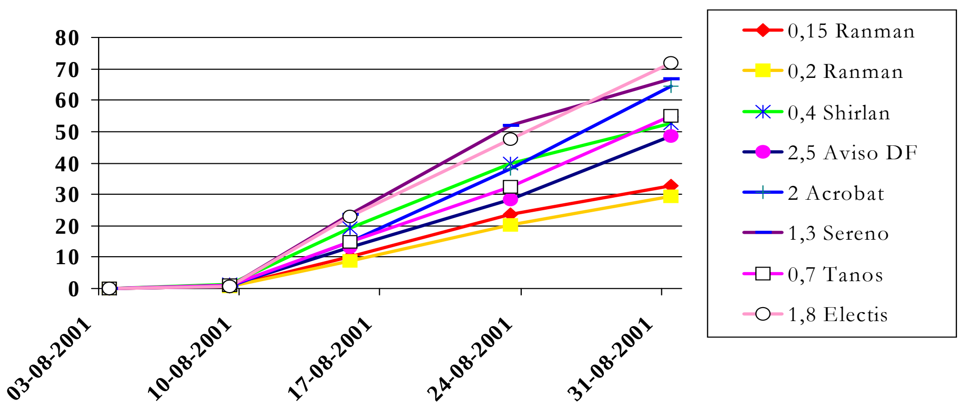


Figure 2:% infested leafsurface Phytin
F2001/836 (n=3)



At harvest the yield and the weight % of blighted tubers was measured.

In table 3 the results are presented. The yield level was between 42 and 49 tons/ha. The products with the highest leaf protection showed also the highest yield. A heavy tuber infestation occurred. Ranman showed very good protection of the tubers even with 0.15 l/ha, a light dose response is shown. Shirlan showed more infestation followed by Sereno and Electis. Tanos and Aviso DF showed the most tuber blight.

Table 3. Yield and yield of healthy tubers in tons/ha and % of yield with tuber blight.

		F2001/836 (n=2)	
li, kg/ha	total yield	healthy yield	% tuber blight
Ranman 0.15	49.4	47.4	4.0
Ranman 0.2	47.2	46.2	2.1
Shirlan 0.4	45.3	40.6	10.3
Aviso DF 2.5	44.2	28.9	34.7
Acrobat plus 2	42.7	32.0	25.2
Sereno 1.3	42.6	34.7	18.7
Tanos 0.7	43.0	28.0	34.7
Electis 1.8	42.4	33.2	21.8

F2001/833: In the first week of August leaf infestation became visible in the plots, resulting from a heavy infection period from 18-24 July, as can be seen from figure 3. The next infection period was 10-15 August. After this period the disease levels increased to 70-100% on 12th September (figure 4). Spray programmes 1, 2 and 3 showed equal results, whereas programme 4 and 5 were less effective as leaf protectants.

Figure 4: % infested leafsurface Phytin
F2001/833 (n=1)

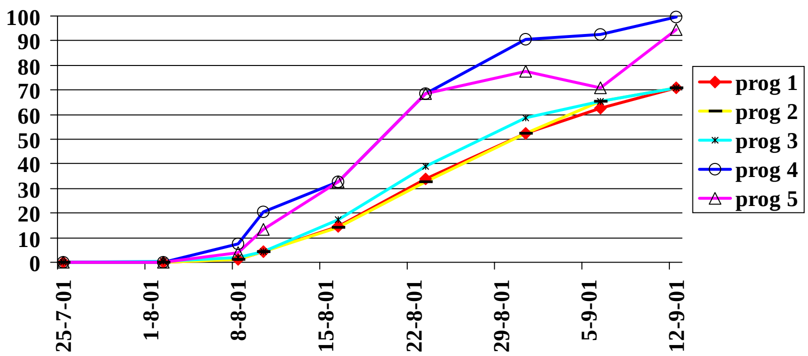


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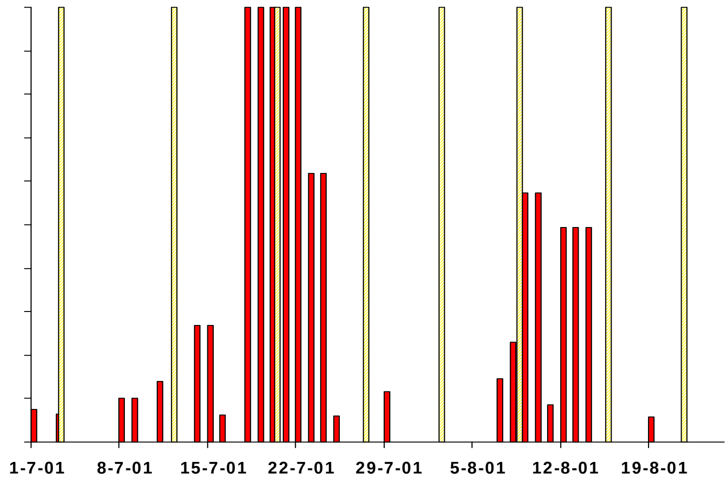
Figure 3: infection risk as calculated by Dacom.
Light bars are applications, dark bars are days with infection risk
F2001/833 (n=1)



At harvest the yield and the weight % of blighted tubers was measured.

In table 4 the results are presented. The yield level was 37-38 tons/ha for spray programme 1-3 and 34-35 tons/ha for programme 4 and 5. The differences in leaf infestation are responsible for these differences.

The first 3 programmes had the same level of tuber infestation around 5 %. Programme 4 and 5 showed higher infestation levels, whereas 5 was clearly better than programme 4.

Table 4. Yield and yield of healthy tubers in tons/ha and % of yield with tuber blight.

	F2001/833 (n=1)		
	total yield	healthy yield	% tuber blight
Spray programme 1	37.3	35.7	4.2
Spray programme 2	38.6	37.1	4.2
Spray programme 3	37.3	35.1	5.8
Spray programme 4	34.0	27.1	20.3
Spray programme 5	35.1	31.2	11.3

Discussion

In a number of trials the efficacy of Ranman against tuber blight was proven.

Ranman was more effective than Shirlan , which product showed also a good effect against tuber blight. Tuber blight can occur when spores are present in the canopy and rainfall

occurs, washing the spores down in the moist soil. The trials showed however no correlation between leaf attack and tuber blight.
In trials of F 2001/836 Tanos, Aviso and Shirlan had comparable leaf infestations, but there was a big difference in tuber protection. Shirlan, known as a good tuber protector gave less tuber infections than the both other products. Sereno, Electis and Acrobat showed more leaf blight than Aviso and Tanos but less tuber blight.
Also in F2001/833 this phenomenon occurred. Shirlan and Acrobat, having comparable leaf infestations differed greatly in tuber blight. Also the comparison between ¾ rate of Ranman and Shirlan showed the same, equal leaf infestation, but much better tuber protection by Ranman.
When lesions occur after application of Ranman or Shirlan it has been shown that neither the lesion size nor the spore density in the lesions differs between these products (Ref. 2). Both products have the same intrinsic effect on prevention of release of zoospores and bursting of these spores. There is however a difference in effect on direct germination of the sporangia in favour of Ranman. The question can be raised if this effect can explain the big differences in tuber protection or that other reasons for instance the spreading of the product over the canopy and the soil is responsible for this effect.
Also in F2001/833 the good effect of Ranman compared to Shirlan is evident. The main infection occurred in block B and when Ranman was sprayed a good effect on tuber blight was achieved. An interesting phenomenon was seen here, comparing programme 4 and 5. Although the main infections occurred in block B, in which block in both programmes Shirlan was sprayed, programme 5 outperformed programme 4 in tuber blight, however not in leaf blight. It can be discussed if the long lasting effect of Ranman on the leaves gives also a long lasting tuber protection.

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Possibilities for control of late blight in early potatoes covered with a polyethylene film

H.G. SPITS, C.B. BUS AND H.T.A.M. SCHEPERS

Applied Plant Research, P.O. Box 430, 8200 AK Lelystad, The Netherlands

Introduction

In The Netherlands, control of late blight (*Phytophthora infestans*) in potatoes has a very high priority. An important part of the control strategy is to prevent the number of sources with primary inoculum. Dumps, volunteers and early potatoes covered with a polyethylene film are well known sources of primary inoculum. In the Masterplan Phytophthora a lot of efforts have been made to increase the awareness of growers that covering dumps and controlling volunteers is a very crucial part in the control strategy of late blight (Schepers *et al.*, 2000). The last few years, many first outbreaks were reported to originate from polythene covered crops (Schepers, 2002). Starting from oospores or latently infected tubers, blight can develop very well under the perforated polyethylene film. Usually fungicides are not applied as long as the crop is covered with the perforated polyethylene film. When the polyethylene film is removed, the infected field becomes a primay inoculum source and surrounding fields are infected already early in the growing season. The objective of this research is to gather more information on how to control a possible late blight epidemic in potatoes grown under a perforated polyethylene film.

Material and Methods

In 2001 and 2002, field experiments (split-plot design, four replicates) with large plots (4.5 m * 8.0 m) of the susceptible cultivar Bintje were carried out at the Research Centre PPO, Lelystad, The Netherlands. Tubers were planted in March and covered with a 5% perforated

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polyethylene film (500 holes/m^2) (2/3 of the trial) or an acryl film (17 g/m^2) (1/3 of the trial). The first spray with fungicides was applied when the plants reached a height of 25 cm (Table 1). Sprays were carried out with Teejet XR110.03 nozzles every five days for four weeks with a spray volume of 300 l/ha. When fungicides were sprayed directly on the perforated polyethylene or acryl film an organosilicone adjuvant (Zipper) was added (0.05%). To prevent differences in growing conditions, a polyethylene film also covered control plots but this film was removed when fungicides were sprayed. In 2002, deposition of spray droplets was estimated by placing water sensitive paper 15 cm under the top of the potato plants.

Tabel 1. Fungicides tested for their efficacy to protect potatoes covered with perforated polyethylene or acryl film.

Treatment	Active ingredient	Mobility	Dose rate[1]
A Untreated	-	-	-
B Tattoo C	propamocarb-hydrochloride (375 g/l)	Systemic	1.5 l/ha
	chlorothalonil (375 g/l)	Contact	
C Fubol Gold [2]	metalaxyl (4%)	Systemic	2.5 kg/ha
	mancozeb (64%)	Contact	
D Curzate M[2]	cymoxanil (4,5%)	Translaminar	2.5 kg/ha
	mancozeb (68%)	Contact	
E Shirlan	fluazinam (500 g/l)	Contact	0.4 l/ha

[1]) in case fungicides were sprayed on polyethylene or acryl film an organosilicone adjuvant (Zipper) was added (0.05%)

[2]) Fubol Gold was used in 2001 and Curzate M was used in 2002

The day after the first spray, the third spray and the fifth spray, 25 leaflets (fourth leaf from the top) were detached from each plot. These leaves were inoculated with blight spores and incubated (RH98% and 15 °C) in the laboratory for five days. The number of the lesions was assessed five days after inoculation.

Results

Deposition of spray droplets was measured with water sensitive paper (Figure 1). It is clear that spraying directly on the potato crop (no cover) resulted in the best deposition. Remarkable was the relatively good deposition under the acryl film although the number of spray droplets was clearly lower compared to the uncovered control. The lowest deposition occurred under the perforated polyethylene film.

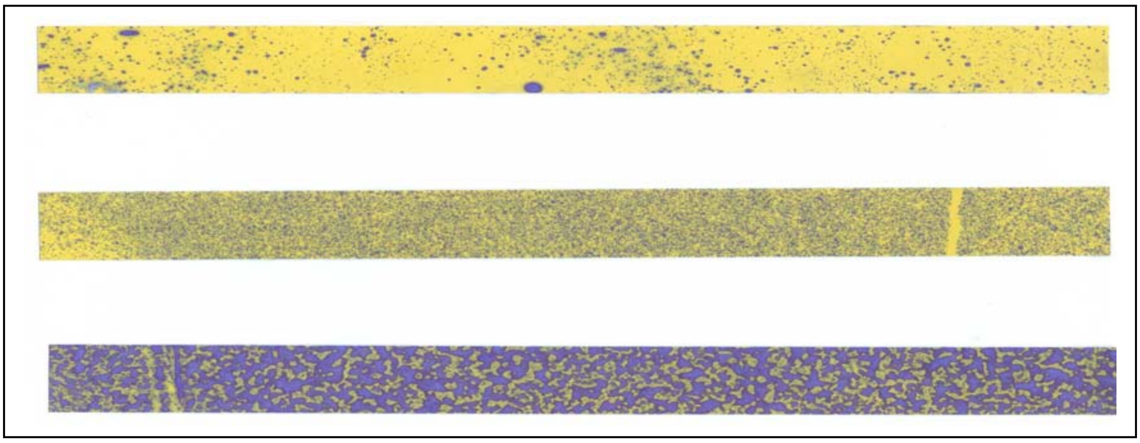

Figure 1. Deposition of spray droplets when sprayed over a perforated polyethylene film (top), acryl film (middle) or an uncovered crop (under).

In 2001 the protection of the leaflets in the uncovered and acryl-covered crop was very good after 1, 3 or 5 sprays (Table 2). After one spray over the polyethylene-covered crop, Fubol Gold resulted in a complete protection of the leaves against blight. Shirlan and Tattoo C were less effective in protecting the leaflets against infection. After three sprays over the polyethylene-covered crop, the protection of the leaflets sprayed with Tattoo C and Fubol Gold was significantly better compared to that of Shirlan. After five sprays over the polyethylene-covered crop, Fubol Gold again provided the best protection followed by Tattoo C and Shirlan.

Table 2. Percentage lesions for each fungicide for each cover material after 1, 3 and 5 sprays in 2001.

Number of sprays →		1			3			5	
Cover material →	No	Acryl	Polyethylene	No	Acryl	Polyethylene	No	Acryl	Polyethylene
Fungicide↓									
Untreated control	33.0	66.0	66.0	94.0	55.0	76.0	72.0	55.0	71.0
Tattoo C	6.0	7.0	62.0	1.0	1.0	2.0	0.0	0.0	23.0
Fubol Gold	6.0	0.0	0.0	1.0	0.0	1.0	0.0	0.0	1.0
Shirlan	5.0	9.0	38.0	11.0	0.0	26.0	0.0	1.0	36.0
LSD (α=0.05)		19.7			9.6			22.3	
F.prob		<0.001			0.020			0.038	
LSD (α=0.05)					17.1				
F.prob					0.075				

In 2002, Curzate M replaced Fubol Gold. The protection of the leaflets in the uncovered and acryl-covered crop was again very good after 1, 3 or 5 sprays (Table 3). Significant differences between fungicides were not observed. All tested fungicides resulted in a significant protection of leaves under the polyethylene film. However, at all three timings Tattoo C resulted in a significantly lower level of protection compared to Curzate M and Shirlan.

Table 3. Percentage lesions for each fungicide for each cover material after 1, 3 and 5 sprays in 2002.

Number of sprays →		1			3			5	
Cover material →	No	Acryl	Polyethylene	No	Acryl	Polyethylene	No	Acryl	Polyethylene
Fungicide↓									
Untreated control	75.0	86.3	83.8	87.5	76.3	67.5	90.0	95.0	91.3
Tattoo C	8.8	2.5	25.0	1.3	2.5	23.8	0.0	0.0	27.5
Curzate M	0.0	1.3	0.0	0.0	0.0	1.3	1.3	0.0	1.3
Shirlan	0.0	3.8	5.0	1.3	0.0	8.8	1.3	0.0	1.3
LSD (α=0.05)		12.1			8.0			7.6	
F.prob		0.112			0.005			<0.001	
LSD (α=0.05)					8.9				
F.prob					0.705				

Discussion and conclusions

In two field experiments the protection of a potato crop against late blight was tested when sprays were applied over the polyethylene and acryl film.

These results show that spraying over perforated polyethylene or acryl film can result in a certain level of protection of the potato leaves. The protection of the crop covered with acryl film was comparable with the protection of an uncovered crop. The level of protection of a polyethylene covered crop was more variable. In 2001, Fubol Gold provided the best protection. Whereas in 2002, both Curzate M and Shirlan protected the crop significantly better than Tattoo C.

In these experiments the level of protection was tested one day after spraying on the fourth leaf from the top. As demonstrated in Figure 1 the amount of spray droplets (fungicide) that is deposited on the leaflets of covered crops is lower compared to uncovered control. Lower deposition of pesticides on covered crops depends on used cover (mesh), spraying technique and water amount (Ester *et al.*, 1994).

At normal dose rates and spray volumes in an uncovered potato crop the intrinsic redistribution of contact fungicides sprayed with large droplets was high enough to reach a good coverage and protection of the leaves (Schepers & Meier, 2001). In the experiments described in this paper the highly surface-active organosilicone adjuvant Zipper was added to increase the "penetration" of the spray droplets through the polyethylene and acryl film ánd to increase the redistribution of active ingredients on the leaf surface. The tests provide an indication that a certain level of protection is present under the covered crops. Since the persistence of the protection in time and the spatial distribution of droplets was not included in this project, more research need to be done under practical situations before reliable recommendations can be formulated.

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Effect of compost extracts on potato late blight (*Phytophthora infestans*)

B. J. NIELSEN[1], L. BØDKER[1], P.E. LÆRKE[2], J. P. MØLGAARD[2]

[1] Danish Institute of Agricultural Sciences (DIAS), Department of Crop Protection, Research Centre Flakkebjerg, DK-4200 Slagelse.

[2] Danish Institute of Agricultural Sciences, Department of Crop Physiology and Soil Science, P.O. Box 50, DK-8830 Tjele, Denmark.

Summary

In the EU project Blight-MOP (development of a system approach for the management of late blight in EU organic farming), bio control agents and compost extracts are tested for their efficacy against late blight. In 2001, three different compost extracts (horse manure, straw and cattle slurry and cattle deep litter) were investigated in leaf bioassay experiments in growth chambers. Based on these experiments, a raw compost and an autoclaved compost of cattle deep litter was selected for further test under field conditions in 2002. The compost extract was compared to a standard copper fungicide. To ensure that all new leaves were protected, the extracts were sprayed twice a week for 12 weeks starting before the first symptoms were observed in the field. Contrary to the leaf bioassay, no effect of the compost extracts was registered under field conditions and there were no differences between autoclaved or non-autoclaved extracts as seen in the bioassay. In 2002, there were more days with rain in June and July than normal and because no stickers were added to the compost extracts, these water based extracts might have been washed off the leaves. Because of the promising results in the bioassay, the experiments will be repeated in 2003 including stickers/surfactants to the compost extracts.

Keywords: Late blight, *Phytophthora infestans*, control, compost extracts

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Introduction

For the organic potato grower it is very important to have some possibilities to extend the length of the growing season because of the devastating effect of potato late blight. Protective copper fungicides are used in many EU countries to control potato late blight but the use of copper fungicides are under discussion in EU and effective alternatives must be found. In the EU project Blight-MOP (development of a system approach for the management of late blight in EU organic farming) different products are tested for efficacy against late blight and among these also compost extracts. The first screening of different compost extracts has been carried out in growth chambers with bioassay using detached leaves. The next phase is test under more natural conditions in field trials. The results of these field trials will be presented here.

Material and methods

The field experiment was carried out at DIAS Flakkebjerg (East Denmark) in 2002 with two varieties (the susceptible variety Bintje and the moderately resistant variety Sava) in a completely randomised design with four blocks. The plot size was 4,5 x 9,5 m. The experiment was carried out in a conventional field but with organic management including 120 kg N (organic manure) in early April. Based on leaf bioassay experiments in 2001, a compost extract from cattle deep litter was selected which showed good effect against potato late blight. The compost extract was used either as a raw extract or autoclaved to exclude any biological activity. A copper fungicide (Fitoran grün, 40 % copper oxychlorid, standard dose 2-3 kg/ha with 8-10 days interval) was chosen as the reference product.

Table 1. Different compost extracts tested against potato late blight in field trial

Plot	Products	Dose pr. ha	Intervals
1	Untreated		
2	Fitoran grün (Cu- product)	1,0 kg*)	3 days
3	Cattle deep litter	400 l	3 days
4	Cattle deep litter, autoclaved	400 l	3 days

**) 1/3 of standard (label) dose.*

The first spraying was done at accumulated risk value 100-110 of NegFry decision support system (Anonymous 1), starting at 21st of June 2002 (Bintje) or 28th of June (Sava) and ending

29th July (Bintje) or 5th August (Sava), in total 12 sprayings. The cattle deep litter compost extract was made at DIAS Foulum and sent to Flakkebjerg at weekly intervals. Composts were started at regularly intervals in Foulum, so that the age of the compost at the day of treatment was approximately 50 days after initiation of the composting process. Both composts and copper were sprayed at 3-4 days intervals with a conventional spray techniques using Hardi flat nozzles (ISO) 03, pressure: 3,75 bar and 4 km/h 400 l water. The compost extract was only filtered and no adjuvants or stickers were added. The dose for the copper reference (Fitoran grün) was 1 kg/ha, which was 1/3 of the standard (label) dose to avoid any possible phytotoxic effect because of the frequent spray. Spraying was done late afternoon to avoid to quick drying in the sun. Artificial inoculation was done with sporangia suspension in two spreader rows between two replicate blocks early July (1000 sporangia/ml). Assessment of late blight and possible phytotoxic effects (yellow leaves) was done weekly throughout the season (Anonymous 2).

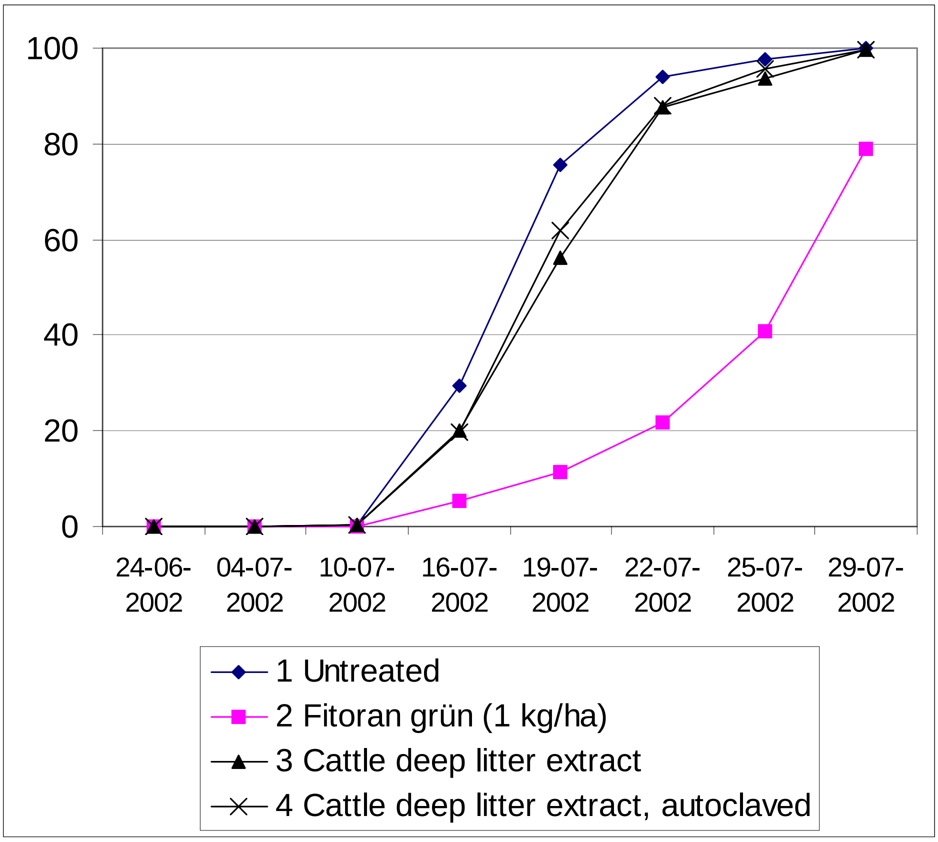

Figure 1. Development of potato late blight (*Phytophthora infestans*) in the variety Bintje treated with either raw or autoclaved extracts of composted cattle deep litter or a copper fungicide (Fitoran grün).

Results

In 2002, the first symptoms of late blight were observed in the susceptible variety Bintje in the last week of June, which was earlier than in a normal year. There was only one week delay in the epidemic development in Bintje compared to the moderately resistant variety Sava. Late blight was observed in all non treated plots and all plots treated with compost extracts already from the start of the epidemic and no significant difference compared to the untreated plots could be seen (fig. 1 and 2). In Bintje, however a small but insignificant delay was observed (fig. 1).

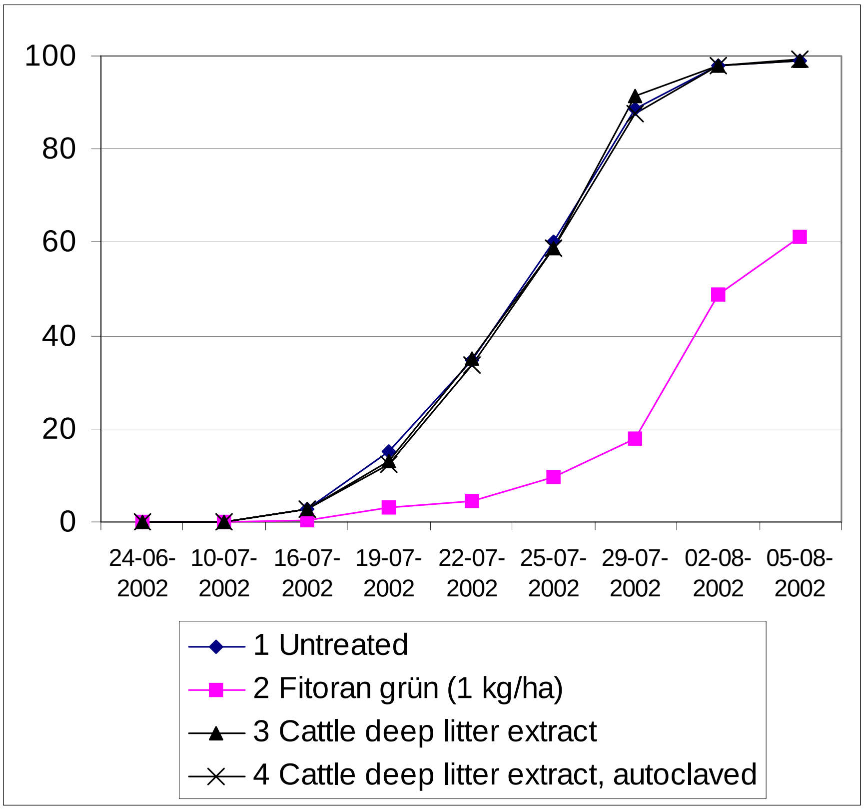

Figure 2. Development of potato late blight (*Phytophthora infestans*) in the variety Sava treated with either raw or autoclaved extracts of composted cattle deep litter or a copper fungicide (Fitoran grün).

A treatment with copper caused a significant delay in the epidemics, which lead to an effect of 49 % control in Bintje and 64 % control in Sava based on the average disease attack. There were no significant differences in yield between untreated plots and plots sprayed with compost extracts. Spraying with copper increased the yield with 19 % in Bintje and 39 % in Sava (data not shown).

Discussion

In the EU project Blight-MOP, the development of a system approach for the management of late blight in EU organic farming is investigated. Different bio control agents and compost extracts are tested for their efficacy against late blight. In 2001, three different compost extracts (horse manure, straw and cattle slurry and cattle deep litter) were investigated in growth chambers by leaf bioassays of detached potato leaves. The compost extracts were autoclaved in one of the experiments and all three different compost extracts showed an increased effect on *P. infestans*, indicating that organic breakdown products are involved in the control of the disease (unpublished results). Based on these experiments, cattle deep litter was selected for further test under field conditions in 2002. The compost extract was used either as a raw, filtered extract or as autoclaved extract and compared to a standard copper fungicide. To ensure that all new leaves were treated, the extracts and copper solution were sprayed twice a week for 12 weeks starting before the first symptoms of late blight could be observed in the field. Unfortunately, there was no effect of the compost extracts under field conditions and there was no difference between autoclaved or non-autoclaved extracts as seen in the bioassay. In 2002, there were more days with heavy rainfalls in June and July than normal and because no stickers were applied, the extracts might have been washed off the leaves. Even a slight delay in the epidemic of potato late blight can increase the yield significantly because the daily yield increase in organic potatoes can be approximately 500-700 kg pr. ha at the time of blight appearance in the field. Because of the promising results from the leaf bioassay, the field experiments will be repeated in 2003 including adjuvants to the compost extracts to provide more rain fastness of the products. In addition, the compost extracts will be sprayed earlier in the season to ensure that all leaves and stems are treated with the extracts prior to the first infections Timing of protective fungicides are very important (Bødker and Nielsen, 2001) and spraying with these less effective extracts should therefore be even more precise or very frequent to enable protection of the potato plants in sudden high risk periods.

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Seventh Workshop of an European Network for development of an
Integrated Control Strategy of potato late blight
Poznan, Poland, 2-6 October 2002

New co-dominant markers for population studies of *P. infestans*

D.E.L. COOKE, A.K. LEES, S. HUSSAIN AND J.M. DUNCAN

Scottish Crop Research Institute, Invergowrie, Dundee, Scotland DD2 5DA

Summary
New microsatellite and single nucleotide polymorphisms are described, together with their advantages and disadvantages compared to existing phenotypic and molecular markers presently used to characterise late blight populations.

Introduction

To date, a few phenotypic and molecular markers have been used more or less universally by blight researchers around the world. The main phenotypic markers, especially mating type, metalaxyl sensitivity and virulence, have been used most widely of all, but some molecular markers: in particular isozymes, mitochondrial DNA (mtDNA), and the moderately repetitive RFLP RG57, have been used almost as widely (1). More recently AFLP has been used but standardising results between laboratories remains a challenge with as yet no agreement on the most useful primer combinations or on 'bands' that could be used to standardise results.
While all these markers have proved very useful in some way and, with the notable exception of AFLP, are relatively simple to use, they have limitations which seriously affect the type of information that can be gained from their application to population studies.
Ideally markers should have the properties listed in Table 1. Although many existing markers have some of them, none have all:

PCR-based, fast, cheap, high throughput	Non-radioactive
Easy to score	Capable of being multiplexed
Usable with leaves or spore washings	Co-dominant
Genomic – revealing sexual recombination	Unlinked and inherited in simple Mendelian fashion

Discussion

Phenotypic markers

Mating type is easily determined in culture and clearly has epidemiological and evolutionary implications but in terms of a marker it is only one locus with apparently complex genetics (2). It may also be influenced by various stimuli - the A2 mating type in particular can be induced to form oospores in single culture.

Phenylamide resistance is also useful but like mating type takes time to determine. Resistance may also derive from different mutations in the same gene (hence, technically different alleles) and possibly even different genes.

Virulence has the merit of being a component of pathogenicity but it is very time-consuming to determine and the results are very dependent on the system used and the experimenter. Like metalaxyl, there is no reason to assume that the same virulence means a common genetic history - different mutations presumably could give the same phenotype.

Molecular markers

Isozymes have been used extensively as markers and have proved to be very useful. They are cheap and simple as well as being co-dominant. However there are limited in number and each enzyme system needs a different assay for assessment. However, poor resolution and estimation of relative band size can lead to inconsistencies in scoring.

MtDNA type is relatively simple to score (3) and the fact that it is maternally inherited makes it an ideal marker for gene flow studies, in which it would complement nuclear markers. Since the assay is PCR-based, it could in theory be applied to DNA extracted from crude spore suspensions washed from leave or from soil.

RG57 is a moderately repetitive RFLP that has been used extensively to ‘fingerprint’ strains and especially to detect ‘hot spots’ of sexual recombination. It has been a useful marker (1) but involves radioactivity. It is not co-dominant and requires quite large quantities of pure DNA of *P. infestans*.

AFLP reveals more markers per assay than any other method has been used extensively in genetic mapping and population analysis (4, 5) of the pathogen. It also employs radioactivity or fluorescent dyes but although it gives good and repeatable fingerprints, again the markers are not co-dominant. PCR-based, the method uses less DNA than RG57 although the DNA must be very pure.

New Markers

Two marker systems with the desired characteristics, or at least capable of being developed to have them, are microsatellites or simple sequence repeats (SSR) and single nucleotide polymorphisms (SNP).

Microsatellites comprise variable numbers of short repeated sequences flanked by conserved regions wherein primers that amplify across the variable region can be located. They require a considerable investment in time and money to find and develop but once developed they are ideal markers in meeting the points listed above. Typical sequences that could be used as microsatellites are shown in Figure 1 below.

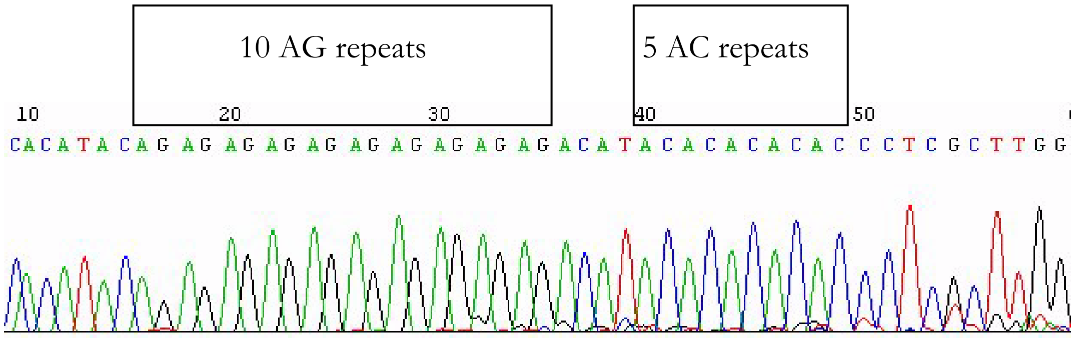

Figure 1. A electropherogram of a DNA sequence from *P. infestans* with 10 AG repeats and 5 AC repeats.

Slippage during DNA replication results in length variation in these tandemly repeated sequences; variations that are easily visualised on high-resolution acrylamide gels. With PCR primers in the conserved regions adjacent to the microsatellite, all alleles are amplified in PCR but each having its own number of repeats has its own characteristic length and therefore subsequent position on a gel. Thus microsatellites are co-dominant and, as they rely on PCR, need very little DNA. In addition, the primers come from *P. infestans* sequences, so plant and other DNA is not amplified enabling microsatellites to be used successfully to fingerprint lesions on leaves or simply sporangial washings from leaves.

Single Nucleotide Polymorphism (SNP) arise through point mutations in the DNA sequence where one base is replaced by another. As in microsatellites, alleles again are amplified by PCR using primers located in invariable sequences flanking the variable region. SNPs may be scored by many methods including direct sequencing, restriction digestion or allele-specific PCR. Unlike microsatellites, they are bi-allelic (*i.e.* there are only two forms at each locus) but they are co-dominant and share many of the advantages of microsatellites detailed above.

To date, most microsatellites and SNPs have behaved as classical Mendelian markers, with independent re-assortment, although a few appeared to be linked. SCRI has developed 9 SNPs and 5 polymorphic microsatellites. Preliminary analysis has identified regional differences in *P. infestans* strains worldwide and these methods will prove powerful tools in tracking isolates rapidly and efficiently, *e.g.* providing early warning of fresh migrations of populations into Scotland (and Europe) such as occurred in the late 1970's when the 'new' population of *P. infestans* arrived.

The microsatellite and SNP markers developed at SCRI, together with the microsatellites developed in Switzerland (6) and at the University of Wales, Bangor (David Shaw and Remi Wattier, pers. comm.), provide sufficient markers for gene flow studies. However, the markers still need to be multiplexed, *i.e.* combined into one or a few tests to increase throughput and reduce costs.

Fluorescently labelled primers have also been developed for the microsatellites and SNPs. This allows high-throughout automated analysis of specific alleles at microsatellite or SNP loci. With such a system 96 samples could be run every hour.

Microsatellite markers have been applied to a well-characterised collection of isolates from across Scotland in 1995-1997 and compared previously by AFLP. AFLP, which generated about one hundred bands per primer combination with about 10-15 polymorphic bands, grouped the isolates into three broad groups with some variation within each group. The new markers grouped the isolates in very similar fashion with certain phenotypes concentrated within some of the clusters; likewise microsatellite markers. One allele of one marker showed a close but not invariable association with the A2 mating type. This might indicate linkage between the two but care must be exercised when drawing a genetic conclusion from population data. It may be that the allele had become 'fixed' to the mating type locus because there had been little or no sexual recombination to separate them. Overall three major ‘clones’ of the pathogen were apparent between which there had been limited genetic exchange to create a more minor pattern of variation overlying the three-cluster structure.

Conclusions

New microsatellite and SNP markers overcome many of the problems of existing phenotypic and older molecular markers. Advantages include speed, cost, throughput (especially in a multiplexed forms) co-dominance, ease of scoring and application directly to field samples without isolation into pure culture of the pathogen. They are also genomic and classically Mendelian in inheritance and thus complementary to mtDNA typing. Together, the two marker systems should allow rapid characterisation of the epidemic as it spreads across Europe, identifying the origin of inoculum and its subsequent spread.

Moreover with present rapid developments in the genomics of *P. infestans*, it is probable that in the next few years, similar markers will be developed that can be used to identify important phenotypic characters, such as mating type, phenylamide resistance and virulence without the need for laborious laboratory and glasshouse testing. With these tools, and future collaboration on characterising late blight populations within the new EUCABLIGHT project (http://www.eucablight.org), it should be possible to look at look at populations of *P. infestans* in detail and on a scale that currently cannot be tackled.

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Help, I have early infections of late blight….

J. HADDERS

Dacom PLANT-Service BV, PO Box 2243
7801 CE Emmen, The Netherlands

Abstract

In The Netherlands, Dacom plays an important role in the mapping of disease outbreaks of Phytophthora infestans in potatoes. Each year farmers are surprised to find P. infestans in their fields so early. Because Dacom is a well known reporting point for Late blight disease mapping, these farmers call the Dacom-office with: "Help, I have early Late Blight in my crop…".

Dacom is a world wide operating company and leading provider for decision support and trace-ability systems for arable food production. The system is called PLANT-Plus. A spin-off product was presented last year at the workshop under the title "Don't call us, we call you…"

By order of the Dutch Masterplan Phytophthora, Dacom has to research first outbreaks of Late Blight in co-operation with Plant Research International (PRI) and Applied Plant Research (PPO) in the Netherlands and report the findings to the Masterplan. Based on the gathered information, table 1 gives a summary of the source of first outbreaks over the years.

Based on current information the starting point for 2003 is expected to be that all seed potato batches have infected tubers and some fields will have suspicion of oöspores. This does NOT mean that per definition we will get an early outbreak. It will depend on the weather conditions but potentially we are facing a dangerous situation. The advice for the coming season should be: no overkill with numerous applications starting at crop emerge but protecting the crop just before an infection event. Dutch farmers including Jacob Bartels will be informed about the infection events again so they can say: "Tuber infected but the crop protected"

PPO-Special Report no.9 (2003), 205-210

Table 1. Source of first outbreaks of late blight over the past years.

Year	Reason for start of outbreak
< 1999	Mainly potato dumps
1999	A spooky field of early potatoes under plastic
2000	The seed tuber caught in the act
2001	Early alert of growers with no specific problems
2002	Infected volunteers at the start

Keywords: *Phytophthora infestans*, PLANT-Plus, disease forecasting

Dacom Plant Service BV

Dacom is a company specializing in the development and marketing of decision support and trace-ability system using the latest technology. In the mean time, farmers in most of the European countries, in Japan, South Africa, Egypt, the USA and Canada are using the system. In other regions like Russia, South America, Australia and New Zealand, negotiations are underway to introduce PLANT-Plus. In this perspective we can speak of a global system. Advice is not only given for a variety of crops and fungus diseases but also on irrigation management and an insect model is being tested.

PLANT-Plus basic system

The PLANT-Plus system consists of integrated modules for data-communication, crop recording, weather data and crop advice. The communication module basically uses the internet but can also interact by phone with a voice response system. Warning messages can be communicated by fax or to a cell phone with SMS. The total concept includes disease mapping and data sharing with crop consultants and partners in the processing chain. The system is coordinated from a central databank in the Dacom Office in Emmen.

The irrigation module exists of two parts: one part calculates the soil water balance based on relevant parameters and displays the results in graphs. The other part is for presenting readings of soil moisture sensors. Because of the great differences in soil types, interpreting the graphical output into irrigating advice is a science in itself. Much experience was gained in countries like Egypt and South Africa.

The insect model will be tested in 2003. It will calculate the dynamics of an insect population in the main insect stages. The purpose is the same as with the fungicide model to support the farmer in his or her decision to use the right product at the right moment.

"Help, I have early infections of Late Blight in my crop!"

Every year, a call like this will come to the Dacom office in the Netherlands. It is not always the farmer himself that calls but also his advisor. Dacom coordinates the research of the first outbreaks in the Netherlands. Looking back over a number of years shows that not one year is the same. This presentation will give a summary of the years before 1999, 1999, 2000, 2001 and 2002. A preview of the 2003 season will also be given.

Before 1999

In the information in the disease mapping system of Dacom, not only a spotted infection is recorded but also where the infection source was found:

- commercial field
- volunteer potato
- dumps
- organic fields
- home gardens

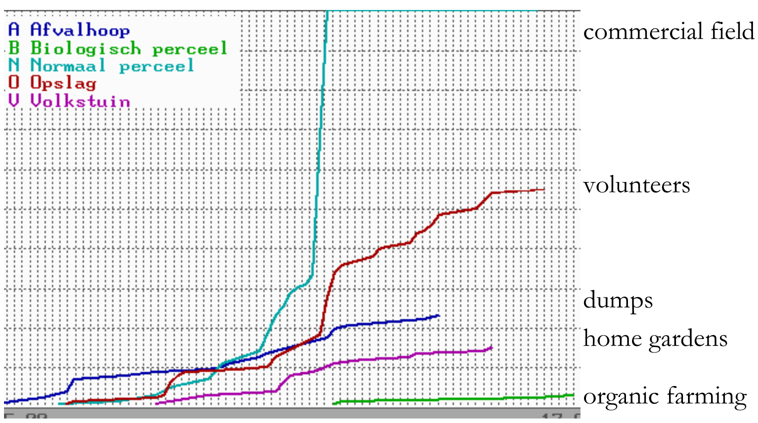


Figure 1. Reports of late blight in time: first on dumps, second commercial field and volunteers, third home gardens and organic farming last.

A closer look at the data shows that over the years, infections on dumps are the first to be reported (first line to appear). This is followed somewhat later in the season with reports in commercial fields (line going straight up in the middle of the graph) and on volunteers. One of the first actions of the Masterplan was to act on prevention of the dumps by putting a fine on having an uncovered dump. This resulted in clearly less reports of dumps from the start in 1999.

1999

In the early part of the 1999 season, just after the commercial fields emerged, a number of infection events took place. Normally, this early in the season, this is not a big problem as the total amount of infected leaf area is still small. In this case however, many reports of Late Blight came in from the South Western part of the Netherlands.

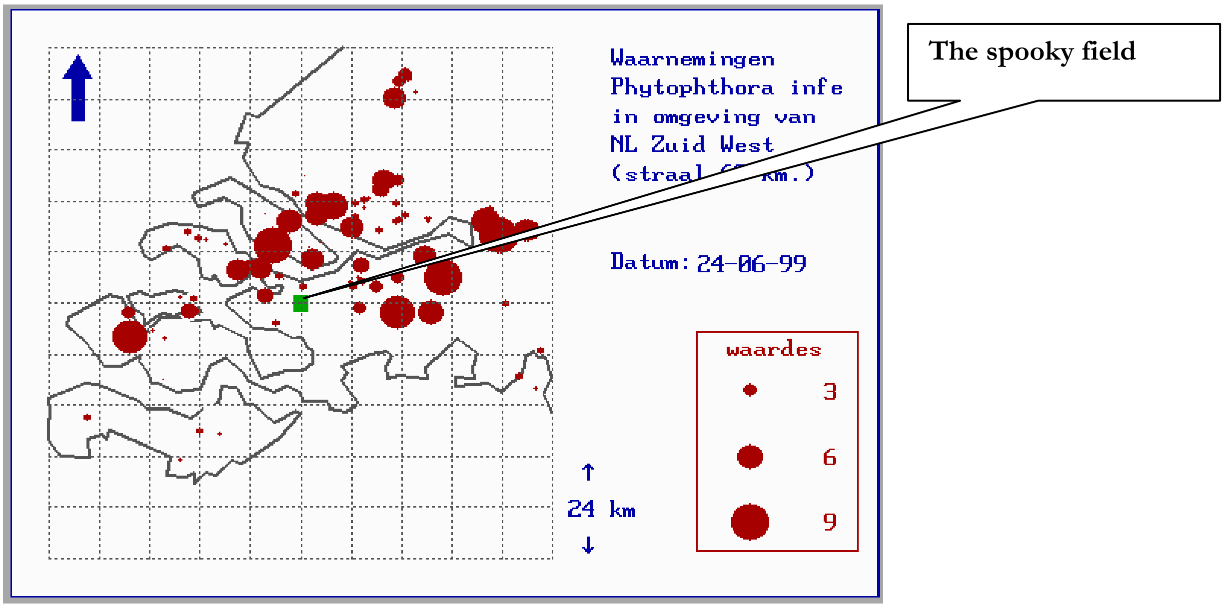


Figure 2. Observations on late blight in the South-West region of the Netherlands (Zeeland, Zuid-Holland and West-Brabant): the bigger the dot, the more infested the spot.

Looking at the reports in combination with the wind direction, a certain spot in the West showed up as a possible source of infection. From 4 infected fields in that region a total of 18 isolates were taken, showing that all the isolates came from the same source! On top of these early infections, another infection event occurred in the middle of June, causing a big alarm and predictions of great losses. However the rest of the season was relative easy with just a small number of infection events. The panic was easy forgotten ….

2000

In 2000 the first outbreaks could be traced to the seed tuber on a broad scale. On the first report, a dump in the North West of the Netherlands (figure 3), the seed tuber was infected. Also the following reports in commercial fields were easy traceable to the seed tuber.

Figure 3. First report in 2000, a dump in the North West of the Netherlands.

In combination with a number of early infection events, the season started off with many reports. This picture continued all summer long as infection events kept re-occurring.

2001

In 2001 the first reports came in on May 15. In general farmers and field managers were very alert on outbreaks because of the situation at the end of last season. This made determination easy as the infections could be read as the growing rings in a tree. In the first half of the season, just three major infection events took place causing a slow spreading of the disease through the commercial fields. By the end of the year, the panic was forgotten.

2002

The first part of the season was relative dry. Infected volunteers caused all the first infections. Typically, this first infected plant would be almost totally destroyed before it could infect near-by plants.

2003

It is impossible to predict the cause of events to the future especially if this future is still some month away. Analysis of seed potato batches show that most of them contain between 0.01 and 0.1% infected tubers. This adds up to 5 – 50 infected plants per hectare! Another potential threat is the fact that at a number of fields oospores are suspected.

Although this starting-point for the coming season is cause for concern, the problems will only occur under the right conditions. Specifically in the period from emerge to row closing, under conditions with extra rain and high temperatures, the infection might go from the tuber to the foliage. This will first show up in the lower parts of a field. The expansion of the disease from one infected plant to the rest of the crop is weather dependent.

In summary, the parameters for expansion of Late Blight are:

- presence of spores
- infection period (=leaf wetness + temperature)
- relative unprotected foliage.

Strategy 2003

The proposed strategy in order to control early infections for 2003 is:

Not to do:

- applications of systemic applications on a calendar schedule
- Panic applications with tank mixes after discovery

To do:

- Early inspections of the field
- Keep an eye on volunteers
- Protect crop before infection event with the right product
- Super sensitive varieties: keep low PP threshold

Conclusion

"Tuber infected but crop protected" of course with the right decision support system!!

"Help, I have early infection of Late Blight!" → if you see it, give Dacom a ring…

Blight Forecaster – a web based DSS using UK local and forecast weather data

H. HINDS

Plantsystems Ltd, Unit 3, The Old dairy Buildings, Winkburn, Nottinghamshire.
Howard.hinds@plantsystems.co.uk

Summary

Blight Forecaster was designed to give a simple interpretation of short term historical and forecast blight risk from different regions in the UK, and is accessed via the web site, www.syngenta-potato.co.uk. In 2002 weather data from 15 UK regions was used.

Using the PLANT-Plus late blight model, Blight Forecaster indicates high, medium or low risk by coloured squares on the map of red, blue and yellow respectively. There is an option to view the risk map over four days, that is; yesterday, today, tomorrow or the day after tomorrow.

In 2002 grower total users were relatively low, however within the browser numbers consultant users were proportionally higher than growers. It is planned to increase the number of regional sites in 2003 and increase exposure of the site.

Key words: Blight Forecaster, Region, Risk Map, PLANT-Plus

Introduction

The PLANT-Plus late blight model has been used in the UK since 1998. The system has been operated mainly by farmers using in field weather stations, local weather forecasts and advisors to monitor the model (Hinds 1999). The estimated area of UK potatoes being run in this pro-active way on PLANT-Plus was around 6000ha in 2002. Because this approach requires an investment in both money and time the system so far has been restricted to the larger innovative farms (Hinds 2001).

There are many other growers, however that are not yet ready for this type of decision support system. They prefer traditional spraying programmes, where spray timing is based on regular intervals (7-10 days) and where the growth stage of the crop or cost of the product influences fungicide choice. Some of these growers will look at systems which give regional disease risk assessment such as that provided by Blight Watch on potatocrop.com (Barrie 2002), providing they do not have to pay for the advice. At present however regional systems only give historical risk assessments, none provide this information based on a short term forecast.

It is from this background that Blight Forecaster, a collaboration between Syngenta, Plantsystems and Dacom Plant Services, was introduced in 2002 to target this group of farmers. The following report gives details of the system and some results on its uptake.

Blight Forecaster

Blight Forecaster gives a short term historical and forecast assessment of blight risk from different regions in the UK. It can be assessed via the Syngenta web site, www.syngenta-potato.co.uk. In 2002 the output of historical risk was based on local weather data from 15 stations and forecast risk was based on 15 synoptic forecasts, one for each region.

Weather data was processed through the PLANT-Plus model, which produced a risk assessment based on an unprotected potato crop. The variety used in the system was one which equated to moderate blight susceptibility of a NIAB rating 5 (NIAB).

The aim of Blight Forecaster is to give a simple interpretation of risk so most viewers could understand the output without any prior knowledge of the PLANT-Plus system.

It does this by representing each weather station site as a square on a map of the UK. The PLANT-Plus system was then adapted to change the colour of each square to high, medium or low, where;

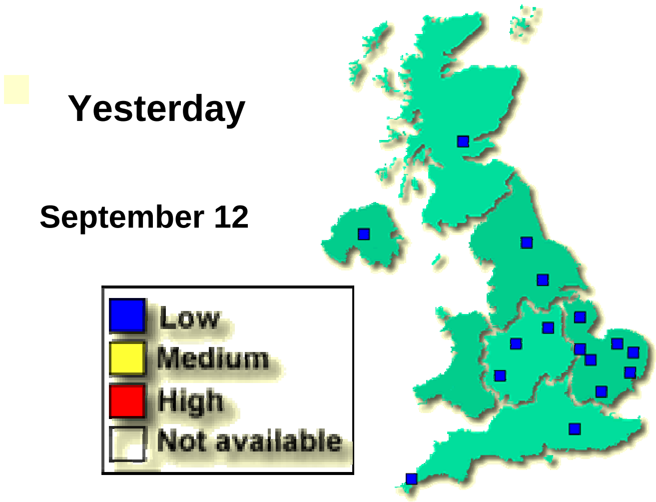
Red = High risk (a score of calculated infections of over 200)
Blue = Medium risk (a score of calculated infections of 50-200)
Yellow = Low risk (a score of calculated infections of below 50)

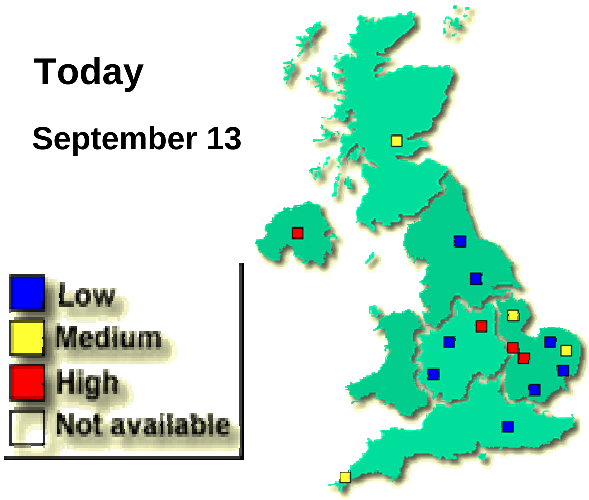
A risk map was then given for four separate days;

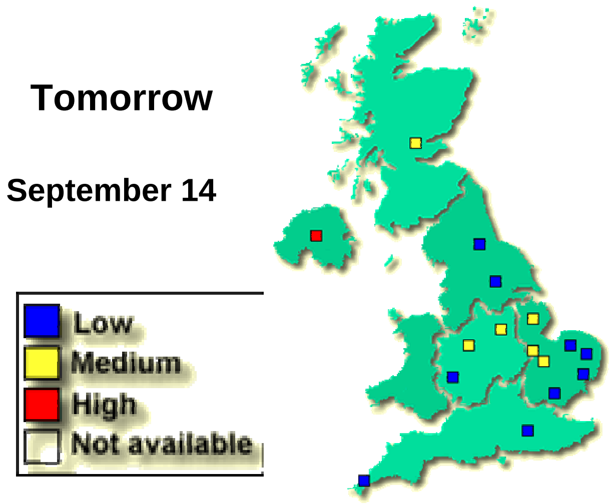
Yesterday	(Historical data)
Today	(Historical data)
Tomorrow	(Forecast data)
The day after tomorrow	(Forecast data)

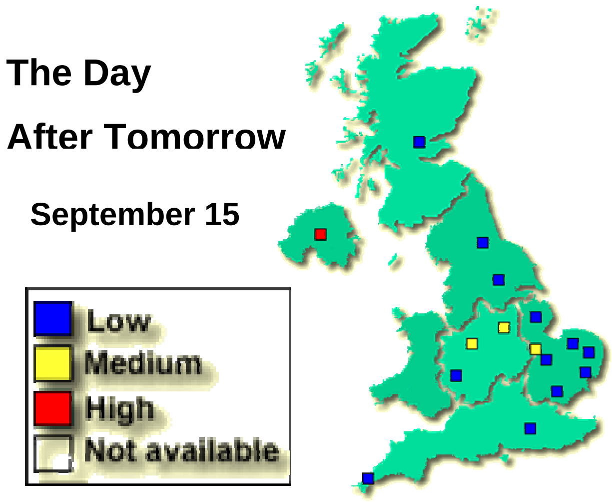
All the browser has to do is click on any one of the maps to view the risk.

Below shows a sequence of Maps from September. (High risk represented by the red square [medium grey], medium risk by the yellow square [light grey] and low risk by blue squares [black]).









Results

Table 1 shows that the number of browers was relatively low at 543. Of this total, farmers constituted 30% with consultants accounting for 35%. The highest number of hits occurred in June. Most farmers viewed the site in July, whereas the highest figures for consultants occurred in June. September showed a large decline in web-site viewers.

Table 1. Browser Use of Blight Forecaster 2002.

Web site hits/ month by user group				
Month	Total hits	Farmer Hits	Consultant Hits	Other* hits
April	55	3 (6%)	22 (40%)	30 (54%)
May	99	18 (18%)	36 (36%)	45 (45%)
June	151	38 (25%)	66 (44%)	47 (31%)
July	118	56 (48%)	33 (28%)	29 (25%)
August	78	27 (35%)	24 (30%)	27 (35%)
September	27	14 (52%)	6 (22%)	7 (26%)
October	15	5 (33%)	3 (20%)	7 (47%)
Total	543	161 (30%)	190 (35%)	192 (35%)

** others made up from chemical manufacturers, retailers, packers and press.*

Discussion

The low number of viewers of the site is a reflection that the web is still used relatively infrequently by UK farmers. A national web site, run by the British Potato Council, estimate that around 800 potato farmers (source BPC 2002) out of a possible 6000 regularly visit the site. Awareness of Blight Forecaster was also relatively low in this first year of the project.

In contrast consultants were some of the most regular users of the site, relative to their numbers. The use of such sites by consultants will also keep the numbers of browers low, as one consultant may be representing 10 or 20 growers. These web-sites provide a good source of information for the more pc friendly technical advisors, however for growers it may not be the best delivery system.

There is now more pressure in the UK for growers to use DSS's in the UK in order to satisfy the requirements of retailer protocols, such as the Assured Produce scheme, to justify spray inputs. Blight Forecaster is a system which may go some way to satisfying this demand, although the risk assessment is not specific for actual farm conditions and cropping. In order to give full justification of spray applications, growers would need to migrate onto the PLANT-Plus system which not only advises spray timing and product type, but also gives a record of all crop recording and disease risk (Hadders 1997)

Plans for 2003 are to expand the number of risk sites in Blight Forecaster to give greater coverage of potato growing areas in the UK. The site may also be linked to other complementary sites such as the one provided by the BPC.

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Posters

Seventh Workshop of an European Network for development of an
Integrated Control Strategy of potato late blight
Poznan, Poland, 2-6 October 2002

First results of the characterisation of Austrian isolates of *Phytophthora infestans*

E. RAUSCHER

Austrian Agency of Health and Food Safety, Agricultural Inspection Service and Research Centre Vienna, Institute of Phytomedicine, Department Potato Pathology, Spargelfeldstr. 191, 1226 Vienna, Austria.

Summary

Over 200 isolates of *Phytophthora infestans* from stems and leaves of commercial potato crops were collected in the season 2002. After isolation these were assessed for mating type, metalaxyl and propamocab sensitivity and mt-DNA haplotype. From 169 isolates 53 % were A1 and 47 % A2. In the Austrian population only mt-DNA haplotypes Ia and IIa are present, the ration of Ia to IIa is 42 % to 58 %. Concerning fungicide resistance 34,5 % of the isolates were found to be resistant to metalaxyl, 35,5 % showed intermediate and 30 % sensitive reactions. Under the same conditions 84 % of the isolates were intermediate to propamocarb and 16 % sensitive to propamocarb.

Keywords: *Phytophthora infestans*, mating types, fungicide resistance, mt-DNA haplotypes

Introduction

Since 1995 no survey of the Austrian population of *Phytophthora infestans* has been carried out. A2 mating type was first found in Austria in the 1990`s. 1995 about 8 % of the isolates taken from potato sites all over Austria belonged to the A2 mating type (Rauscher 1996). The isolates were also examined for their metalaxyl resistance. 42 % were resistant to metalaxyl (Schiessendoppler 2001).

The aim of this project is to characterise the Austrian population of *Phytophthora infestans*. Therefore isolates from commercial potato crops have been taken.

Materials and Methods

Samples

Leaves and stems of potato plants infected with late blight were collected from different potato production areas all over Austria in 2002. Over 200 cultures could be isolated from these last summer.

Isolation and maintenance

All isolates were weekly maintained on potato sandwiches according to Schöber and Höppner 1972. They were also transferred to rye agar containing benomyl (0,01 g/l), pimaricin (0,4 ml/l) and rifamycin (0,03 g/l). The pure cultures were maintained on rye agar without fungicides and antibiotics at 16 °C in the dark.

Mating types

Defined cultures of A1 and A2 mating type were used. The unknown isolates were inoculated on rye agar plates together with each of the defined cultures. Oospore formation was determined after 14 days. The tested isolates were considered the opposite mating type of that with which it produced oospores.

Polymorphism: determination of mt-DNA haplotypes

DNA was extracted according to Griffith and Shaw 1998. Polymorphism in the isolates was determined by mt-DNA haplotypes according to Griffith and Shaw 1998.

Fungicide resistance

The resistance of *Phytophthora infestans* isolates to metalaxyl and propamocarb was tested using the floating disc method according to Dowley and O`Sullivan 1985. Potato leaves of cultivar Bintje were used for the test. Metalaxyl and propamocarb were both used in 2 concentrations: 5 mg/ml and 100 mg/ml.

Results

Mating types (see table 1)

In the main potato growing areas of Lower Austria 43 % of the isolates belonged to the A1 mating type and 55 % to the A2 mating type. The frequency of the A2 mating type is very high in areas with ware potato production: Weinviertel South-West and Marchfeld: 90 %. With 86 % the

A1 mating type still dominates in the main seed potato production area, in the Waldviertel. 37 isolates of other Austrian provinces were examined, only 1 isolate of Salzburg belonged to the A2 mating type.

Table 1. Mating types in the different production areas

Province / Production area	No. of samples	Mating type	
		A1	**A2**
Lower Austria	***132***	***53***	***79***
Waldviertel	43	37	6
Weinviertel South West	39	4	35
Weinviertel North East	7	5	2
Marchfeld	30	3	27
Tullnerfeld	11	3	8
Mostviertel	1	1	0
Wiener Becken	1	0	1
Upper Austria	***10***	***10***	***0***
Mühlviertel	5	5	0
Eferdinger Becken	2	2	0
Machland	3	3	0
Styria	***6***	***6***	***0***
Gleisdorf	1	1	0
Grazer Becken	1	1	0
Murboden	4	4	0
Carinthia	***14***	***14***	***0***
St. Veit/Glan	14	14	0
Salzburg	***7***	***6***	***1***
Lungau	7	6	1
Total	**169**	**89**	**80**

mt-DNA haplotypes (see table 2)

No Ib from the old population could be found. In Lower Austria 40 % belonged to haplotype Ia and 60 % to haplotype IIa. In the Waldviertel, the main seed potato production area, 62 % of the isolates were haplotype Ia and 38 % haplotype IIa. In the areas of ware potato production haplotype IIa dominated with 88 %. 16 isolates from other provinces were also tested for mt-DNA haplotypes. Mainly Ia is present in Upper Austria, Styria and Salzburg. In Carinthia only IIa could be found. According to these results haplotype IIb is not present at the moment.

Table 2. Mt DNA hapltypes in the different production areas

Province / Production area	No. of samples	mt DNA haplotype			
		Ia	Ib	IIa	IIb
Lower Austria	*116*	*47*	*0*	*69*	*0*
Waldviertel	37	23	0	14	0
Weinviertel South West	34	3	0	31	0
Weinviertel North East	7	5	0	2	0
Marchfeld	20	3	0	17	0
Tullnerfeld	13	8	0	5	0
Mostviertel	5	5	0	0	0
Upper Austria	*5*	*4*	*0*	*1*	*0*
Mühlviertel	2	1	0	1	0
Eferdinger Becken	1	1	0	0	0
Machland	2	2	0	0	0
Styria	*3*	*2*	*0*	*1*	*0*
Gleisdorf	1	1	0	0	0
Grazer Becken	1	1	0	0	0
Murboden	1	0	0	1	0
Carinthia	*5*	*0*	*0*	*5*	*0*
St. Veit/Glan	5	0	0	5	0
Salzburg	*3*	*3*	*0*	*0*	*0*
Lungau	3	3	0	0	0
Total	*132*	*56*	*0*	*76*	*0*

Fungicide resistance (see table 3)

In the intensive potato growing areas of Lower Austria (Weinviertel South-West and Marchfeld) 6 % of the isolates were sensitive to metalaxyl, 40 % were intermediate to metalaxyl and 54 % were resistant to metalaxyl. No isolate was resistant to propamocarb. 84 % of the isolates showed intermediate reaction to propamocarb and 16 % were sensitive. In the seed potato production area, in the Waldviertel, 26 % were sensitive to metalaxyl, 46 % were intermediate to metalaxyl and 28 % were resistant to metalaxyl. Concerning resistance to propamocarb no resistant isolate could be found, but 84 % of all tested isolates were intermediate and 16 % were sensitive to propamocarb.

Table 3. Fungicide resistance in the different production areas (sens = sensitive, inter = intermediate, resist = resistant).

Province / Production area	No. of samples	Fungicide resistance					
		Metalaxyl			Propamocarb		
		sens	inter	resist	sens	inter	resist
Lower Austria	*158*	*32*	*61*	*65*	*26*	*132*	*0*
Waldviertel	50	13	23	14	8	42	0
Weinviertel South West	41	4	17	20	8	33	0
Weinviertel North East	9	1	2	6	0	9	0
Marchfeld	35	1	13	21	4	31	0
Tullnerfeld	15	13	2	0	4	11	0
Mostviertel	7	0	3	4	2	5	0
Wiener Becken	1	0	1	0	0	1	0
Carinthia	*12*	*12*	*0*	*0*	*0*	*12*	*0*
St. Veit/Glan	12	12	0	0	0	12	0
Salzburg	*12*	*8*	*4*	*0*	*1*	*11*	*0*
Lungau	12	8	4	0	1	11	0
Styria	6	*3*	*3*	*0*	*0*	*6*	*0*
Murboden	4	3	1	0	0	4	0
Grazer Becken	1	0	1	0	0	1	0
Gleisdorf	1	0	1	0	0	1	0
Upper Austria	*9*	*4*	*2*	*3*	*5*	*4*	*0*
Mühlviertel	4	3	1	0	1	3	0
Eferdinger Becken	3	0	1	2	2	1	0
Machland	2	1	0	1	2	0	0
Total	197	59	70	68	32	165	0

Discussion

The ratio of A1 to A2 changed from 92 : 8 in 1995 to 53 : 47 in 2002. In Lower Austria no A2 was found in 1995, last season A2 dominated the population with 60 %. Oospore formation has become a possible threat now. In one potato field both mating types were found. Early occurrence of late blight may indicate oospore infections on one hand and more aggressive isolates on the other hand. Further investigations are necessary.

The old population seems to be completely replaced by the new one. Only haplotype Ia and IIa were found until now. Mainly A1 corresponded with haplotype Ia and A2 with IIa.

Metalaxyl resistance is still very high (34,5 %) among the isolates even if metalaxyl is recommended to be used only twice on one site in Austria and farmers have to cope with restrictions in the integrated production scheme. There is only a small decrease in the percentage of resistant isolates during the years. In 1995 42 % were resistant, in 2002 34,5 % were resistant and 35,5 % showed intermediate reactions. Metalaxyl resistance correlated mostly with A2 mating type and mt-DNA haplotype IIa.

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Research of alternatives to copper in the protection against potato late blight in biological production

L. DUBOIS ANDDUVAUCHELLE

S.R.P.V. Nord Pas-de-Calais, BP47 - 62750 Loos-en-Gohelle, France

Ludovic.DUBOIS@agriculture.gouv.fr

Serge.DUVAUCHELLE@agriculture.gouv.fr

Introduction

Protection against potato late blight in biological production is based exclusively on the prevention (choice of the varieties) and on the use of authorised products within the biological principles and conditions (copper).

In anticipation of the European legislation which is likely to evolve from here within a few years to a modulation or a prohibition of the use of copper and in order to improve the reasoning of fungicidal protection, a program of studies was set up within the framework of an interregional project Nord/Pas-de-Calais area and Flandre Occidentale area.

At first a literature study was carried out in order to gather references of alternatives or modulation of the use of copper. Secondly, experiments were conducted for two years intended to test active substances being able to limit or replace copper.

Material and methods

On the level of late blight, the comparison of various fungicides and the reasoning of their applications with the assistance of epidemiologic models were followed in parallel.

A follow-up of the tolerance of the varieties to the late blight was carried out with the setting places of a variety trial in 1999, 2000 and 2001.

- In 2000: different products containing copper or associating copper were tested Two products without copper were also integrated in the trial.
- In 2001: products having shown the most interesting results in 2000 were again tested.

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Table 1. Products tested in the experiments of 2000 and 2001.

Product	Amount of product	Proportion of copper	Quantity of copper in treatment	Tested in 2000	Tested in 2001
Bordeaux Mixture (BM) with high amount	10 kg/ha	20 %	2000 g/ha	X	
BM with reduced amount	4 kg/ha	20 %	800 g/ha	X	X
BM reduced + Héliosol	4 kg/ha + 0.71 l/ha	20 %	800 g/ha	X	
BM very reduced	2 kg/ha	20 %	400 g/ha		X
BM very reduced + Héliosol	2 kg/ha + 0.71 l/ha	20 %	400 g/ha	X	X
Promild 2 (Cu, Fe, Mn, Zn)	6 l/ha	5 %	300 g/ha	X	X
Ferticuivre (oxychlorised copper, vegetable extracts)	6 kg/ha	4 %	240 g/ha	X	X
Myco-Sin (rock powder, vegetable extracts)	8 kg/ha	0	0	X	
Prêle + Ortie (nettle)	20% + 5%	0	0	X	

Results 2000

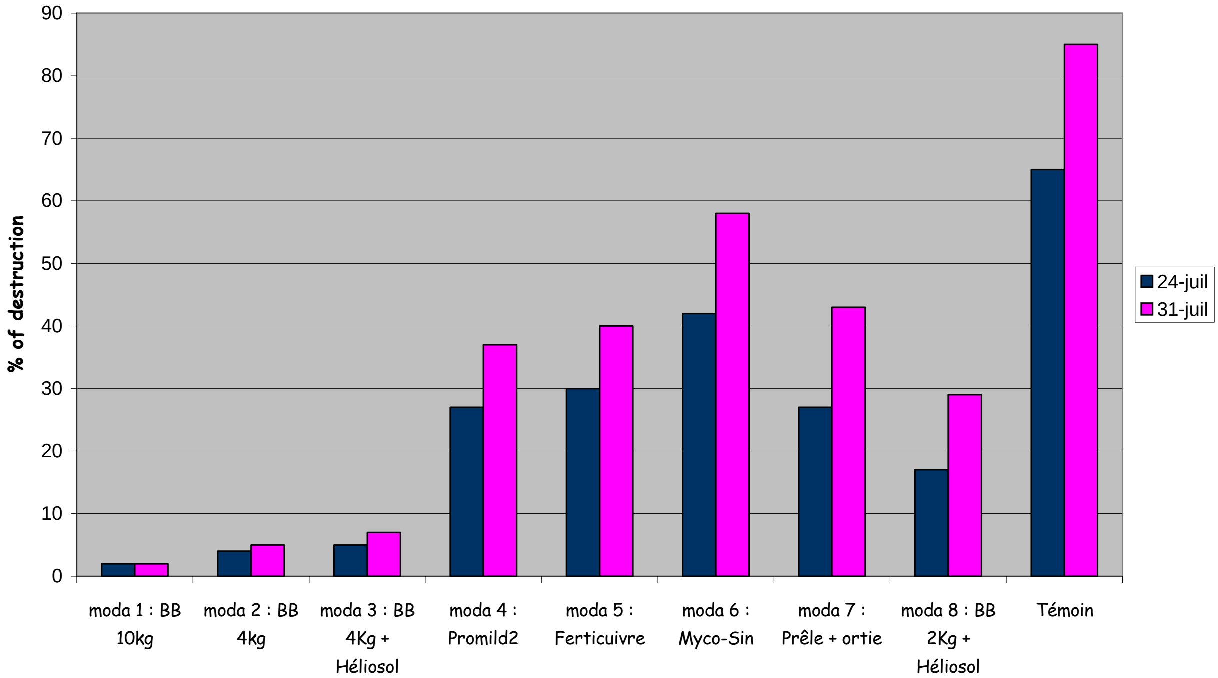

Figure 1. Percentage of destruction on 24 and 31 July 2000 in the experiment.

In 2000, the pressure of late blight was significant as from mid-July (control untreated destroyed with 85 % on July 31). Bordeaux Mixture (à 10 kg/ha and with 4 kg/ha) allowed to limit the attacks of late blight (less than 5 % of destruction at the end of July), with little difference between the two amounts.

Bordeaux Mixture à 2 kg/ha + Héliosol and the Promild 2 gave intermediate results with 30 to 40 % of destruction at the end of July.

Addition of Héliosol with Bordeaux Mixture with reduced amount (4 kg/ha) did not improve its effectiveness.

The Ferticuivre, specialty containing copper and extracted vegetable, gave the least satisfactory results on the whole of the products containing copper.

For the two products without copper (Myco-Sin and liquid manure with Prêle and Ortie (nettle)), the results are not very satisfactory with more than 40 % of destruction of the foliage at the end of July.

Results 2001

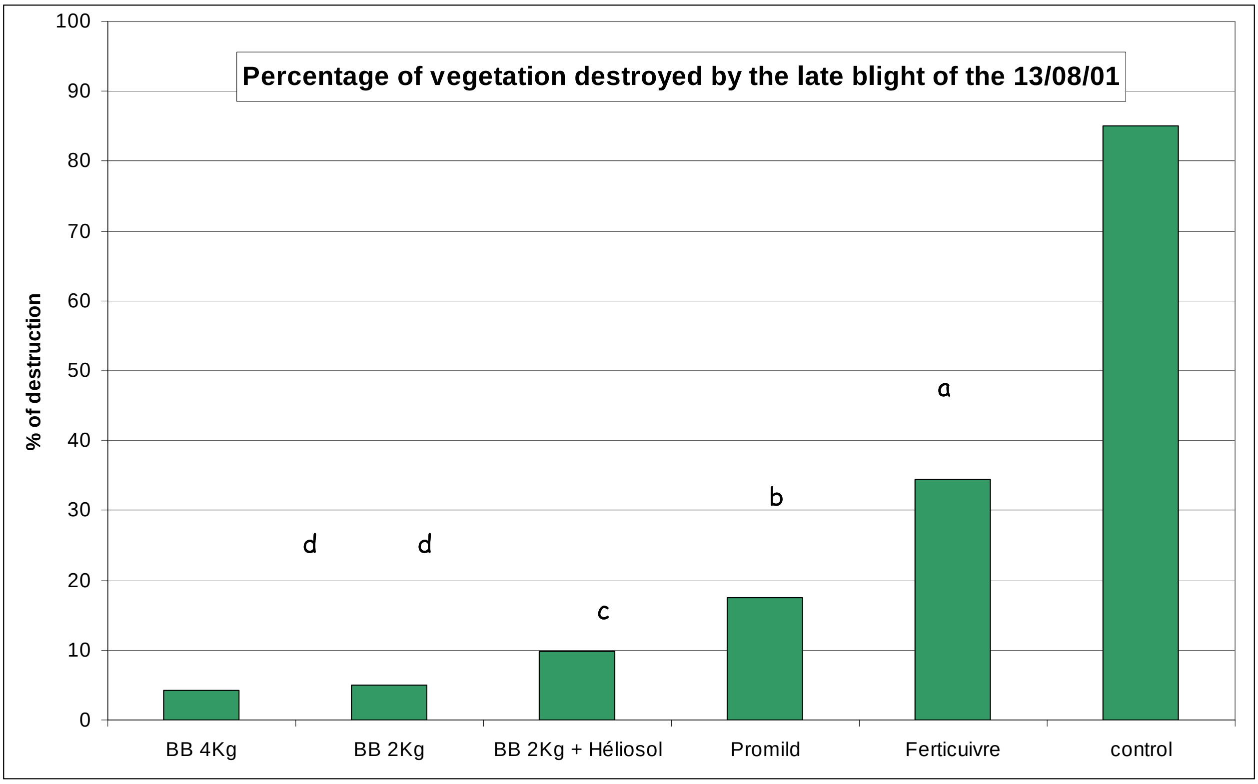

Figure 2. Percentage of destruction on August 13, 2001 in the experiment of 2001.

The Bordeaux Mixture gave the best results in the control of the late blight. Reductions of amounts of Bordeaux Mixture are nevertheless possible: results being equivalent between Bordeaux Mixtures with 4 kg and with 2 kg/ha (5 % of destruction by the late blight mid-

August). The addition of Héliosol did not improve the effectiveness of the Bordeaux Mixture.
The Promild 2 gave satisfactory results (18 % of destruction) while allowing an interesting copper reduction.
In 2001, the pressure of late blight was shown to be very high on the test at the end of July. In the middle of August, the control untreated was destroyed with more than 85 % by the late blight.
The Ferticuivre gave the least satisfactory results (34 % of destruction).
On potato, the results of the tests show that it is possible to reduce the copper amounts used. Total substitution of copper is nevertheless dangerous. In the event of high pressure, the effectiveness of the products without copper remains low.

Remark : in figure 2 b, bc and c are the results of the statistical analysis of the notation of August 13, it acts of the result of a classification of Newman & Keuls by descending order.

Conclusion

These first results are to be confirmed by a continuation of the trial:
new experiments will be designed by testing various strategies intended to reason the sprays while limiting the copper amounts .

Seventh Workshop of an European Network for development of an
Integrated Control Strategy of potato late blight
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Experiences with Decision Support Systems for the late blight control under Polish climatic conditions

ANDRZEJ WÓJTOWICZ

Institute of Plant Protection
Miczurina 20,60-318 Poznań, Poland

Summary
Four methods of late blight control were compared in Winna Góra in 1999. Three of them consisted in fungicide application according to the recommendation of systems based on meteorological data registration. One system proposed only the initial fungicide spray, while the two others scheduled the initial application and the subsequent control treatments. Experiments showed that NegFry and Simphyt systems enable better control of late blight than routine applications.

Key words: Phytophtora infestans, DSS

Introduction

Late blight caused by *Phytophtora infestans* (Mont.) de Bary belongs to the major diseases affecting potatoes in Poland. The average number of infested plants over the period of last 20 years amounted to 41%. The highest infestation took place in 1997 when almost 86% of plants showed symptoms characteristic for late blight. In 1988 it turned out that A2 mating type of *P. infestans* is present in Poland. Probably because of this late blight is more dangerous now than before. Due to the commonoccurrence of the casual agent of the late blight and presence of A2 mating type about 6-8 applications during the growing season should be performed in Polish conditions. Whereas Polish farmers usually spray less than twice per season. Poor economical situation of Polish farmers is the reason of that situation, as they

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can not afford spraying more frequent. Fast improvement of Polish farm economical situation is not expected. However, a reliable method for determining first treatment seems to be very needed in Poland. That is why DSS dealing with late blight control induced interest of Polish scientists.

Materials and Methods

In 1999 the experiment was carried out at one location in Winna Góra 70 kilometers south of Poznań. Two potato cultivars, Bekas and Mila, were used in the experiment. The design for the trail was a randomised complete block with four replications per treatment. Each plot was 22 m long and 3 m wide. Plant spacing was 0.20 m within rows and 0.75 m between rows. Weed control consisted of Titus 25 WG (50g/ha), Sencor 70 WG (0.3 kg/ha) and Trend 90 EC (0.1%) applied after emergence. Insect control consisted in application of Decis 25 EC (0.25 l/ha) against Colorado potato beetle. Details of fungicide treatments used in 1999 are given in table 1.

The aim of the experiment was validation of three DSS: NegFry, Simphyt and Stephan in comparison with results obtained from routine treated and untreated plots.

The meteorological data were recorded by Hardi Metpol station.

Table 1. Details of spray treatments 1999

cultivar	System	Fungicide			
		Ridomil Gold MZ 68 WP	Acrobat MZ 69 WP	Dithane 75 WG	Bravo 500 SC
Bekas	Simphyt	18.VI	29.VI	6.VII, 28.VII	13.VII
	NegFry	15.VI	24.VI	6.VII, 4.VIII	16.VII
	Stephan	24.VI	5.VII	15.VII, 5.VIII	26.VII
	Routine	24.VI	5.VII	12.VII, 26.VII	19.VII, 2.VIII
Mila	Simphyt	18.VI	29.VI	6.VII, 28.VII	13.VII
	NegFry	15.VI	24.VI	6.VII, 4.VIII	16.VII
	Stephan	24.VI	5.VII	15.VII, 5.VIII	26.VII
	Routine	24.VI	5.VII	12.VII, 26.VII	19.VII, 2.VIII

Results

Prognosis of first spray

First symptoms of *P. Infestans* on the trial site were recorded on 18th of June. NegFry system recommended first spray on 15th of June, Simphyt on 18th and these two results were validated as correct. Unfortunately, Stephan and Routine systems recommended first spray on 24th of June, which was definitely too late.

Number of application according to the validated systems

Simphyt, NegFry and Stephan systems recommended five fungicide applications but plots protected according to recommendation of Routine system were treated with fungicides six times.

Development of Disease symptoms on potato plants

First symptoms of late blight on potato plants of cultivar Bekas appeared at the end of June on all experiments combinations. Later the diversity of symptoms developments was recorded. Between 1st of July and 10th of July the symptoms development on untreated plots was much faster than on plots protected with fungicides. The slowest rate of disease symptoms development was observed on plots treated according to NegFry and Simphyt systems. Until 5th of August the plants infestation representing these two systems did not exceeded 5 % (Fig. 1).

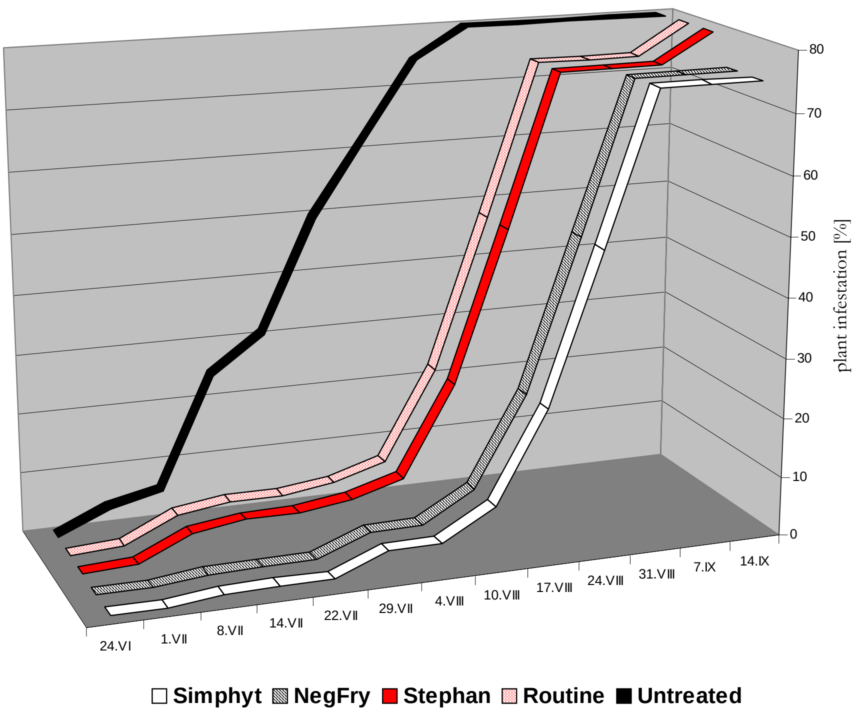

Figure 1. Developmentof late blight symptoms on cultivar Bekas in Winna Góra in 1999.

The disease symptoms development on cultivar Mila was much slower than on cultivar Bekas but again the highest rate of disease development was observed on untreated plots, and the slowest one on plots treated according to NegFry and Simphyt systems (Fig. 2).

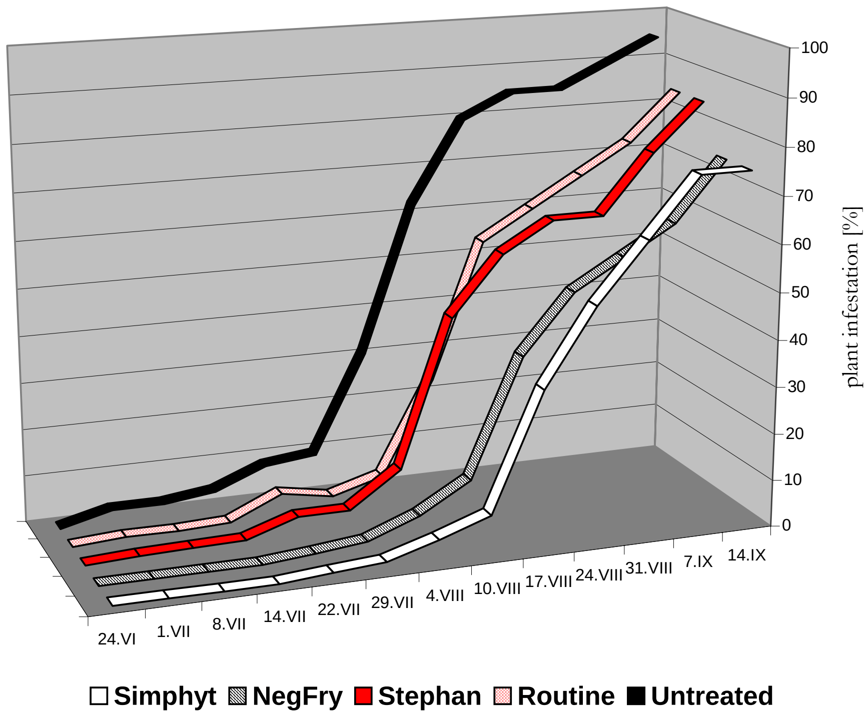

Figure 2. Development of late blight symptoms on cultivar Mila in Winna Góra in 1999.

Yield and quality of tubers

Chemical control of *P. infestans* caused potato yield increase. The highest tuber yield was achieved from plots treated according to NegFry and Simphyt recommendations. Analyses of variance revealed significant differences between these yields and yields obtained from the other experimental treatments (tab. 2). The systems did not cause differences between quality of tuber coming from different experimental treatments (tab. 3).

Table 2. Yields of Bekas i Mila cultivars in Winna Góra in 1999

Cultivar/system		Yield dt/ha	significance
Cultivar	Bekas	234.1	a
	Mila	231.2	a
System	Simphyt	258.7	a
	NegFry	258.5	a
	Stephan	224.8	b
	Routine	232.6	b
	Untreated	188.5	c

Table 3. Tuber infestation by Late blight of Bekas i Mila cultivar

Cultivar/system		Number of infested tuber (%)	sign.diff.
Cultivar	Bekas	3.3	a
	Mila	4.7	a
System	Simphyt	4.6	a
	NegFry	5.0	a
	Stephan	2.8	a
	Routine	4.1	a
	Untreated	3.4	a

Conclusions

Although NegFry and Simphyt systems were not developed in Poland, the results of validation achieved in Poland in 1999 showed that both could be useful in Polish conditions. Compared with standard treatment schedule and Stephan system, NegFry and Simphyt triggered the first treatment much more accurately. Moreover they enabled to slow disease development on potato plants more effectively than other systems and guaranteed higher yield of tubers.

Early blight on potato – field experiments and laboratory studies in 2002

H. HAUSLADEN AND E. SCHULLER

Chair of Phytopathology, TU München – Weihenstephan
Am Hochanger 2, D-85350 Freising, Germany

Summary

During the last few years, early blight of potato caused by the fungi *Alternaria solani* and *Alternaria alternata* became more and more important in all German potato growing areas. Because up to now the disease was unknown as a problem in Germany, there are still many questions concerning epidemiology and disease management. An early blight research project of the TUM Weihenstephan deals with the following subjects:

in which German regions does early blight appear on potato and how does it develop there
which fungus is important for infection and typical early blight symptoms
under which conditions can early blight cause yield losses
what kind of disease management is possible and sensible

Keywords: Alternaria solani, Alternaria alternata, early blight

Mapping of disease severity

During the last two years farmers all over Germany were asked to report early blight in their potato fields. In 2001 *Alternaria* could be detected in all potato growing areas in Germany. Already in July many southern regions, but also a few areas in the North showed medium to high disease severity.

Spore trapping and analysing of leaf samples

Using a spore sampler (Burkard Manufacturing Co. Ltd) *Alternaria* spores could be analysed daily at two different sites. In the following only a preliminary result of the daily spore

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dispersal can be presented. The majority of *Alternaria* spores is released in the morning. Figure 1 shows the average daily spore dispersal calculated over a few days with no respect to weather data. Of course there are differences in spore release depending on rainfall, temperature or wind force but these data are not evaluated up to now.

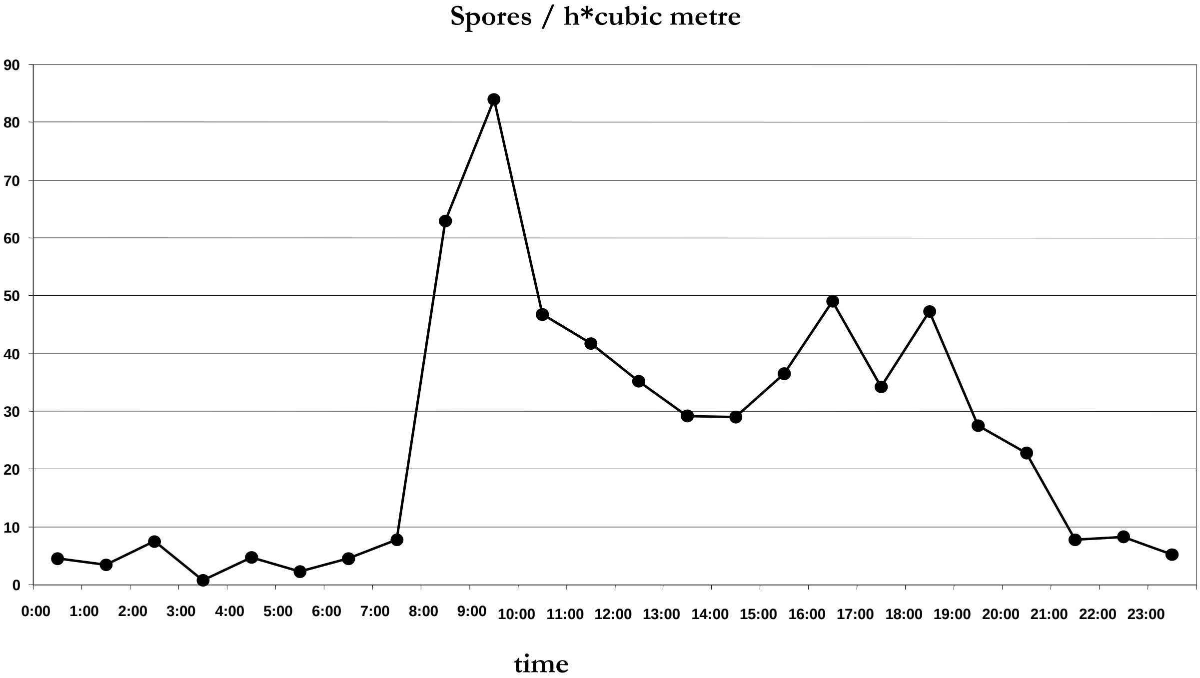


Figure 1: Daily spore release.

In order to find out which fungus is important for infections leaf samples were collected during the vegetation period. After surface sterilisation leafs were placed on PDA and V8 agar (with antibiotic ingredients) and incubated at 25°C (12h light and 12h dark). After about five days samples could be analysed under the microscope. Both fungi could be detected at both sides. *A. alternata* could be isolated more often than *A. solani*, but this circumstance may be connected with cultivation, because *A. alternata* is easier to grow under laboratory conditions.

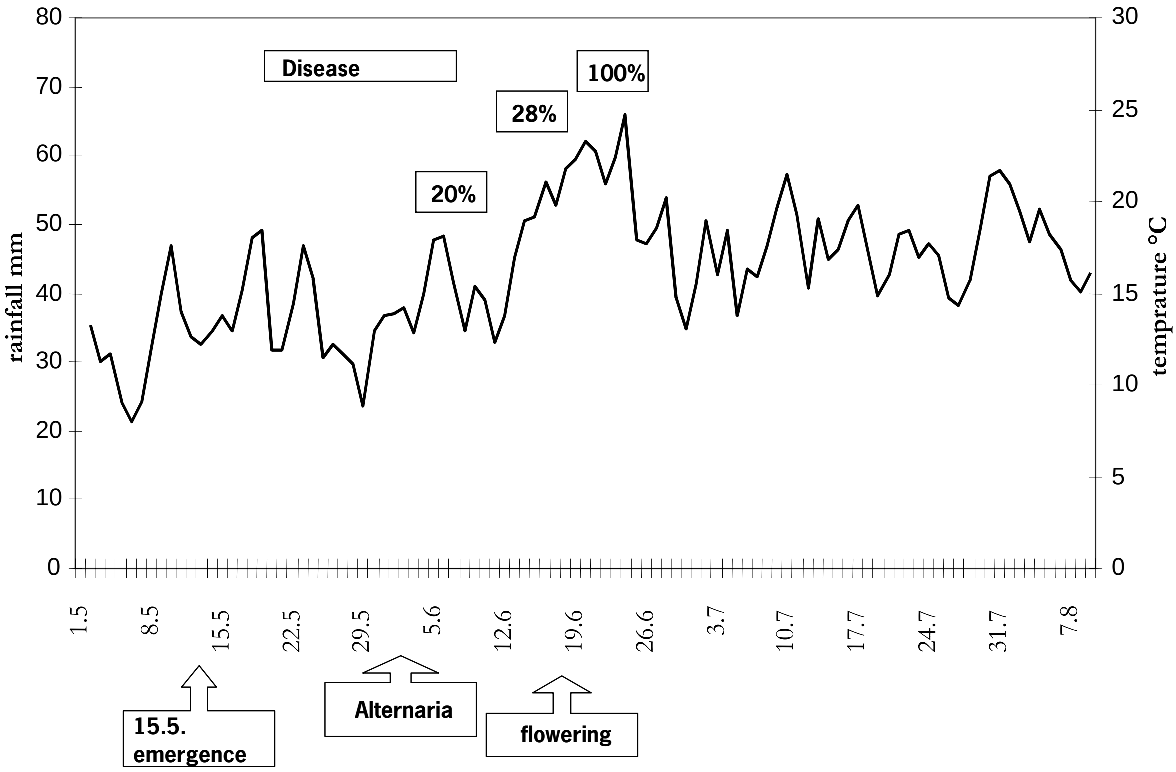
Fungicide treatment with respect to spraying start

To test *Alternaria*-effects of different spraying starts and fungicides a field trial was performed in Kirchheim (Munich).

In the following weather data are shown related to the development of infestation frequency (fig.2). An increase of disease in the middle of June confirms that above all the spread of early blight depends on temperature. The growing stage of potato plants is not so important for a beginning of *Alternaria* infections.

Figure 2: Weather and disease frequency (Kirchheim)

An experimental fungicide could show, that spraying start has to be adapted to local weather conditions. Applications started later than the infection period in the middle of July were less successful compared to fungicide treatments started with the first appearance of early blight symptoms (fig.3). The results indicate that spraying start is very important for the control of early blight.



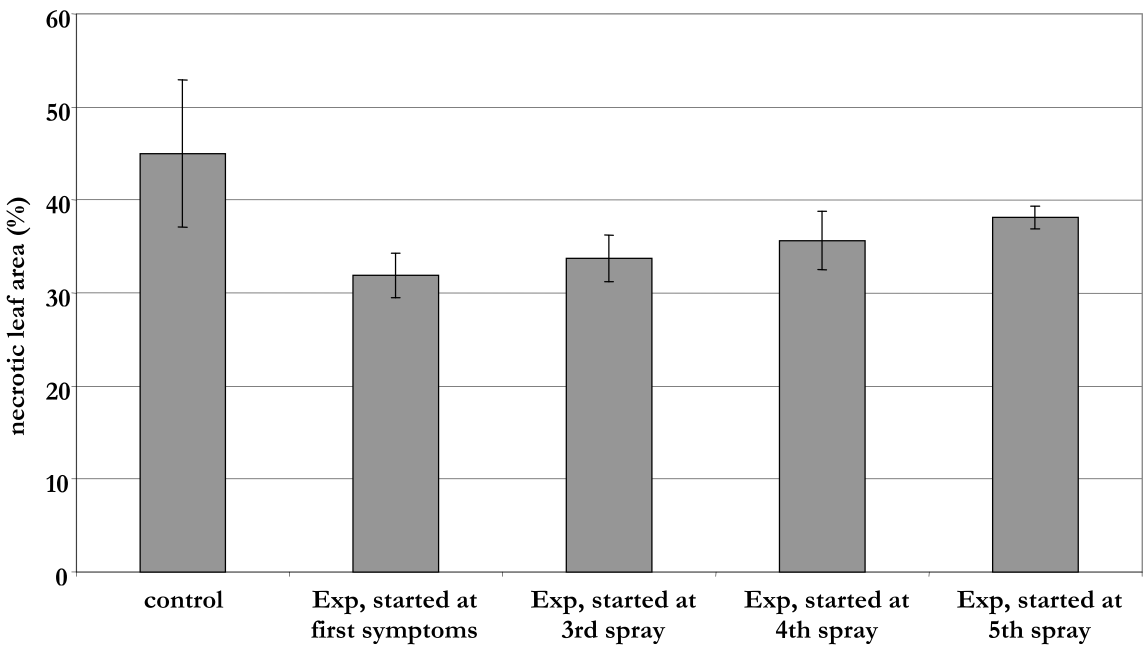


Figure 3: Effect of spraying start (Kirchheim 3.8.2002).

Conclusions

During the last few years early blight could be detected in all German potato growing areas. Under favourable weather conditions *Alternaria* is able to cause severe leaf damages and yield losses.

New disease management systems have to be found to treat potato both against *Phytophthora infestans* and *Alternaria sp.*, because the two pathogens are favoured by different weather conditions. So if fungicide strategies are adapted to temperature and rainfall and the actual intensity of infestation, a control of early blight can be successful.

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Tuber treatment against *Phytophthora infestans*

R. BÄSSLER[1], J. HABERMEYER[2] AND M. ZELLNER[3]

[1)] Lehrstuhl für Phytopathologie, Technische Universität München–Weihenstephan, Freising (baessler@lrz.tum.de)

[2)] Kuratorium Bayerischer Maschinen- und Betriebshilfsringe, Neuburg

[3)] Bayerische Landesanstalt für Bodenkultur und Pflanzenbau, Freising

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 isolates of *Phytophthora infestans* and dressed with different fungicide solutions during 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

In years with heavy rainfall and soil moisture in spring stem infection of late blight in potatoes appears earlier and more often. The fungus grows directly from the seed tuber into the sprout and is able to form first inoculum sources in the stem under favourable weather conditions (ADLER, 2000).

Furthermore *Phytophthora infestans* has the possibility to infect other stems in an indirect way by soil water after sporulation on the tuber surface!

These two ways of stem infection lead to primary infections in the field which are responsible for an outbreak of a late blight epidemic.

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Regarding this, because of improved storage conditions latent infected seed tubers are a more important source of inoculum today than in the past. Additionally there are discussions about a change in population agressiveness of *Phytophthora infestans*.

Because of these changes it is undispensable to supress stem infections which result from latent infected seed tubers!

Is there a possibility to reduce primary infection and epidemic rate and to give a save period for spraying start by tuber treatment?

Material and methods

Inoculation

On 22rd of April seed potatoes were inoculated artificially by a syringe filled with a solution of zoospores. So each tuber was infected with 100-300 zoospores, using a mixture of isolates.

Tuber treatment

For each variant 252 tubers were treated with (table1):

Table 1. Variants in the experiments.

no.	variants
1	Control
2	Control (inoculated)
3	Metalaxyl 80 (inoculated)
4	Metalaxyl 80 (inoculated) [Emulsion Polymer]
5	Metalaxyl 80 (inoculated) [$^1/_2$ Emulsion Polymer]
6	Experimental Product + Cymoxanil 120 (inoculated)

Tubers were planted manually and sprayed with fungicide solutions before covering. In this way only the upper side of the tubers was treated with active ingredients.

Planting

In each plot 84 tubers were planted on 1st of May 2002 in a randomized block with three replications per variant.

Assessments

During the vegetation period emergence and stem infections were estimated.

Results

Weather and essential events

After heavy rainfall during emergence the first primary infections could be detected already six weeks after planting in the inoculated control (fig.1).

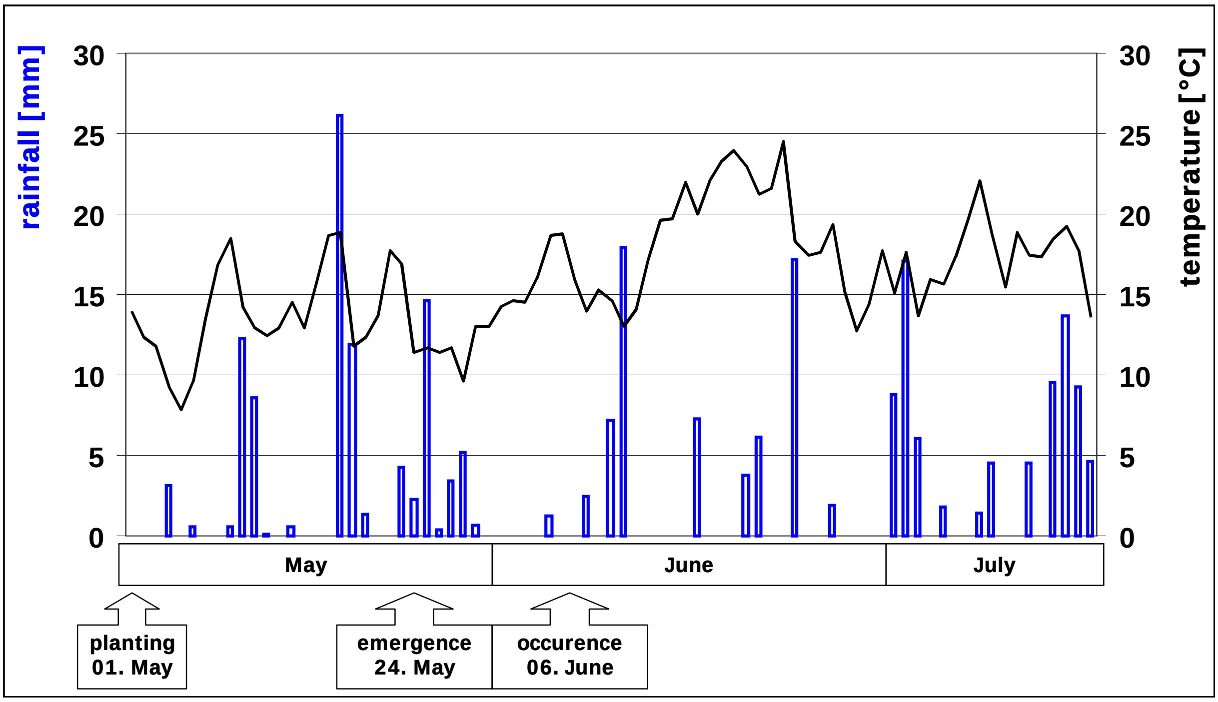

Figure 1. Weather and essential events of the field experiment.

Emergence and stem infection

Because of inoculation emergence of the control was reduced by 26% (arrow).

All fungicides were able to decrease the effect of inoculation and in this way also to increase the rate of emergence (fig.2).

In the inoculated control the earlier and higher infestation of *Phytophthora infestans* is clearly evident (fig.3).

The variants including Metalaxyl showed a significant reduction of stem infection. The addition of an emulsion poymer caused a decrease of infestation again (black circle) (fig.4).

In figure 5 the delay of outbreak is illustrated by numbers. Until 28th of June no stem infection could be detected in the treated variant. A reduction of the epidemic rate can be indicated by the lower increase of the black continuous line until the 4th of July.

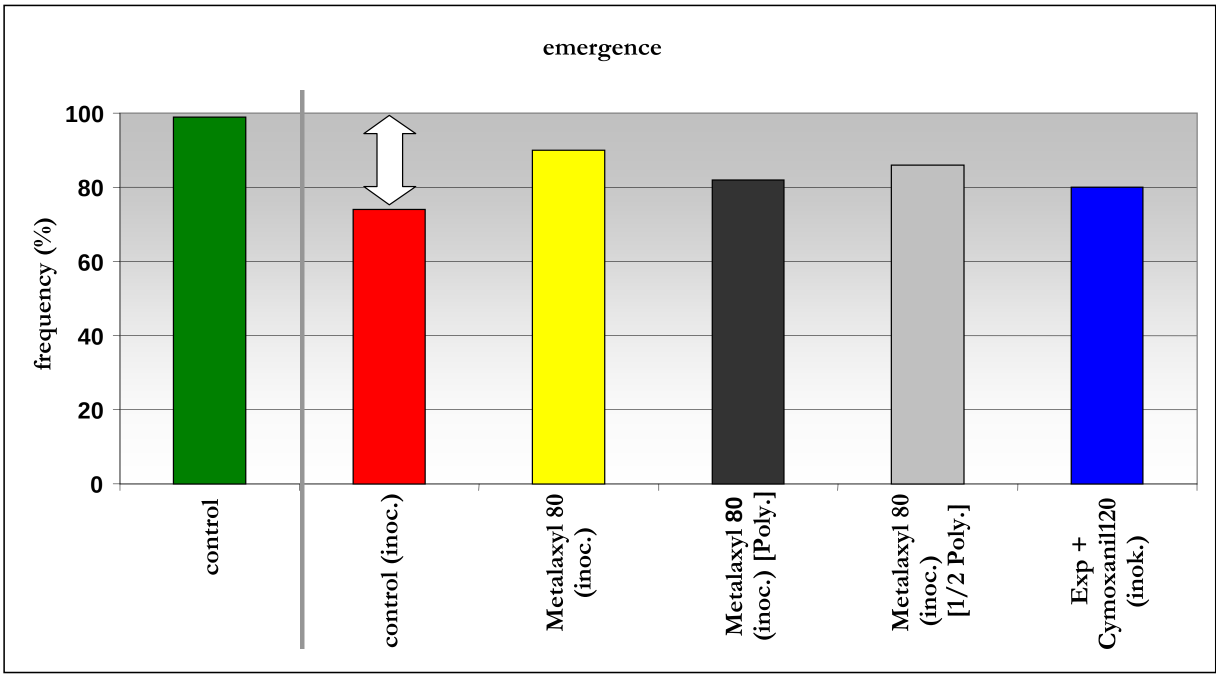

Figure 2. Emergence of the variants.

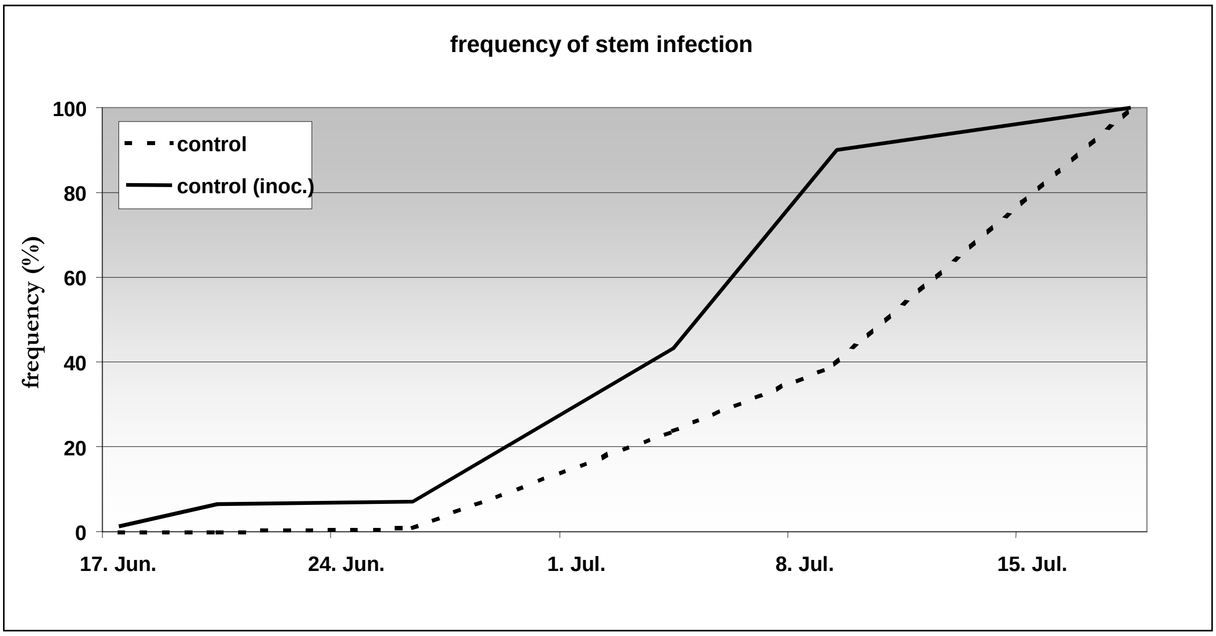

Figure 3. Frequency of stem infection (controls).

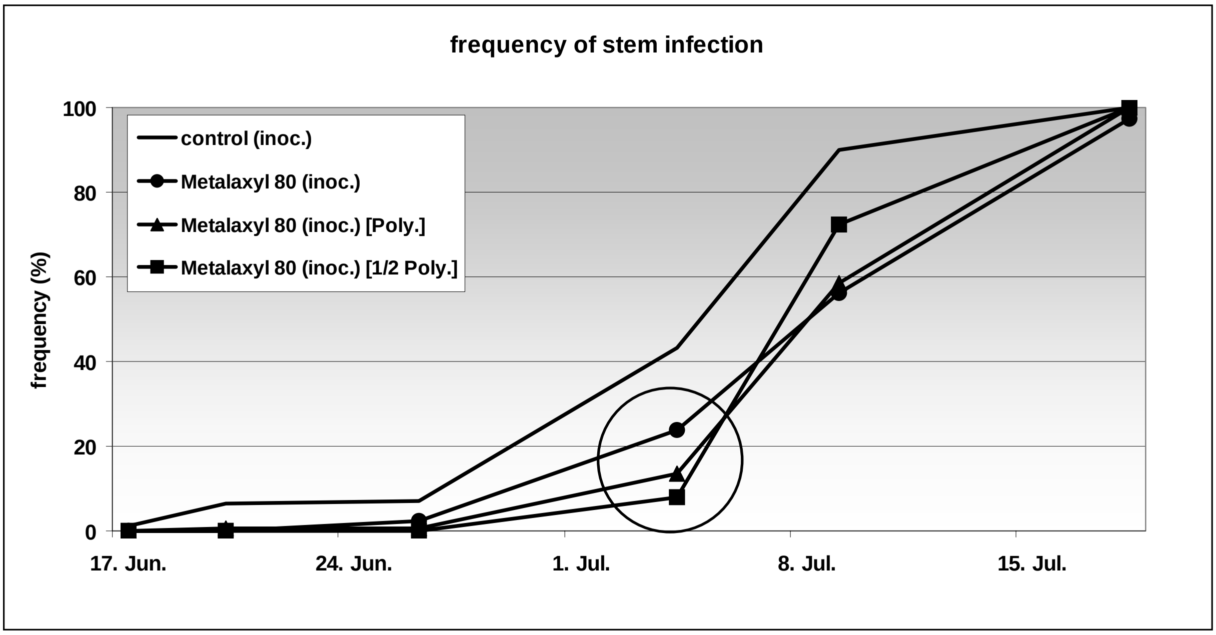

Figure 4. Frequency of stem infection (Metalaxyl + Polymer).

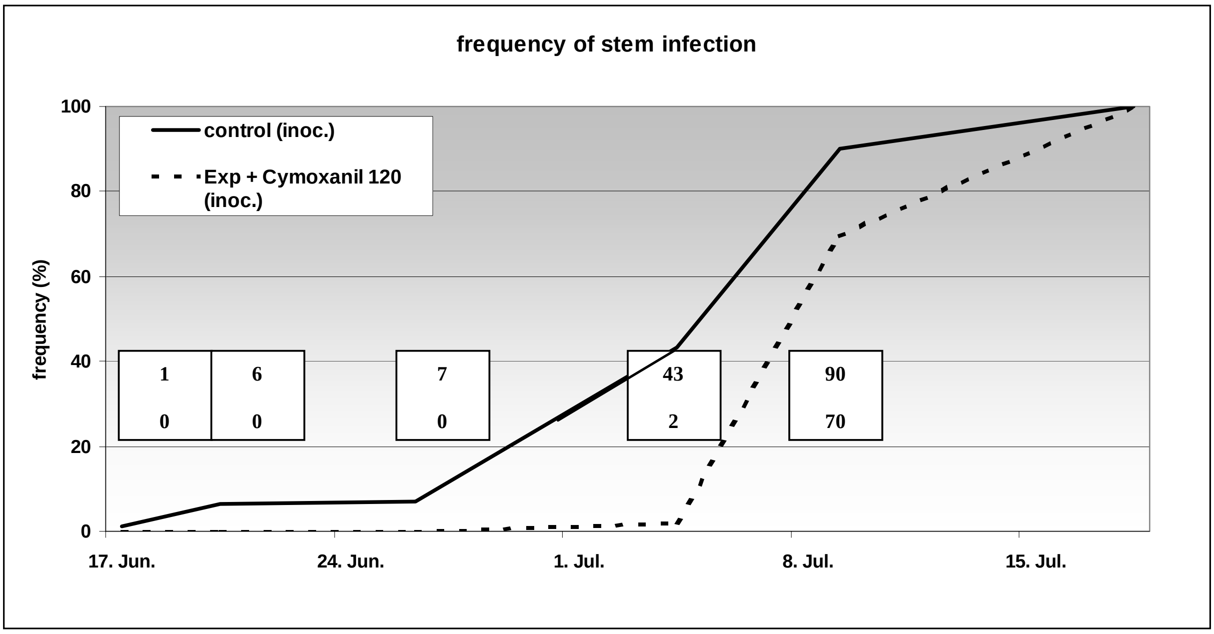

Figure 5. Frequency of stem infection (Experimental Product + Cymoxanil).

Discussion and conclusions

Tuber treatment was effective to:

- reduce primary infection in the field;
- decrease the epidemic rate during the vegetation period;
- postpone at least for two weeks the outbreak of *Phytophthora infestans* (Ensurance of spraying start / assistance of decission support systems).

In combination with an emulsion polymer Metalaxyl was able to supress stem infection with highest efficiency. This variant showed good long time effect in 2001.

So above all, tuber treatment could be able to ensure the period of first application and to reduce intensity of primary infection!

If licences for active ingrediences or the amount of applications should be restricted tuber treatment could be able to support disease management.

Regarding to the spraying start decision support systems could be improved by extension of the period for the important first application.

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Seventh Workshop of an European Network for development of an
Integrated Control Strategy of potato late blight
Poznan, Poland, 2-6 October 2002

Vapour activity of late blight fungicides

H.T.A.M. SCHEPERS AND R. MEIER

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

huub.schepers@wur.nl

Introduction

Fungicides sprayed to control late blight in potatoes act by direct contact between the active ingredient and spores and/or mycelium of *Phytophthora infestans*. There are indications that some active ingredients protect plant parts also beyond the areas of the fungicidal deposits (Hislop, 1967; Rohm & Haas, 1999). This might indicate that also the vapour phase of active ingredients could positively contribute to the protection of plant parts with no fungicide deposit. However, weather conditions that favour volatilisation could lead to a reduced efficacy of active ingredients with a relatively high vapour pressure (Schepers, 2000).

The objective of this research was to measure whether the vapour pressure of fluazinam, mancozeb and chlorothalonil could lead to protection against late blight of unsprayed plants and study the effect of an adjuvant that reduces volatilisation.

Experimental design

Potato plants (cultivar Bintje) grown in pots were sprayed with fungicides three times with an interval of four days (day 0, 4 and 8), in a spraying cabin. The spray boom with three TeeJet 110.03 nozzles placed 50 cm apart, was moving at a speed of 5.66 km/h about 40 cm above the top of the plants. With the pressure at the nozzles set at 3 bar, a spraying volume equivalent to 250 l/ha was sprayed on the potato plants. The plants were treated with the fungicides Penncozeb (mancozeb 75%) 3 kg/ha, Shirlan Flow (fluazinam 500 g/l) 0.4 l/ha, Daconil 500 Vloeibaar 3 l/ha (chlorothalonil 500 g/l) and Shirlan 0.4 l/ha + a natural wax-based adjuvant 2 l/ha supplied by Modify BV.

Immediately after the first treatment eight plants of each fungicide were placed in a tent like structure along with three untreated plants (Photo). The three untreated plants did not touch the treated plants. The eight treated plants remained in the tent except for a brief period to apply the second and third spraying. Two days after each spraying (day 2, 6 and 10) one untreated plant was removed from the tent and assessed for vapour activity of the fungicides by inoculating twenty leaflets from 4 leaves with a droplet of a sporangia suspension of *P. infestans*. The leaves were then incubated at a temperature of 15 °C and high relative humidity. After one week the percentage diseased leaflet area was estimated. As a reference untreated plants from outside the tents were inoculated each time.

Results and conclusions

The experiment was repeated 4 times. In experiment 1, all unsprayed plants that had stood amidst the plants treated with all 3 fungicides showed some degree of protection against *P. infestans* (Figure 1). The protection was most pronounced with fluazinam which has the highest vapour pressure of the 3 active ingredients, namely 1.5 mPa. With fluazinam and chlorothalonil a tendency was observed that the protection was higher as the length of time

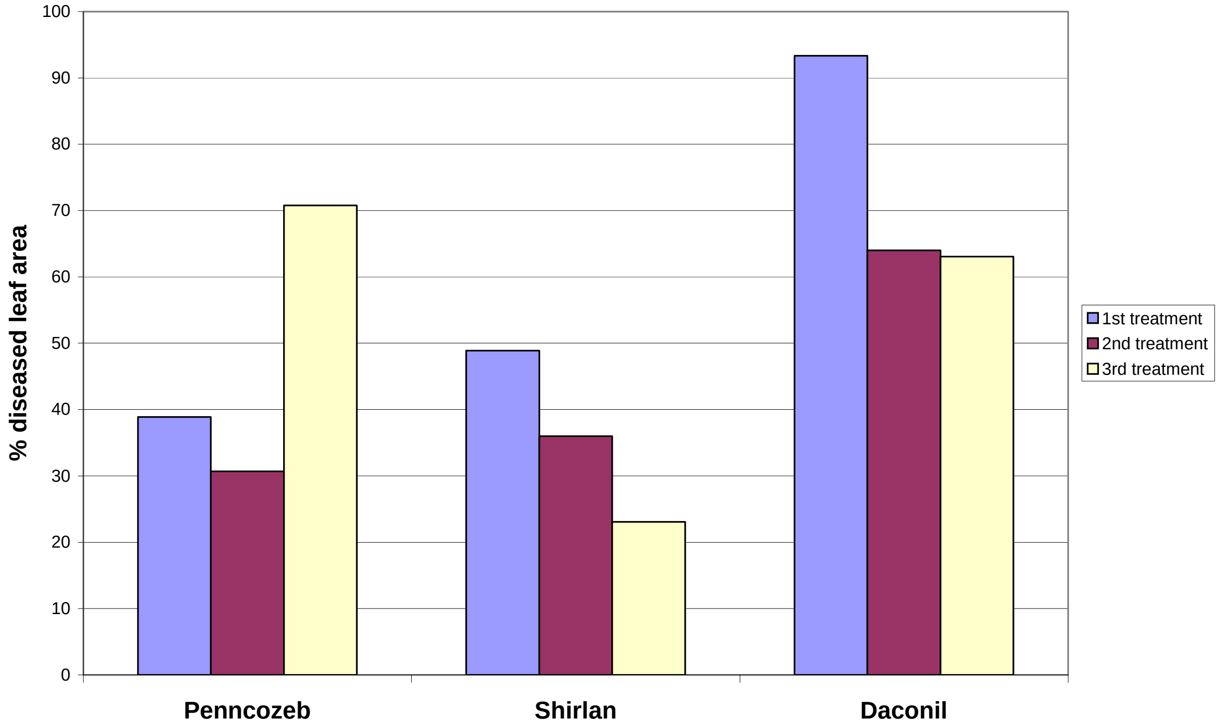

Figure 1. Experiment 1: Percentage diseased leaf area per leaflet in relation to the untreated plants 2002.

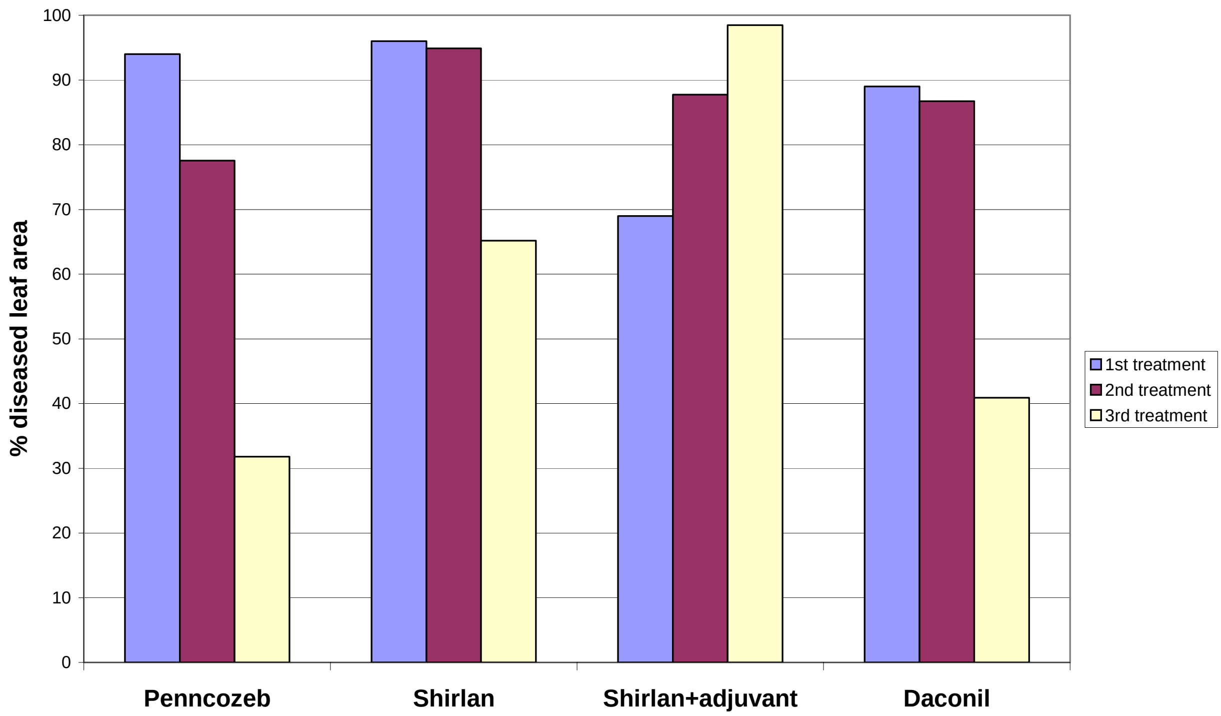

Figure 2. Experiment 3: Percentage diseased leaf area per leaflet in relation to the untreated plants 2002.

the unsprayed plants had stood amidst the sprayed plants was longer. In experiment 3 the level of protection of the unsprayed plants was lower (Figure 2). The effect was most pronounced on plants that were exposed longer to the fungicide vapour. There was an indication that the adjuvant reduced the vapour activity of fluazinam. In experiment 2 and 4 no clear indications of a vapour activity were observed. Different temperatures and relative humidities during the experiments can probably explain the differences between the four experiments. The tent-like structures were placed inside a glasshouse and the temperate and RH inside the tent varied according to the conditions in the glasshouse. Temperature and RH were measured inside the tent. These data will have to be studied in detail in order to explain the observed differences between the experiments.

The results show that under specific conditions the tested fungicides can protect unsprayed plants by vapour activity.

Further experiments under controlled conditions have to reveal the conditions that promote the vapour activity. Field experiments will have to be carried out to show whether the balance between (1) protection of unsprayed plant (parts) and (2) losses to the air can be positively influenced by an adjuvant that inhibits volatilisation.

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Prophy Advice Program

W. NUGTEREN AND K. VOGELAAR

Opticrop B.V., P.O. box 34, NL-2140 AA Vijfhuizen, The Netherlands
Tel. +31 – 23 5583041, Fax +31 – 23 5581963, Email: wim@opticrop.nl

Company

The Opticrop company is dedicated to assist the modern farmer in optimising crop management by means of innovative advice systems. Our main interest in crop protection involves the control of fungal diseases. Opticrop manages a network of 75 weatherstations in The Netherlands. Together with regional weatherforecasts, the data is processed by the disease models for continous monitoring of the various diseases.

Opticrop offers the following advice systems:

- Phytophthora in potatoes (ProPhy)
- Botrytis squamosa and Perenospora destructor in onions
- Mycosphaerella in brassica (Mycos)
- Botrytis in flowerbulbs (Optibol)
- Septoria in celery
- Various diseases in cereals (CerDis)

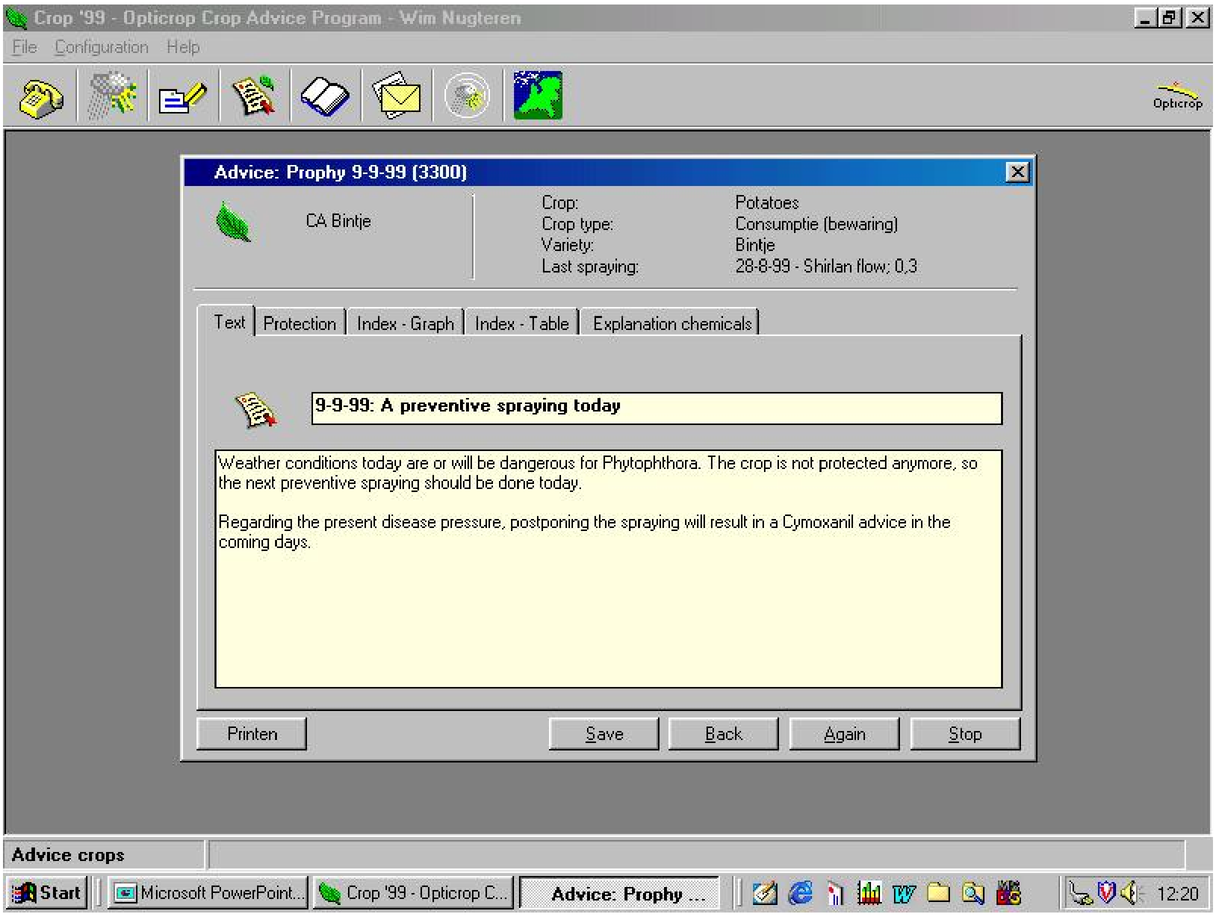
- Optimal timing and dosage of sprayings (Gewis)
- Irrigationplanner
- Harvest-planning seedpotatoes
- Registration and planning nutrients (Minasplanner)
- Weedcontrol (MLHD)

PPO-Special Report no.9 (2003), 249-253

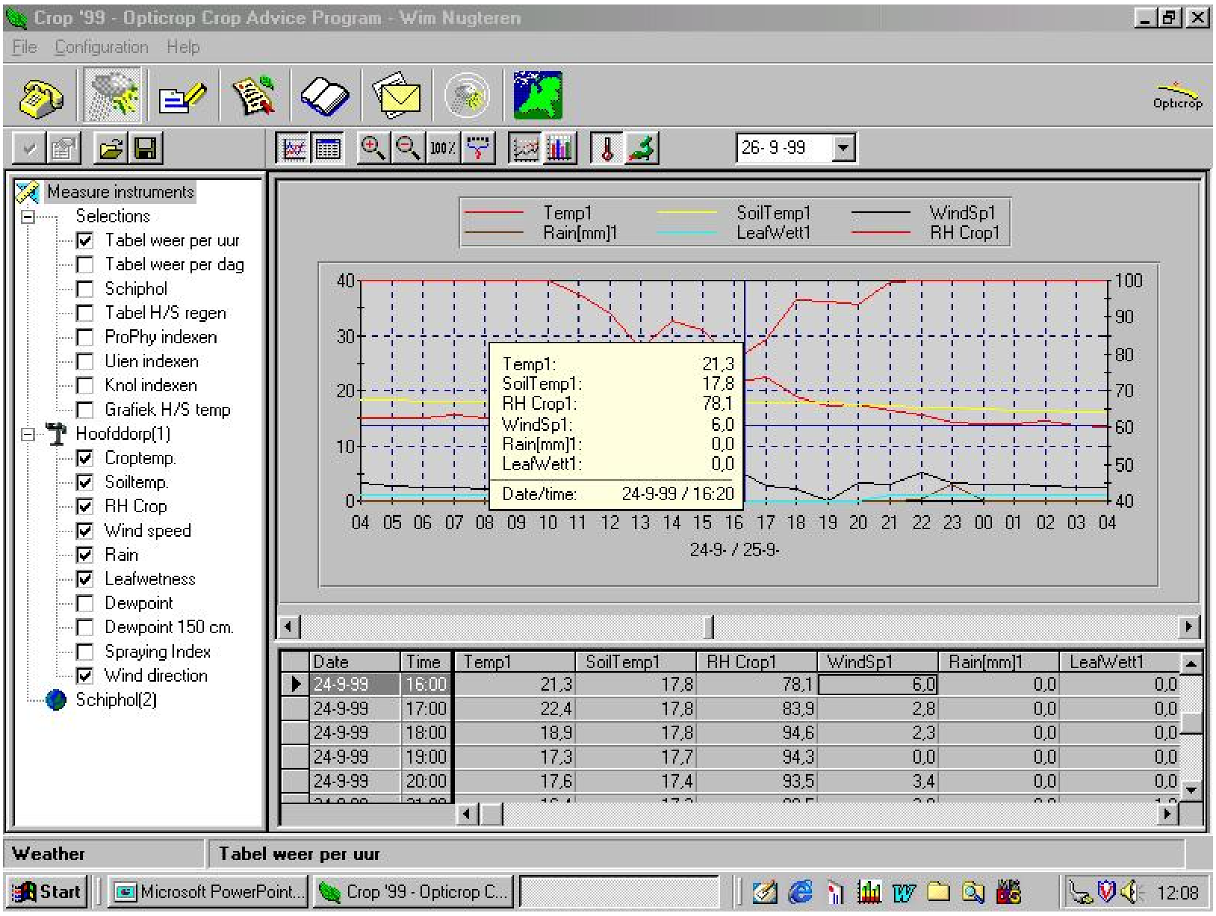
- Organic matter and mineralisation (OptiSoil)
- Database holding detailed descriptions/pictures of diseases, weeds, insects etc. + detailed information on chemicals (Gezonde Gewassen)

The farmer and advisor can choose 3 different ways of using the advice systems:

- The Crop program on their own computer. Crop is the overall system holding all the communication facilities, field registration, presentation of weatherdata, precipitation radar etc.. It has proven to be very user-friendly. The advice modules offer detailed and field-specific advices and lots of background information.
- Online internet-applications. Behind the log-in, the farmer finds all weather and disease information which is hourly updated. By interactive dialogue, general advices can be specified for your own fields, varieties etc..
- Fax. One gets 3-6 fax messages per week. The fax message generally contains an overview of the weatherconditions in relation to a specific disease, a detailed regional forecast and crop protection advices.



All together we have over 2500 farmers advisors using our services. Annual costs range between € 95 for a single advice-fax to approximately € 500 for the Crop PC program with all advice modules.



History

Initial development of ProPhy started back in 1987. After a prototype season in 1988, it was introduced and tested by 15 farmers in 1989. In The Netherlands it was definitely the first advice program especially developed to be used by farmers on their home computer. Since then there have been interesting developments. The company behind the program changed from Vicon to Prolion and finally became Opticrop. Originally every farmer had his own weatherstation directly linked to the computer, while now groups of 5-50 farmers all access the data of a weatherstation by an internet-server. In the early 90's the regional weatherforecasts became available by electronic means, which was a major step towards good preventive disease control. In cooperation with research institutes (PPO), the ProPhy program was finetuned and validated in many field-trials. Over the years, a lot has changed in the available chemicals. Shirlan, and recently Ranman replaced Dithiocarbamates. A curative component Metalaxyl was forbidden in 1998. The focuss used to be on saving sprayings for economical and environmental reasons. By now, the Phytophthora has become so agressive that good and reliable control is the nr. 1 priority. A first spraying right after emergence is not unusual, whereas the criterium once used to be "row closing". 500 farmers using the ProPhy program on their computer now join the first innovators. Another 1300 Dutch farmers use ProPhy by fax, e-mail and internet. With the decreasing number of farms, further market penetration now seems to slow down. The ProPhy program has set a good example for similar systems in other crops, like onions, flowerbulbs and cereals.

Weather

As for every weather-related disease, the basis of ProPhy is in translating accurate micro-climate measurements into disease parameters (sporulation, release, survival, infection, incubation etc.). Opticrop operates a network of 75 on-farm weatherstations of which the data is collected hourly. Also, a 5 day forecast is included for 40 regions in The Netherlands. For the farmer the model output is expressed in two clear parameters on daily basis. First there is a daily judgement, purely based on weather conditions, on the danger of Phytophthora infection: yes or no (plus an indication of the degree of danger). Then there is a disease pressure (0 .. 100) as a running average simulating presence and severity of sporulating sources.

Protection

ProPhy calculates how long a spraying gives a sufficient level of protection, by taking in account all influencing factors: chemical type, dosage, crop growth, variety susceptibility, disease pressure and wash-off. For clear understanding, all these factors and the endresult are presented in days. The dynamic calculations can lead to protection periods anywhere between 5 and 15 days.

Advice

Whenever dangerous conditions occur on a non-protected crop, this leads to a spraying advice. The Prophy program not only indicates timing, but also advices on chemical type and dosage. This strongly depends on the situation (disease pressure, infection probability and – if so – actual Phytophthora in the field).

31 trials 1994-2001

Many official field trials (mainly by PPO) have validated the ProPhy advice system. Although setup and objective of the trials were different, there was always one treatment sprayed according to the ProPhy advices and one treatment that can be considered "standard". The standard treatment used to be a fixed weekly spraying routine, and in later trials it is usually an "optimal" routine according to the manager of the research farm. The graphs show the main results of all the individual trials: the level of Phytophthora control and the number of sprayings. The result of the standard treatment is set to 100, so it shows the relative results of Prophy vs the standard.

The upper graph makes clear that spraying according to ProPhy results in similar or even better disease control. At the same time, the number of sprayings was reduced down to 60%. This is clear evidence ProPhy is successfull in its objectives: (1st) good and reliable Phytophthora control and (2nd) with a minimum of chemical input.