Chapter 8:

Integrated Systems Approach for the management of late blight in organic potato production systems in the EU.

Section 1: Data analysis and modeling: analysis of weather data

Section 2: Field evaluation of novel blight management systems

Chapter 8: Integrated Systems Approach for the management of late blight in organic potato production systems in the EU.

General Introduction

The relative effect of individual component strategies (resistance management, diversification, agronomic methods and alternative treatments) and most effective combinations of them will depend on local conditions. For example, improved volunteer control strategies of all farms in a region may be essential for regions with maritime climates which have a low incidence of ground frost, but may have no impact in regions of continental Europe where severe ground frosts kill most tubers left in the ground. In addition, in some cases the opportunity to adopt certain potentially useful component strategies may be limited either by weather or practical or market requirements. Moreover, regional and site specific environmental conditions (climate and soil type, fertility and water availability; inoculum sources; microclimatic conditions) will influence the start and subsequent development and spread of late blight epidemic (i.e. ‘local blight pressure indices’) and hence the efficacy of different component strategies. Consequently, the optimum blight management strategies are likely to differ between organic production systems and regions of the EU. Clearly, there is a need to identify interactions (both synergistic and antagonistic) between the main novel components to help to formulate optimum late blight management systems in organic potato production that are adapted for different regions within the EU.

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Section 1: Data analysis and modeling: analysis of weather data

Summary

Infection of potatoes with *Phytophthora infestans* is highly dependent upon weather conditions. At the Agroscope FAL Zurich-Reckenholz, rules for detecting these crucial weather conditions were developed during the 1995-1997. The Main Infection and Sporulation Period (MISP)-model detects days with weather conditions favourable for infection and sporulation of *P.infestans* (Cao et al., 1997). Since 2001 the MISP model has been integrated in an internet based decision support system for the control of potato late blight on potatoes in Switzerland.

Within the EU Blight MOP project, regional and local environmental late blight conditions of the different partner countries were analysed according to the Swiss MISP-model. At the end of the potato growing season, partners in the United Kingdom, France, Norway and Switzerland who conducted variety trials from 2001 to 2003 (Chapter 3) sent seasonal weather data recorded at an in-field (or the nearest official weather station) to Agroscope FAL for collation. Late blight assessments made on the same two varieties from these trials and also where possible, data about the regional late blight situation were also collected. The two varieties Bintje (susceptible) and Santé (moderately resistant) were chosen as the standards to compare the late blight situation in the different countries and years. For 2004, weather data were received from the field trials which were conducted on LINK and MODEL farms in the United Kingdom, France, Norway, Switzerland, Germany, Netherlands and Denmark. There were large differences in the number of MISP days between years, countries and within countries indicating that the risk of late blight impact varies markedly. Usually the disease progressed more rapidly in Bintje than in Sante reflecting differences in disease susceptibility but in the UK in 2001 there was no difference in the pattern of infection between the two varieties.

Late blight epidemics cannot be explained exclusively by weather data. The presence of inoculum is essential and also knowledge of the real late blight situation in a parrticular area is required. Because data sets were incomplete and the weather and epidemic onset between years and locations was so variable, it was not possible to define a regional or even local-specific weather-based infection risk index. Characterisation of the local weather risk index would require a mean number of critical weather periods of the order of ≥ 10 years. Although it would be possible to estimate the basic weather risk for a region based on such an index, the development of the actual epidemic cannot be predicted or explained. Even though no correlation was found between the total number of critical weather periods and the epidemiological parameters used in these analyses, we are convinced that critical weather periods have an important influence on the development of late blight epidemic. The onset and the progress of late blight epidemic depends on the presence of infectious material and on the subsequent incidences of MISP days either as single or consecutive events; not on the sum of MISP days.

Introduction

Late blight of potato is considered to be the most important disease of potato worldwide (Robertson, 1991, Fry et al., 1997).The disease progress of the causing pathogen, *Phytophthora infestans* (Mont.) de Bary, depends, beside the availability and susceptibility of the potato crop, strongly on weather conditions. At the Agroscope FAL Zurich-Reckenholz, rules for detecting these crucial weather conditions were developed during the years 1995-1997. The so called Main Infection and Sporulation Period (MISP)-model detect days on which weather conditions are favourable for the infection and sporulation of *P.infestans* (Cao et al., 1997). Since 2001 the MISP model is integrated in an internet based decision support system for the control of potato late blight on potatoes in Switzerland.
Within the EU-project BlightMop, regional and local environmental late blight conditions of the different partner countries were analysed based on the Swiss MISP-model.

Materials and Methods

The Swiss MISP model requires hourly data of the three weather parameters temperature (°C), rainfall (mm) and relative humidity (%) to detect crucial weather conditions favourable for late blight. Partners who conducted variety trials (WP 2.1) from 2001 to 2003 sent weather data of an in-field or the nearest official weather station at the end of the potato growing season. In addition, late blight assessments of these trials and if possible also data about the regional late blight situation were sent to the Agroscope FAL. The two varieties Bintje and Santé were chosen as a standard to compare the late blight situation in the different countries and years. For the year 2004, weather data were received of the field trials which were conducted on Link and Model farms in the seven countries United Kingdom, France, Germany, Denmark, Norway, Netherlands and Switzerland. Again weather data of an in-field or the nearest official weather station were sent. Our existing weather data model MISP had to be updated and the weather data were standardised and subsequently analysed for their integrity and quality. No interpolations were done in case data were missing. For further analysis, only the real MISP days were taken into account (see annex). In addition weather data were analysed for daily risk values (DRV) ≥ 7 to have a comparable tool to our model (NegFry, Hansen 1993).

Characterisation of weather data

- Potato growing season 2001 & 2002:

  To characterise the weather situation at the different locations, days with MISP conditions were determined. The number of MISP days from the 1st of May until the 31st of August or from the 1st of May until the day with 50% disease severity was counted up. Also the number of MISP days within the single months was counted.
- Potato growing season 2003:

  As weather conditions were very special in 2003 – almost everywhere hot and dry – late blight developed hardly at the different locations. Therefore these data were not considered for the analysis.

  Potato growing season 2004:

  In 2004, total number of MISP days from the 1st of May until the 31st of August and the number of MISP days within the single months was counted.

For an overall characterisation of the weather data, all available MISP data from 2001 to 2004 of the weather stations in the different countries N, DK, UK, D, F and CH were summarised. As weather data of the Netherlands were only available for the year 2004, these data were disregarded. To characterise and compare weather based infection risks, we selected the data set of the years 2002 and 2004, as for these years weather data were available for all countries.

Epidemiological parameters (2001-2002)

To evaluate local late blight epidemics in Bintje and Santé, the disease progress curves were transformed with the logistic model (Campell & Madden, 1990). Then, according to the linear equation, the slope (r-values) of the curves and the Julian day with 50% disease severity were calculated for each situation.

Relationship weather data – late blight epidemics (2001-2002)

To evaluate the relationship between weather data and local epidemics, the number of MISP days was correlated with the epidemiological parameters. MISP days were counted on from planting until harvest.

From the years 2001 and 2002 eight complete sets of Bintje and Santé disease, local weather data and phenological data were received (tab.1).

Tab.1: Weather and disease data records received of the variety trials in 2001-2002. Complete data sets are highlighted.

Country	Year	Nb. of weather data sets	LB-assessments Bintje and Santé	planting	emergence	Harvest
Norway	2001	1	received	18.05.2001	07.06.2001	15.09.2001
	2002	1	received	16.05.2002	30.05.2002	10.09.2002
Denmark	2001	1	not received	not received	not received	not received
	2002	1	available for Bintje & Sava	not received	not received	not received
UK EFRC Newbury	2001	1*	received	09.05.2001		from 1.10.2001
	2002	1	received, only Santé in trial	29.04.2002		from 27.08.2002
UK Newcastle	2002	1	received	25.04.2002	27.05.2002	24.09.2002
CH Rheinau	2001	1	received	30.04.2001		21.08.2001
	2002	1	received	18.03.2002		04.09.2002
Germany	2001	1**	only available, for Linda & Agria	03./04.05.01	31.05.2001	17-21.09.01
	2002	1*	only available, for Linda & Agria	15./16.05.02	17.06.2002	02.-06.09.02
France Ploudaniel	2001	1	received	14.05.2001		31.08.2001
	2002	1	received	25.04.2002		04.09.2002
France Avignon	2002	1	no LB	not received	not received	not received

LB= Late blight, *missing data, ** weather data only from 14.7.01 on

After processing and visualising the weather data of the different trial sites with the help of our model, missing values could be detected easily. The weather data 2001 from the UK location (partner No.5, EFRC) had some missing data and the data records from Germany started only at 14th of July. In 2002 there were hardly any missing data; therefore the quality of the weather data 2002 was much better than that of 2001.

Weather data for the potato growing season 2004 were high-quality and only few data sets were missing or incomplete (tab.2).

Tab.2: Summary of analysed weather data sets of the different countries of the potato season 2004.

Country	Location of weather station	Trial site	Nb. of complete weather data sets	comments
N	Saerheim Ilseng Sande Lyngdal (south of N)	Model farm Link farm Link farm Link farm	4	Weather data from May 1 - August 31 for all weather stations
DK	Jyndevad Svanholm Hoven Taasinge	Link & Model farm Link farm Link farm Link farm	2	For Svanholm weather data are incomplete For Taasinge no precipitation data available
UK	Newcastle	Link & Model farm	1	Weather data from May 1 - August 31
F	Lycée Suscinion Toreille Lorgies	Link & Model farm Link farm Link farm	1	For Toreille data set incomplete For Lorgies only daily weather data available
NL	Biddinghuizen Kapelle Werkendam Zwaagdijk	Link & Model farm Link farm Link farm Link farm	4	Weather data from May 1 - August 31 for all weather stations
D	Hebenhausen Klima DFH Ebergötzen Etzenborn	Model farm Link farm Link farm Link farm	1	For Klima DFH weather data from May 14 – August 20 and incomplete. No weather data for Ebergötzen and Etzborn available
CH	Rheinau	Model farm	1	Weather data from May 1 - August 31

Results 2001 and 2002

Characterisation of weather data

Analysis of weather data revealed big differences in the number of MISP days between the years, countries and even within the countries (tab.3). It is obvious, that the risk impact of a given month varies strongly within a year and over the two years. For example in Switzerland, in June 2001 the number of MISP days was higher than in 2002. Even if two locations in the United Kingdom (Newbury, south of England and Newcastle, north of England) are compared in 2002, the pattern of MISP days per month is different (tab.3).The same result can be observed for France 2002 (Ploudaniel, Bretagne and Avignon, south of France).

For 2002 the weather data available were of good quality and to our astonishment the total number of MISP days is roughly the same for the different locations with the exception of France (Avignon) and Norway. This is the first indication that the number of critical weather periods only during a restricted period should be of interest.

Same analyses were conducted with the daily risk values (DRV) ≥ 7. The overall pattern was rather the same and the two models corresponded well.

Tab. 3: Monthly number and total number of MISPs at the different location of weather stations in the year 2001 and 2002. Analysed period May 1 – August 31

Country	Year	May	June	July	August	Total number of MISP days
N	2001	0	2	10	14	26
DK	2001	3	16	4	9	32
UK**	2001	2	/	1	4	7**
F Ploudaniel	2001	1	0	6	2	9
D*	2001	/	/	1	3	4*
CH	2001	6	12	8	10	36
N	2002	6	15	11	6	38
DK	2002	5	5	10	4	24
UK Newcastle	2002	3	7	8	7	25
UK EFRC	2002	4	2	6	9	21
F Ploudaniel	2002	8	7	8	1	24
F Avignon	2002	3	2	2	2	9
D**	2002	4	8	4	2	18**
CH	2002	7	2	6	5	20

*weather data available only from 14.7.01 on, ** missing data

Epidemiological parameters

Between the years and the countries there were big differences for the Julian day with 50% disease severity. With the exception of one trial in England (2001), Bintje and Santé showed clearly distinct characteristics (tab.5). In 2001, it seems that the later the disease started, the smaller the differences became in the 'Julian day 50% disease severity' between the two varieties: at the UK location EFRC (2001), late blight epidemic started very late and no significant difference in the 'Julian day 50% disease severity' for the two varieties was found. At the location in Switzerland however, the epidemic started early in May and there, big differences (26 days, see table 5) occurred in the Julian day with 50% disease severity. With the exception of the data set of France in 2002, this trend could also be seen in the potato growing season 2002.

Table 5: Number of days between Bintje and Santé Julian day with 50% disease severity at the different locations in 2001 and 2002.

Location and Year	variety	Julian day with 50% disease severity	Difference of days
Norway 2001	Bintje	213	17
	Santé	230	
UK, EFRC 2001	Bintje	238	1
	Santé	239	
Switzerland 2001	Bintje	193	26
	Santé	219	
France 2001	Bintje	210	15
	Santé	225	
Norway 2002	Bintje	210	15
	Santé	225	
France 2002	Bintje	186	11
	Santé	197	
Newcastle 2002	Bintje	221	9
	Santé	230	

In general, the slope of the disease progress curve was steeper for the susceptible variety Bintje than for the moderate susceptible variety Santé (tab.6). With the exception of three locations, UK 2001, Norway 2002 and France 2002, there was a significant difference in the r-values of the two varieties. At the UK location 2001, there was not only no difference between the slope of the disease progress curves, but also for the day with 50% disease severity for both varieties. It seems as if the moderate variety Santé was as susceptible as the highly susceptible variety Bintje. Though, the r-values of the location in Norway 2002 and France 2002 were not statistically different, Bintje reached the level of 50% disease severity 15 respectively 11 days prior to Santé.

Tab.6: Slope of the progress disease curves (r-values) for the two standard varieties Bintje and Santé in 2001 and 2002.

Country	Year	Variety	Mean r-values
N	2001	Bintje	0.4
		Santé	0.3
	2002	Bintje	0.5
		Santé	0.4
UK	2001	Bintje	1.1
		Santé	0.7
	2002	Bintje	1.2
		Santé	0.9
F	2001	Bintje	0.6
		Santé	0.4
	2002	Bintje	0.6
		Santé	0.3
CH	2001	Bintje	0.7
		Santé	0.4
	2002	Bintje	0.7
		Santé	0.4

Relationship weather data – late blight epidemic

No correlation was found by evaluating the relationship between weather and disease data. Therefore only few data are summarised in the table 7.

Tab.7: Evaluation of the relationship between weather and disease data. Only some results shown. Year 2001 and 2002 and all countries summarised.

Variety	Numbers of days with	Disease parameter	Correlation coefficient R^2
Bintje	MISP	r-values	0.18
Santé			0.28
Bintje	DRV ≥ 7	r-values	0.25
Santé			0.09
Bintje	MISP	AUDPC	0.2
Santé			0.01
Bintje	DRV ≥ 7	AUDPC	0.4
Santé			0.22

Even though no correlation was found between the total number of critical weather periods and the epidemiological parameters of the local epidemics on Bintje and Santé, we are convinced that critical weather periods have an important influence on the development of late blight epidemic.

Results 2004

As in the precedent weather data analysis big differences in the total number of MISPs between the different countries and within the countries was confirmed (tab.8)

Tab.8: Monthly number and total number of MISPs at the different location of weather stations in the year 2004. Analysed period May 1 – August 31 2004.

Country	Location of weather station	May	June	July	August	Total number of MISPs
N	Saerheim	2	10	10	13	35
	Ilseng	0	3	0	7	10
	Sande	3	6	6	7	22
	Lyngdal	1	5	4	9	19
DK	Jyndevad	6	14	10	10	40
	Svanholm*	1	/	2	4	/
	Hoven	3	10	11	9	33
UK	Newcastle	1	6	9	6	22
F	Lycée Suscinio	1	1	6	11	19
NL	Biddinghuizen	1	4	7	8	20
	Kapelle	3	4	5	10	22
	Werkendam	1	4	5	9	19
	Zwaagdijk	2	7	5	12	26
D	Hebenhausen	7	7	11	9	34
	Klima DFH*	/	8	9	/	/
CH	Rheinau	3	6	7	5	21

*If more then 10% of weather data were missing, MISPs were not considered.
🟩 1-4 low, 🟨 5-7 intermediate, 🟧 ≥ 9 high number of MISP

Looking at the number of MISP days within the single months, big differences between the weather stations in Norway were registered (tab. 8). Distances between these weather stations were huge; up to ±500 km. At several weather stations in the northern countries, weather conditions for late blight were favourable during the months June, July and August 2004, at the weather stations located more southerly July and August were favourable. This can be explained by the general weather situation; for example in June there was a high pressure area over Central Europe and therefore several low-pressure areas crossed over the northern part of Europe (reference MeteoSchweiz).

Overall characterisation of weather data 2001, 2002 and 2004

By ranking the number of MISP days for the two years 2002 and 2004, we observed a gradient from north to south. During these two years there were more MISP days registered at the northern than at the southerly weather stations (tab.9). Nevertheless this statement has not to be generalised. This is the result for the weather stations used and analysed in these two years. But it is also important to realise, that at these weather stations MISP situation vary strongly from year to year. Therefore a period of four years is much too short to determine a region- or even location-specific weather based infection risk index. Furthermore, a general weather based infection risk index for a country can not be defined on the basis of one weather station, particularly not for a wide country as for example Norway.
A study within the PhytoPRE project of the Agroscope FAL Reckenholz showed that by means of long term weather data (≥ 10 years) a ‘local weather risk’ can be calculated, which allows comparison of different locations (data not shown).

Tab.9: Total number and ranking of MISPs for the year 2001 to 2004.

	2001	2002	2003	2004	Sum of rank 2002 & 2004
N	26	36		35	**3**
DK	33	24	13	37	**5**
UK		25		22	**6**
F	9	25		19	**8**
D		18		34	**9**
CH	33	20	14	21	**10**

Discussion

Late blight epidemics can't be explained by using only weather data. Knowledge of real late blight situation respectively the presence of inoculum is essential. With this small, incomplete set of data and the variation (weather and epidemic onset) between years and locations, it is not possible to define a regional or even local-specific weather based infection risk index. A mean number of critical weather periods of a length of ≥ 10 years could give a characterisation of the local weather risk index. Based on such an index the basic weather risk for a region can be estimated, but the development of the real epidemic can't be predicted or explained. Even though no correlation was found between the total number of critical weather periods and the epidemiological parameters used in these analyses, we are convinced that critical weather periods have an important influence on the development of late blight epidemic. The onset and the progress of late blight epidemic depend on the presence of infectious material and on the follow up of MISP days as single or consecutive events; not on the sum of MISP days.

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Annex

Definition of the MISP-rules which were used to analyse the weather data:

Main Infection and Sporulation Periods are periods of 24 hours with:

An average temperature of ≥ 10°C
and
Number of hours with rainfall (≥ 0.1 mm) ≥ 6 or the sum of rainfall within these 24 hours ≥ 15 mm
and
the number of consecutive hours with a relative humidity (≥ 90%) ≥ with ø Temp. ≥8°C or 6h-periods interrupted by max. 2 hours with 90% ≥ rel. humidity ≤ 85%.

Section 2: Field evaluation of novel blight management systems

Summary

‘Novel’ late blight management systems were designed for evaluation on one MODEL (Research) and four LINK (Commercial) farms in Denmark, France, Germany, Netherlands, Norway, Switzerland and the United Kingdom. These ‘novel systems were built up by

- Firstly, critically reviewing the currently used late blight management system (CULBMS) on MODEL and LINK farms to identify where improvements to practice were possible or appropriate
- Secondly, identifying promising component strategies with potential to improve upon CULBMS (from the programme of previous experiments that had tested them independently of other component strategies and described in Chapters 2 to 7 inclusive)
- Thirdly, modifying the CULBMS by replacing one or more existing components with more effective ones or including ones that were absent

The design of each integrated late blight management strategy was specific to each individual situation and therefore regionally adapted, recognising that each of the component strategies will be useful in a specific set of circumstances, but not in others. The physical and financial performance of CULBMS and the ‘novel’ strategies was determined and included a cost benefit analysis of the new strategies (i.e. margin over costs EURO/ha).

Some strategies, such as intercropping, variety mixtures, foliar sprays & microbial inocula, volunteer removal, planting configuration, compost extracts, microbial antagonists & plant extracts and alternative sprays are not (yet) applicable in practice, because of limited effectiveness or problems with implementation. Other strategies are applicable in practice and some agronomic practices, benefit yield and tuber quality without affecting late blight infection directly. These include more resistant varieties, chitting, and earlier planting date, optimized fertilization regime, position in rotation and optimized irrigation regime. Of course, advantages would only be realised by growers who do not already use these techniques and many already do so. Defoliation strategy and more sophisticated sprayers can improve blight management, but the investment required for the equipment would be difficult to justify solely on the basis of the level of blight protection achieved.

On all MODEL farms, the currently used management system was improved upon, demonstrating that the approach is promising and has considerable potential. On 16 out of 28 the LINK farms (57 %), the optimized system resulted in a higher margin than the currently used management system. Some of the improvements were caused by a reduction in foliar blight, others by an increase in marketable yield independent of effects on blight and occasionally by a reduction of costs. No single technique or component strategy was effective enough for the management of late blight when applied as a sole treatment but some combining selected ones into an integrated strategy were (but there is no single blueprint that is universally applicable). This represents a sustainable approach to stabilize yields of organic potatoes and to reduce or eliminate the use of copper fungicides in organic potatoes in the longer term. In the short to medium term, where National Legislation and Certification Authorities permit, applying progressively lower doses of copper-based fungicides than those currently permitted is applicable on a wide scale and is a relatively cheap option. Whilst this is not an ideal solution, it may be a useful interim measure until they become redundant or withdrawn from use.

Promoting adoption of this integrated systems approach in practice requires a combination of intensive communication between researchers, extension services and farmers, technical publications and demonstrations now and in the future. By leading to better management of late blight infections caused by *Phytophthora infestans* will help to sustain the production and profitability of organic potato growing in Europe for the benefit of all stakeholders.

Section 2: Field evaluation of novel blight management systems

A) Evaluation of individual component strategy efficacy and design of integrated late blight management strategies for field testing in different situations

Introduction

The objectives of the first phase of field evaluation of novel, integrated late blight management systems (WP 7.1) were:

- to analyse the efficacy of individual component strategies evaluated under WPs 2.1 to 6.2 and discussed in previous chapters which have potential to contribute to an overall, integrated late blight management strategy.
- to quantify & then rank the efficacy of the individual components
- to design regionally adapted blight management systems, which could then be used as a basis for field testing in WP 7.2.

Materials and methods

Quantitative evaluation of the suitability of individual components for inclusion in a late blight management strategy included assessments of: effect on foliar blight, tuber blight and yield; material, labour and machinery costs. Qualitative evaluation assessed aspects such as efforts needed to facilitate introduction into practice and to overcome potential bottlenecks; domain of application, constraints, technical requirements; interactions with other components of an integrated strategy; risks; comments; availability for testing in the field in the MODEL and LINK farms (WP7.2).

Results

Table 1 summarizes the major characteristics of each of the component strategies. This is followed by a brief overview over each component strategy. A fuller account, presented in standardized format, can be found in Chapter 8 Annex 1.

Table 1: Summary of the major characteristics of the component strategies.

Name of strategy	**Is the strategy promising?**	**Notes on the applicability**
A) varieties	Very promising (for some varieties)	Immediately applicable (but new varieties become available continuously)
B) alternating rows	Promise for limited reduction of foliar blight	Ideal combinations not yet developed
C) intercropping	Promise for limited reduction of foliar blight	Not yet fully developed
D) variety mixtures	Promise for limited reduction of foliar blight	limited to special cases at present
E) planting date	Promise for limited yield increase	Potential already exploited to a large degree
F) chitting	Promise for limited yield increase	limited by practical considerations such as labour requirements
G) defoliation	Promise for limited reduction of tuber blight	mainly limited by availability of equipment
H) fertilization	Promise for significant yield or quality increase	immediately applicable
I) rotation	Promise for some yield or quality increase	depends on crop rotation
J) foliar sprays & microbial inocula	No clear, experimental proof of efficacy	- - -
K) volunteer removal	No clear, experimental proof of efficacy	- - -
L) planting configuration	No effect within reasonable densities	- - -
M) irrigation	Promise for significant yield or quality increase	limited by availability of water & equipment
N) compost extracts	No clear, experimental proof of efficacy	- - -
O) microbial antagonists & plant extracts	No clear, experimental proof of efficacy	- - -
P) application equipment	Promise for limited reduction of foliar blight	limited by costs for investment
Q) alternative sprays	No clear, experimental proof of efficacy	- - -
R) low dosage of copper	Promise for similar protection against foliar blight with lower copper use	immediately applicable

Individual component strategies

A) Varieties

Replace existing varieties with a new variety that is more blight tolerant or resistant.

- Change of variety influences numerous aspects of production, storage and processing. Varieties must be evaluated for each purpose of use separately.
- Introduction requires a lengthy process of (1) variety testing for national/ recommended list; (2) convincing adoption by the market and producers; (4) several years' seed multiplication to meet demand
- Depending on the genetics of resistance of the new variety, the risk of breakdown of resistance varies.
- Success of this strategy depends on each individual variety. For all countries involved, promising varieties were available, which if used widely would allow drastic reductions of foliar and/or tuber blight infections.

B) Alternating rows

Two or more varieties are planted in alternating rows or alternating beds of two or four or more rows.

- This strategy will be most effective under low disease pressure. Varieties to be alternated should have different types/level of resistance to late blight.
- The main limitations are of practical nature and depend on the machinery used and the organization of the work. Varieties should be similar with respect to fertilisation needs, harvesting time etc.
- This strategy is not yet fully developed for practical application.

C) Intercropping

Beds or potato 'fields' of different size and/or orientation are separated by barriers composed of other crop species, such as clover or wheat.

- This strategy will work best under low disease pressure.
- The main limitations are of practical nature and depend on the machinery used, the local geography, the organization of work and the crop rotation of the farm.
- This strategy is not yet fully developed for practical application. Combinations with row-crops other than cereals might be interesting (example from China: potato-Maize)

D) Variety mixtures

Two or more varieties are planted at random in an intimate mixture within each row.

- This strategy is a more pronounced version of the strategy of alternating rows and expected to be somewhat more effective.
- Varieties should be similar with respect to fertilisation needs, harvesting time etc.
- The main limitation is at present that trade will not accept mixed variety lots for most purposes. However, the method may be acceptable for some smallholders. Grading machinery using sophisticated image analysis technology can be used to separate different varieties on the basis of colour or shape post-harvest, but at present use of this technology is likely to be very expensive and used mainly for conventional stocks of potato tubers..

E) Planting date

Earlier planting extends the growing period and hence tuber bulking, before the advent of the blight epidemic, and thus possibly leading to a higher yield.

- With early planting, the risk of cold and/or wet weather and frost damage is higher which offset the potential advantages. N-availability may be restricted because of a low rate of mineralisation in early spring restricting the rate of crop growth.
- As most growers have already exploited this strategy, it has relatively little potential for further improvement.

F) Chitting/pre-sprouting seed tubers

Chitting seed tubers in trays, bags or crates has direct effects on foliar blight, but brings tuber bulking forward, possibly leading to a higher yield before the blight epidemic ends the life of the crop (and therefore similar in effect to earlier planting).

- The main limitations are the additional labour involved with chitting, and possible problems with fully automatic planters, which may break off larger sprouts and remove the beneficial effect.
- In some countries, e.g. Switzerland, and in other countries for some growers, chitting is standard practice. In these situations, there is little potential for improvement.

G) Defoliation strategy

Defoliation with a propane gas burner kills blight mycelia and blight-spores (at least partly). The other major defoliation method – flailing - does not and may be less effective at destroying the foliage. However, both methods are more effective than allowing the foliage to be completely defoliated by the disease.

- Selective burning of localized patches of the crop infected with foliar blight may slow down the epidemic. Burning infected fields reduces tuber blight.
- The main limitations are the availability of defoliation equipment and the material costs for the gas. In some areas, environmental concerns (use of fossil energy) are also important.
- A combination of flailing and burning is aseffective as burning alone, but greatly reduces the use of gas because the quantity of foliage to be burnt is much reduced.

H) Optimized fertilization regime

Crops with a poor nutritional status are more susceptible to late blight; otherwise no direct effects on foliar blight. However, optimized fertilization regime has other beneficial effects on yield and tuber quality.

- The main limitations are (1) availability of manure on the farm; (2) environmental legislation; (3) organic standards. The fertilization regime is usually optimized in view of yield rather than blight control.
- The levels of nutrients available to the potato crop also depend on the previous crop and on the weather, which affects mineralization.

I) Position in rotation

The position of potatoes in the crop rotation has effects on yield via nutrient availability and soil structure set by the preceding crop, but no direct effects on blight susceptibility.

- The main limitations are the structure of the crop rotation and the position available for the potato crop. Growing potatoes in a better position in the rotation may result in a less optimal position for another crop, e.g. cereals. Finally, some positions in the crop rotation have higher risks of tuber pests and diseases such as *Rhizoctonia solanii*, drycore, wire worms.
- Many farms have already exploited the potential of this strategy, but the survey described in Chapter 2 (Socio-economic impact & ‘state of the art’ blight management) showed that there is potential to improve the rotational position and design in a considerable number of farms that grow potaoes.

J) Foliar sprays & microbial inocula

Use of foliar sprays or microbial inocula for direct control of late blight.
- Although this approach is effective in some crops, its effectiveness against late blight of potatoes has not been demonstrated under field conditions.

K) Volunteer removal

The occurrence of volunteer plants in the following year, which are a important source of disease inoculum is reduced by grazing pigs on harvested potato fields.
- The main limitations of this strategy are the availability of pigs on the farms, the labour involved erecting and moving sheds, fences and the animals. Further, pigs may severely damage the soil structure under certain conditions on some soil types.
- Because this method reduces the sources of inoculum in the following year, its effects are not evident. Together with the limitations described above, this method will be poorly accepted by most farmers.

L) Planting density and configuration

Planting density and an optimized planting configuration may alter crop structure, and thereby influence microclimate and blight.
- Only very low plant densities reduce blight.
- Planting configuration is usually designed to optimize tuber size, and facilitate mechanisation. Further, planting density influences the amount of seed required, which is a major variable cost of production.
- To be effective on late blight, planting densities and configurations outside 'normal' commercial practice are required. Therefore, this is not a feasible component strategy.

M) Optimized irrigation regime

Optimized irrigation regimes must avoid long periods of leaf wetness (to avoid blight infection), as well as periods of drought (to ensure good yield and tuber quality). Therefore, these regimes vary considerably for wet and dry regions.
- The main limitations are the availability of water and of irrigation equipment. Further, the equipment must be removed before all cultivation measures can proceed, which causes considerable labour requirement.
- Most improvements can be achieved by the use of irrigation on farms which currently do not irrigate. However, not all farms have water available and can afford investments into the irrigation equipment.

N) Compost extracts

Use of compost extracts for direct control of late blight.
- Although this approach has been reported to be effective in some crops, its effectiveness against late blight of potatoes has not been demonstrated under field conditions.
- Even if effectiveness was shown, concerns over hygiene, toxicology and possible effects on non-target organisms need to be addressed.
- This method is not yet developed to the stage of practical applicability. It is not clear which materials of origin and which methods of preparation of the extracts should be used, and how often and at what concentration the extract should be applied. As a consequence, the costs for labour and possibly extraction equipment are not clear at present.

O) Microbial antagonists & plant extracts

Spraying antagonists or plant extracts for direct control of late blight.

- Although such sprays showed efficacies up to 70 % in glasshouse trials, and up to 45 % in semi-field trials, their efficacy was low under field conditions. From the present experiments, it cannot be concluded whether effectiveness under field conditions could be improved by altering the formulation, e.g. increasing UV protection or rainfastness.
- At the moment, there is no effective product available which could be applied in practice.

P) Spray application equipment

Underleaf spraying technology leads to a more equal cover of the canopy with plant protection products. For compounds with contact action in particular, such as copper fungicides, this improves efficacy.

- The main limitation is the high investment for such equipment, particularly if the existing spray equipment does not need replacement.
- Underleaf sprayers treat fewer rows than standard equipment, which increases the labour for treatment. When the canopy is closed, the spraying droplegs may also damage the canopy.
- The spacing of the droplegs has to be adjusted to the row width of the crop. If crops other than potatoes with different row spacing also have to be sprayed, this may necessitate frequent adjustments.
- In a preliminary trial, air assisted sprayers gave similar coverage as underleaf sprayers. They lack the disadvantages described above, but represent an even larger investment.

Q) Alternative sprays

Spraying alternative, commercially available or novel products for direct control of late blight.

- The choice of potential products is tightly restricted by the Regulation on organic farming 2092/91 EEC.
- Within this limit, no products with good efficacy were found. Therefore, this strategy has no practical application at the moment and requires further research and development.

R) Low dosage of copper

Copper fungicides are applied at lower dosages, resulting in a lower total usage of copper. At the same time, the timing of application is optimized by the PhytoPRE or other, similar decision support systems.

- With this strategy, drastic reductions in total copper use were possible with only slight reductions in protection (5 – 35 %). We estimate that ca 2 kg/ha/year of pure copper are sufficient to protect potatoes (i.e. one third of the amount currently allowed by the organic regulation 2092/91 EEC).
- This strategy is widely applicable. It can contribute to a reduction of copper use, but will not result in its elimination.
- The main limitation of this strategy is the fear of farmers that reduced dosages of copper might not be sufficiently effective. This might be overcome by extension activities and demonstration trials, but the farmer’s own experience will be the most important factor.

Discussion

For various reasons, some of the strategies are **not (yet) applicable in practice**. These include intercropping, variety mixtures, foliar sprays & microbial inocula, volunteer removal, planting configuration, compost extracts, microbial antagonists & plant extracts and alternative sprays. These methods are not discussed further here. With alternating rows, even small incidences of carelessness might lead to involuntary mixing of varieties at both planting and harvesting leading to problems of admixture. Because this would severely affect the marketability of the crop, this method is unlikely to be adopted by a majority of organic farmers.

Among those strategies which are **applicable in practice**, several groups can be distinguished. Some strategies, particularly those involving a change in agronomic practices, have major effects on **aspects other than blight**. Such practices will only be adopted, if their overall impact is beneficial. These include varieties, chitting, and planting date, optimized fertilization regime, position in rotation and optimized irrigation regime. However, advantages would only be realised by growers who do not already use these techniques.

Defoliation strategy and application equipment can make a useful contribution to the blight management strategy. Farms that have already adapted this strategy have invested in the necessary equipment, but for some farms, the expenditure required would be difficult to justify on the basis of the level of blight protection achieved.

Spraying lower dosages of copper than the amounts used in current practice could be widely practiced. However, the main limitation of this strategy is the concern of farmers that reduced dosages of copper might not be sufficiently effective. This might be overcome by extension activities and demonstration trials, but the farmer's own experience will be the most important factor.

Some of the more easily applicable strategies are **already widely used in current practice** on certain farms or in certain regions. These include resistant varieties, early planting dates, chitting of seed tubers, defoliation strategy, optimized fertilization regime, position in rotation, optimized irrigation regime and low dosage of copper. In these cases, the strategy is already incorporated as a part of the existing blight management system, and cannot therefore be used for further improvements.

In conclusion, each of the component strategies will be useful under a specific set of circumstances, but not applicable under certain other circumstances. Consequently, different strategies were selected for field-testing in different countries and even on different farms in the same country under WP 7.2 for both MODEL and LINK farms.

B) Field tests of optimised blight management systems

Introduction

The main objective of WP 7.2 was to validate the efficacy of optimised, regionally-adapted blight management systems developed under workpackage 7.1 in field trials.

Materials and Methods

Experimental design

Experiments were carried out in seven countries in 2004: CH, NL, DK, NO, UK, FR, DE. In each country, experiments were carried out on 1 MODEL farm and 4 LINK farms.

MODEL farms

Replicated field trials: To avoid extremely large polyfactorial experimental designs and to allow for large experimental plots, an "additive trial" design was used with treatments comprising combinations of 1, 2, 3, 4 or 5 components strategies (see workpackages 7.1, Section A Chapter 8). Component strategies (CS) were sequentially added to the currently used late blight management system (CULBMS). Treatments were:

1. CULBMS
2. CULBMS plus CS1 (predicted to have the highest impact)
3. CULBMS plus CS1 and CS2 (predicted to have the 2nd highest impact)
4. CULBMS plus CS1, CS2 and CS3 (predicted to have the 3rd highest impact)
5. CULBMS plus CS1, CS2, CS3 and CS4 (predicted to have the 4th highest impact)
6. CULBMS plus all strategies predicted to have an impact on late blight in WP 7.1.

Minimum plot size was 500 m^2; there were 4 replicates per treatment. Where possible, plots were split to include a comparison of copper fungicide/untreated. In Germany, the design was slightly altered (see Table 1).

LINK farms

An optimized system was compared with the currently used late blight management system (CULBMS). The optimized system was adapted to each farm's CULBMS and needs, and was therefore different for each farm. Treatments were:

1. CULBMS
2. CULBMS plus all strategies predicted to have an impact on late blight in WP 7.1.

Minimum plot size was 1000 m^2; there were no replicates, but the experiment was repeated on four farms. LINK farms were widely spread over the countries, and included farms with differing potato management systems.

Data recording

Assessments were made on 4 – 8 sub-plots per plot on the MODEL farms and on 7 sub-plots per plot on the LINK farms. Foliar blight was assessed as disease severity (% of leaf surface diseased). Assessments were made at regular intervals, at least once per week. To assess yield and tuber diseases, the sub-plots were harvested manually. Tubers were then stored at ca 12 °C for ca 2 weeks, to allow full development of tuber blight and other diseases in infected tubers. Tubers were graded into three categories: too small, too large or marketable (i.e. within size limits), then each category was weighed. To determine tuber quality, a sample of 50 tubers of marketable size was taken. Tubers which had a quality defect and tubers which were of marketable quality (i.e. minor or no quality defect) were weighed. From this, the marketable yield (in t/ha) was calculated.

For the economic calculations, the material, machinery and labour costs of all CS were determined. Where possible, statistical data were used; otherwise, costs were estimated. Returns were calculated on the basis of the country-specific prices given in Tamm *et al.* (2004).

Results

MODEL farms

An overview over the results from the MODEL farms is given in Table 1. In Switzerland, the change in variety from Agria to Naturella had the strongest effect, mainly by reducing foliar blight. In the Netherlands, lower planting density had the strongest effect, by reducing seed costs and increasing returns. In Denmark, early planting had the strongest effect, by increasing returns. In Norway, chitting had the strongest effect, by increasing marketable yield. In the United Kingdom, copper had the strongest effect, by reducing foliar blight. In France, yields were unusually low and the results have to be interpreted with care. Here, the change in variety from Charlotte to Eden had the strongest effect, mainly by reducing foliar blight. In Germany, the change in rotational position had the strongest effect, mainly by increasing marketable yield. (More detailed results of the MODEL farm experiments in each country are shown in Chapter 8 Annex 2).

LINK farms

The results from the LINK farms are shown in table 2. In Switzerland, the optimized system reduced foliar blight in all cases. However, the margin improved only on one LINK farm, while decreasing it on three farms, due to lower marketable yields of the optimized system. In the Netherlands, the optimized system led to higher margins on two out of four farms. Substantial differences between treatments occurred at the level of foliar blight, marketable yield, returns and costs. In Denmark, the optimized system improved margin on one farm. The major treatment differences occurred at the level of marketable yield. In Norway, the optimized system improved margin on all four farms, mainly due to better marketable yields. In the United Kingdom, the optimized system improved margin on all four farms, due to a significant reduction in foliar blight and/or better marketable yields. In France, the optimized system improved margin on three out of four farms. Treatments affected mainly foliar blight and/or marketable yield. In Germany, the optimized system did not improve margin, mainly due to the elevated costs of the improved system. (More detailed results of the LINK farm experiments in each country are shown in Chapter 8 Annex 2).

Discussion

There are obvious, large differences between countries and also between farms within a given country with regard to potato crop management and performance in organic cropping systems, the impact of late blight and growers' attitudes to the disease. Such differences have been reported and discussed elsewhere (See Chapter 2 and Tamm *et al.*, 2004). Therefore, this discussion is restricted to differences between treatments.

On all MODEL farms, at least one of the experimental treatments gave better economic results than the currently used management system. This demonstrates that the approach of improving management systems is promising, and that in most cases there is scope for improvements of the current management system.

It is noteworthy that the improvements did not always work via the same mechanism. In Switzerland, France and the United Kingdom, the improvements were caused by a reduction in foliar blight. In Norway and Germany, the improvements were caused by an increase of marketable yield. In Denmark, the improvements were caused by an increase of returns. In the Netherlands, the improvements were caused by a reduction of costs and an increase of returns.

Results from the LINK farms must be interpreted more cautiously. Because treatments were not replicated, limited conclusions can be drawn from a single experiment. On the other hand, the large plot sizes and the wide geographic spread of the farms allow to draw conclusions on practical applicability of the selected strategy. On 16 out of 28 the LINK farms (57 %), the optimized system resulted in a higher margin than the currently used management system. Among these, the improvements can be attributed to reduced foliar blight on 7 farms, to increased marketable yield on 8 farms and to increased returns on 1 farm.

Whether improvements were possible was dependent on several factors:

- The degree of sophistication of the potato management system varies greatly between farms. As a consequence, the potential for improvements also varies greatly.
- The «background noise» from random factors is very high, if farms from different parts of the country are compared. In Switzerland, for example, 2004 was a good year for LINK farm 1, and the optimized system improved margin further. By contrast, LINK farms 2 and 3 experienced difficulties with tuber quality which would require profound changes of the management system. Here, short-term optimization of the management system was not effective. On LINK farm 4, the optimized system included alternation of the varieties Charlotte (part of the CULBMS) with Innovator. Although the two varieties were selected for similar maturation times, the plots had to be defoliated earlier than a pure stand of Innovator would have needed. This reduced returns of the optimized system.
- Several CS tested were still in development and might need to be further improved, or adapted to local conditions.

In conclusion, no single technique or component strategy under test was identified that was effective enough for the management of late blight when applied as a sole treatment. However, a number of component strategies were found which can contribute to a reduction of late blight as part of an integrated management system. By combining a range of different component strategies both additive and synergistic effects may operate (but of course, care must be taken to avoid negative interactions between component strategies that result in more severe infections).We believe that this is the most sustainable approach to stabilize yields of organic potatoes and to reduce or eliminate the use of copper fungicides in organic potatoes in the longer term. In the short to medium term, where National Legislation and Certification Authorities permit, applying progressively lower doses of copper-based fungicides than those currently permitted appears to be a way forward until they become redundant or withdrawn from use.

How to make use of this knowledge

The approach of improving the entire potato management system is demanding, because it requires a detailed analysis of the current system and good knowledge of alternative strategies. We emphasize that this approach deviates fundamentally from the conventional approach to plant protection that places great reliance on a range of synthetic active ingredients, and requires considerably more flexibility from the farmer.

At the community level, this approach requires intensive communication between researchers, extension services and farmers. Publications in farmers' journals and on the internet, presentations at workshops and conferences and all work of extension services may prove useful for this task. Most probably, a combination of these approaches will be most effective.

At the farm level, this approach requires sound and up-to-date knowledge, not only at the local level, but also at regional and national levels. The farmer may acquire this knowledge by himself from the sources of information described above, or with the aid of advisory and consultancy services.

These experiments give proof of concept for the systems management approach. At the practical level, however, the potato management system of each farm has to be optimized individually: there is no single blueprint that is universally applicable. To a certain extent, the results obtained in Workpackage 7.2 described in this chapter may serve as a basis for this optimization. Nevertheless, the fine-tuning requires some experimentation by the farmer, and possibly also some applied research. The process of optimization is a challenge, which will take several years in most cases. Intensive communication between farmers, extension services and researchers will speed up the process and minimize failures in the experimentation phase. Whether or not a given component strategy is useful on a specific farm, and acceptable to the farmer depends on a multitude of aspects, such as the properties of the soil, the climate and the farm, the economic environment and the availability of alternatives. Also, optimization of the management system may lead to conflicts between potatoes and other crops (e.g. position in the rotation). Finally, more specialized potato growers have different options than mixed farmers. This socio-economic background is described in Tamm *et al.* (2004). Because organic potato production operates in a dynamic economic environment, even an optimized system can never be considered as a final state, but rather as a provisional optimum which needs to be reconsidered regularly.

Most of the Research Institutes involved in the Blight MOP project work closely with farmers. Their communication strategies and advice should lead to the translation and implementation of the results into commercial practice. Better management of late blight infections caused by *Phytophthora infestans* will help to sustain the production and profitability of organic potato growing in Europe for the benefit of all stakeholders.

References

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Table 1: Results from MODEL farms. First column: abbreviation for countries. The additive treatments design is explained in Materials and Methods; where there were treatments with and without copper, these are abbreviated by "-" (no copper) and "+" (copper). Only the last treatment added is shown, the others are abbreviated by "…". Where treatments included more than one variety, foliar blight and marketable yield are shown separately for each variety, while returns, costs and margin are averaged. Results for the treatment with highest margin are shown in **bold**; results for treatments including copper fungicides are shown in *italics*.

	treatment		**variety**	**foliar blight (AUDPCst)**	**marketable yield (t/ha)**	**returns (EUR/ha)**	**costs (EUR/ha)**	**margin (=returns-costs) (EUR/ha)**
CH	C0	CULBMS	Agria	13.91	24.8	14861	8144	6717
	C0 + C1	**… + resistant variety**	**Naturella**	**0.00**	**31.2**	**18726**	**8144**	**10582**
	C0... +C2	… + alternating varieties	Agria / Naturella	6.56 / 0.00	26.9 / 29.1	16794	8420	8374
	C0... +C3	… + commercial fertilizer	Agria / Naturella	6.22 / 0.00	28.5 / 30.5	17706	8592	9114
	C0... +C4	… + clay minerals	Agria / Naturella	7.22 / 0.00	26.2 / 29.4	16629	9054	7575
	C0... +C5	… + underleaf application of clay	Agria / Naturella	5.23 / 0.00	29.5 / 27.5	17116	9879	7237
NL	C0	CULBMS	Remarka	5.90	21.7	4948	3999	949
	C0 + C1	… + commercial fertilizer	Remarka	5.55	22.2	4922	4127	795
	C0... +C2	… + compost	Remarka	5.87	24.7	5141	4267	874
	C0... +C3	… + chitting	Remarka	5.34	24.1	5310	4337	973
	C0... +C4	**… + lower plant density**	**Remarka**	**5.19**	**25.5**	**5608**	**4034**	**1574**
	C0... +C5	… + plant strengthener	Remarka	5.12	24.3	5199	4119	1080
DK	C0	CULBMS	Sava	28.49	11.00	1803	2001	-198
	C0 + C1	… + tolerant variety	Ditta	31.79	11.73	1995	2001	-6
	C0... +C2	**… + early planting**	**Ditta**	**35.84**	**12.98**	**2344**	**2001**	**343**
	C0... +C3	… + chitting	Ditta	35.02	16.04	2645	2496	149
	C0... +C4	… + soap	Ditta	31.67	17.47	2840	3460	-620
	C0... +C5	… + early variety	Marabel	29.71	9.49	1827	3460	-1633

Table 1, continued.

	treatment		**variety**	**foliar blight (AUDPCst)**	**marketable yield (t/ha)**	**returns (EUR/ha)**	**costs (EUR/ha)**	**margin (=returns-costs) (EUR/ha)**
NO	C0	CULBMS	Troll	45.61	7.2	4255	6002	-1747
	C0 + C1	… + tolerant variety	Peik	41.79	8.0	4766	5758	-992
	C0... +C2	… + alternating rows	Troll / Peik	47.02 / 41.85	6.2 / 8.5	4301	5894	-1593
	C0... +C3	**… + chitting**	**Troll / Peik**	**49.96 / 44.40**	**9.7 / 13.8**	**6916**	**5964**	**952**
	C0... +C4	… + OASE (plant stengthener)	Troll / Peik	49.30 / 43.74	10.1 / 14.9	7219	6370	849
	C0... +C5	… + variety-mixture	Troll & Peik mixed	47.98	11.6	6936	6370	566
UK	C0	CULBMS	Santé	13.61	16.8	5038	2655	2383
	C0 + C1	… + resistant variety	Lady Balfour	2.80	22.9	6882	2589	4293
	C0... +C2	… + chitting	Lady Balfour	9.23	28.3	8253	2752	5501
	C0... +C3	… + commercial fertilizer	Lady Balfour	5.45	33.3	9723	4112	5611
	C0... +C4	… + plant extract	Lady Balfour	8.17	36.8	10601	4192	6409
	C0... +C5	***… + copper***	***Lady Balfour***	***0.01***	***38.5***	***11113***	***4442***	***6671***
FR	C0-	CULBMS	Charlotte / Eden	65.29 / NA	0.8 / NA	351	5968	-5617
	C0 + C1-	**… + resistant variety**	**Charlotte / Eden**	**NA / 33.66**	**NA / 3.8**	**1455**	**5408**	**-3953**
	C0... +C2-	… + alternating varieties	Charlotte / Eden	64.16 / 29.04	1.3 / 3.5	943	6048	-5105
	C0... +C3-	… + chitting	Charlotte / Eden	66.49 / 31.27	1.5 / 3.3	959	6663	-5704
	C0... +C4-	… + early planting	Charlotte / Eden	72.03 / 0.83	1.8 / 2.3	837	6663	-5826
	C0... +C5-	… + clay minerals	Charlotte / Eden	69.74 / 21.70	1.5 / 2.4	797	6870	-6073
	C0+	*CULBMS + copper*	*Charlotte / Eden*	*57.67 / NA*	*2.0 / NA*	*914*	*6163*	*-5249*

Table 1, continued.

	treatment		**variety**	**foliar blight (AUDPCst)**	**marketable yield (t/ha)**	**returns (EUR/ha)**	**costs (EUR/ha)**	**margin (=returns-costs) (EUR/ha)**
DE	C0	CULBMS	Nicola	35.43	13.1	4574	3535	1039
	C0 + C1	… + chitting	Nicola	39.80	12.5	4573	4084	489
	C0... +C2	… + clay minerals	Nicola	42.18	11.6	4540	4315	225
	C0A	**CULBMS + better rotation**	Nicola	**49.97**	**18.7**	**6459**	**3535**	**2924**
	C0 + C1A	… + chitting	Nicola	55.83	18.4	6567	4084	2483
	C0... +C2A	… + clay minerals	Nicola	54.22	17.0	6670	4315	2355
	C0AB	CULBMS + better rotation + wheat intercrop	Nicola	44.23	18.1	6442	3677	2765
	C0 + C1AB	… + chitting	Nicola	47.51	17.0	6368	4226	2142
	C0... +C2AB	… + clay minerals	Nicola	49.34	17.6	6119	4501	1618

Table 2: Results from LINK farms. C0 = currently used management system; C plus = optimized system For all other explanations see table 1.

Farm		treatment		variety	foliar blight (AUDPCst)	marketable yield (t/ha)	returns (EUR/ha)	costs (EUR/ha)	margin (=returns-costs) (EUR/ha)
CH	1, Muri	C0	CULBMS	Agria	0.30	28.8	17280	8274	9006
		C plus	Alt. Varieties + *B.subtilis* + clay	Agria / Naturella	0.13 / 0.00	39.2 / 37.9	23100	7590	15510
	2, Tann	C0	CULBMS	Désirée	1.63 / NA	11.3	6780	8144	-1364
		C plus	Alt. Varieties + *B.subtilis*	Désirée / Appell	0.54 / 0.00	7.2 / 12.0	5760	8440	-2680
	3, Hindelbank	C0	CULBMS	Charlotte	3.45	28.5	17100	8210	8890
		C plus	resistant variety	Naturella / Appell	0.08 / 0.00	10.9 / 37.3	14460	8210	6250
	4, Cossonay	C0	CULBMS	Charlotte	0.00	43.7	26220	8210	18010
		C plus	Alt. Varieties + *B.subtilis*	Charl. / Innovator	0.00 / 0.00	34.6 / 39.2	22140	8440	13700
NL	1, Zeeuw	C0	CULBMS	Agria	30.81	20.5	6787	3782	3005
		C plus	extra fertilization	Agria	25.51	24.9	7930	3794	4136
	2, Nordermeer	C0	CULBMS	Agria	0.59	24.8	7425	4145	3280
		C plus	flower strip	Agria	0.27	23.9	5382	3527	1855
	3, Twisk	C0	CULBMS	Ditta	1.10	19.5	5846	4162	1684
		C plus	fertilization (Vinasse)	Santé	1.58	32.7	9800	4288	5512
	4, Hootegem	C0	CULBMS	Nicola	4.49	17.9	5366	3762	1604
		C plus	compost fertilization	Nicola	0.06	8.6	2589	3858	-1269
DK	1, Tinglev	C0	CULBMS	Sava	43.64	10.1	5280	1897	3383
		C plus	chitting + soap	Ditta	42.93	12.3	6016	3162	2854
	2, Hoven	C0	CULBMS	Ditta	28.60	22.1	3160	1862	1298
		C plus	chitting + soap	Ditta	34.63	28.7	4507	3162	1345
	3, Svanholm	C0	CULBMS	Ditta	15.57	15.9	2548	1771	777
		C plus	chitting + soap	Ditta	25.40	20.7	3422	2934	488
	4, Svendborg	C0	CULBMS	Ditta	25.46	39.9	6191	2314	3877
		C plus	chitting + soap	Ditta	26.93	32.5	5045	3071	1974

Table 2, continued.

	Farm	treatment		variety	foliar blight (AUDPCst)	marketable yield (t/ha)	returns (EUR/ha)	costs (EUR/ha)	margin (=returns-costs) (EUR/ha)
NO	1, Ottestad	C0	CULBMS	Troll	12.91	15.7	11788	5556	6232
		C plus	chitting + blight-free seed	Troll	12.79	15.6	14093	5958	8135
	2, Stange	C0	CULBMS	Pimpernel	3.26	11.8	7434	4348	3086
		C plus	other variety + EM (effective microbes)	Beate	6.05	14.3	9600	4720	4880
	3, Sande	C0	CULBMS	Sava	46.62	27.8	18171	5592	12579
		C plus	OASE (plant strengthener)	Sava	45.92	32.3	21402	5685	15717
	4, Vanse	C0	CULBMS	Grom / Oleva	29.36 / 13.07	10.4 / 10.8	10671	5583	5088
		C plus	variety mixture	Grom / Oleva	24.70 / 19.49	14.7 / 17.0	12500	5590	6910
UK	1, Nafferton	C0	CULBMS	Santé	12.17	19.8	5860	2655	3205
		C plus	resistant var.+chitting+ fertilization	Lady Balfour	7.81	36.4	10457	4192	6265
	2, Hartford	C0	CULBMS	Santé	19.85	17.8	5596	2655	2941
		C plus	resistant var.+chitting+ fertilization	Lady Balfour	9.21	44.2	13034	4192	8842
	3, Gilchester	C0	CULBMS	Santé	17.53	12.1	3585	2655	930
		C plus	resistant var.+chitting+ fertilization	Lady Balfour	20.79	17.1	5278	4192	1086
	4, Aberdeen	C0	CULBMS	Santé	0.47	26.6	9452	2655	6797
		C plus	resistant var.+chitting+ fertilization	Lady Balfour	0.24	46.8	14171	4192	9979
FR	1, Taulé	C0	CULBMS	Charlotte / Eden	35.12 / NA	9.3 / NA	4185	5037	-852
		C plus	alternating varieties	Charlotte / Eden	50.18 / 4.93	5.6 / 17.8	4650	4810	-160
	2, Lanvallec	C0	CULBMS	Charlotte / Eden	64.49 / NA	14.8 / NA	6462	5720	742
		C plus	alternating varieties + clay min.	Charlotte / Eden	58.91 / 0.38	12.8 / 19.9	7235	5632	1603
	3, Fredon	C0	CULBMS	Ditta / Eden / Raja	35.8 / NA / NA	7.7 / NA / NA	1668	3285	-1617
		C plus	alternating varieties + clay min.	Ditta / Eden / Raja	11.2 / 0.0 / 0.0	8.4 / 9.6 / 6.3	2183	3698	-1515

Table 2, continued.

	Farm	**treatment**		**variety**	**foliar blight (AUDPCst)**	**marketable yield (t/ha)**	**returns (EUR/ha)**	**costs (EUR/ha)**	**margin (=returns-costs) (EUR/ha)**
	4, SICA	C0	CULBMS	Béa / Charlotte / Eden	7.8 / NA / NA	0.2 / NA / NA	231	7392	-7161
		C plus	3 alternating varieties	Béa / Charlotte / Eden	2.7 / 3.9 / 0.4	0.1 / 0.9 / 1.5	1211	8145	-6934
DE	1, Ebergötzen	C0	CULBMS	Marabel	47.07	14.3	5546	3714	1832
		C plus	Intercr. + clay minerals	Marabel	46.46	14.4	5534	4073	1461
	2, Eichenberg	C0	CULBMS	Nicola	63.65	20.7	6356	3459	2897
		C plus	Intercr. + clay minerals	Nicola	60.65	19.6	5667	3854	1813
	3, Etzenh.	C0	CULBMS	Nicola	49.42	12.8	5546	3647	1899
		C plus	Intercr. + clay minerals	Nicola	51.20	17.7	5534	3974	1560
	4, Frankenh.	C0	CULBMS	Agria	44.95	13.5	6190	3371	2819
		C plus	Intercr. + clay minerals	Agria	35.35	10.2	4648	3985	663