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Important Threats in Potato Production and Integrated Pathogen/Pest Management

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Abstract Since the 1970s climate in Europe warmed rapidly. Over the next years climate is expected to become gradually milder and more humid in northern Europe and hotter and drier in southern Europe. These changes are forecasted to be responsible for major changes in the distribution of plant and animal species, pathogen/pest prevalence and their biodiversity. On the other hand, some changes in variability and epidemiology of pathogens are affected by biological factors. In the first part of this paper an overview is given of pathogens and pests that are potentially affected by climate change and are or will become a significant threat in potato production. The second part of the paper deals with integrated crop protection of potato against various pathogens and pests, considered the best solution for these disease and pest problems. Management of persistent and recurrent diseases and pests of potato requires the integration of many control measures to achieve an efficient crop protection. The protection of potato has to start very early before planting.

Keywords Climate change · Integrated crop protection · Pathogens · Pests · Potato · *Solanum tuberosum*

Introduction

Climate changes on the earth have been observed over the last 100 years and are reflected in an increase in temperature caused by changes in chemical content in the atmosphere, called the greenhouse effect. Increasing atmospheric concentrations of greenhouse gasses (mainly carbon dioxide by 30%, methane by 145% and nitrous oxide by 15%) are the main reasons for climate changes (IPCC 2001). It is assumed that if that trend continues, the amount of carbon dioxide will double by the end of the 21st century and it will cause an increase in the mean temperatures near the earth

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surface in a range of 4–5 °C by 2050 in the region of the Mediterranean Sea and of only 0.8–1.0 °C in the tundra (Bach 1988). Positive and negative consequences will vary and depend on the region. Warmer climate might intensify evaporation thus we could expect higher mean rainfall caused by both a higher frequency and a higher intensity of rainfall events. However, some areas will become drier. Rainfall will increase by 5–10% in the northern hemisphere between 35° and 55° latitude in winter while in the summer of southern Europe and the central states in the USA precipitation and soil moisture will decrease (Lipa 1997).

There are numerous papers discussing the effects of climate changes on agriculture. Several aspects are taken into consideration, such as evaluation of potential yield, changes in water supplies, and more severe occurrence of pests and diseases (Górski et al. 1997; Demidowicz et al. 1999; Górski 2002).

The objectives of this paper are (i) to present the impact of climate change on crucial pathogens and pests being a significant threat in potato production and causing significant economic losses; (ii) describe options for integrated crop protection of potato against various pathogens and pests as the best solution to control disease and pest problems.

Changes in Potato Production

Changes in potato production area and increasing production concentration have been observed in Europe since the early 1990s (Table 1). In southern Europe, in Spain the area declined from 250,000 ha in the 1990s to 88,000 ha in 2007. A significant decrease in potato area has also been recorded in central and eastern European countries and this might be due to poor competition with northern and western European countries and smaller production for animal fodder.

The decline in the production area in Belgium, France, the Netherlands and Germany, countries considered as the most important in potato production in northern and western Europe, was insignificant and compensated for by higher tuber yields per ha.

Table 1 Potato production in recent years

Region	1992[a]	2003	2004	2005	2006	2007
Area in million ha						
World	18.1	19.0	19.0	18.7		
Europe	4.3	8.2	8.0	7.8		
EU 25	–	2.2	2.2	2.0	1.9	2.0
EU 15	1.6	1.2	1.2	1.2	1.2	1.2
Poland	1.8	0.8	0.7	0.6	0.6	0.6
Mean yield in Mg ha^{-1}						
World	14.9	16.6	17.6	17.0		
Europe	19.6	16.0	17.8	17.2		
EU 25	–	26.5	30.3	29.4	27.0	29.5
EU 15	30.6	34.2	39.1	37.4	35.1	37.8
Poland	13.3	17.9	19.6	16.6	15.0	19.7

Sources: FAO, EUROSTAT, GUS

[a] Europe without Soviet Union

Pathogens and Pests Potentially Affected by Climate Change

Plant pathogens and pests significantly affect the yields and play an essential role in agricultural production. Each arable crop has its own particular "enemies", which occur more frequently than others; only when efficiently controlled, the conditions for high and healthy yield are optimal. Climate changes have an impact on life cycles of the pathogens and insects regarding duration of their developmental stages. Pathogen variability, for instance, is often affected by biotic and abiotic factors. Higher temperatures may affect pest distribution and migration and may cause the appearance of new thermophilic species. It is important to remember that all these factors affect the whole system formed by host plant and pathogen/insect and they might change:

- the physiology of pathogens/insects and host plant;
- the host plant resistance to infection/infestation;
- the critical temperature and related to it an infection threshold, and forecasting of pathogen occurrences, resulting in changes in efficacy of plant protection and yield ranges.

Some of these consequences have already been observed on potato fields and they mainly concern changes in development and incidence of major potato pathogens.

Late Blight

The first pathogen to be taken into consideration is *Phytophthora infestans,* the causal agent of late blight. Late blight is a very common disease that causes losses of up to 70% in uncontrolled fields (Hoffman and Schmutterer 1983), and at early infections 100% loss of tuber yields (Fry 1994). An increase in infection potential of *P. infestans* caused by genetic changes in pathogen population and higher infection pressure was observed all over the world over the last two to three decades (Spielman et al. 1991; Fry et al. 1993; Andrivon 1994; Drenth 1994; Duvauchell and Lherbier 1996; Sujkowski et al. 1996; Turkensteen et al. 1996; Hermansen et al. 2000). The occurrence of new populations of *P. infestans* becomes evident during the development of late blight. These changes result in earlier outbreak of late blight and higher disease rate despite conditions not always favouring infection occurrence (Table 2). The potato crops become more vulnerable to late blight infections and it becomes more problematic to control the disease.

Table 2 Dates of the first recorded outbreaks of late blight in potato crops in Europe (data from 17 European countries, years 1998–2006)

The earliest infections	Years								
	1998	1999	2000	2001	2002	2003	2004	2005	2006
In season	20.04	Early 04	30.04	Early 04	10.04	21.04	06.05	04.04	18.05
In potato field	10.05	08.05	11.05	14.05	02.05	06.05	13.05	04.04	24.05

Source: www.euroblight.net, Schepers 2004, Schepers and Spits 2006, Hansen et al. 2007

Besides changes due to the genetic diversity of the pathogen there are other factors affected by meteorological factors. Currently the role of primary sources of pathogen inoculum has become an issue. There may be sources of inoculum such as discarded potatoes from the previous season and self-sown tubers (warmer winters support an overwintering). The occurrence of late blight at early stages of development of the plants (BBCH<39) indicates the importance of additional sources of inoculum in the soil, such as infected tubers. Early severe infections might also be caused by oospores that can survive in the soil under low temperatures for more than 7–12 months (Hermansen and Amundsen 1996; Andersson et al. 1998; Flier and Turkensteen 1999; Medina and Platt 1999).

Generally speaking, basic elements affecting the occurrence of infection on the fields and changing infection pressure of *P. infestans* are influenced by meteorological factors during the growing season. High humidity necessary for pathogen development needs to be synchronised with certain temperature and pathogen/host plant features as well. It is very apparent that first infections of late blight are usually found on potato stems (stem blight). The stem blight is a result of stem infections with *P. infestans*, it is not a secondary infection from leaf infection. The infection of leaves is then considered as the next step in disease development. Stem lesions appear as oily, brown areas that later turn black. They may extend along and around the stem. If lesions surround the entire stem a plant can break at that point (Kapsa 2001). Sporulation (white, dense mass of sporangiophores) is common on stems on the entire lesion under conditions of high relative humidity.

Up to now the data from trials conducted in Poland at the Plant Breeding and Acclimatization Institute at Bonin have shown that there are several threats to potato crops associated with late blight infection which started on stems. The stem blight can occur on the plants earlier than foliage blight, it develops much faster on some cultivars even under less conducive weather conditions, and can cause mass tuber decay at time of harvesting. The survey conducted in Poland in the years 1997–2007 revealed that stem blight as primary infection was on average recorded on 56.6% of the evaluated fields (Fig. 1).

Stem blight might play an important role during the growing season as a constant source of inoculum. Authors (Clayson and Robertson 1956; Rowe 1996; Bain et al. 1996) working mostly on stem blight point at the importance of stem lesions as a source of inoculum for the infection of progeny tubers. If weather conditions turn dry and hot, leaf lesions expansion stops, and the pathogen does not develop. Lesions on potato stems stay active during the growing season and once favourable conditions appear the disease again develops.

Stem blight increases the amount of zoospores in the environment. At higher humidity *P. infestans* sporulates on leaves around necroses induced by the pathogen. Abundant sporulation is observed on the entire area of the affected stem (Kapsa 2001).

Early Blight

Recent years also showed an increase in the importance of a fungal disease called early blight. Early blight that is caused by two species of the genus *Alternaria*, occurs worldwide on potato crops, particularly in regions with high temperature and alternating periods of dry weather and high humidity. According to Fry (1994), maximum documented yield reductions are usually 20–30%. In Polish climatic

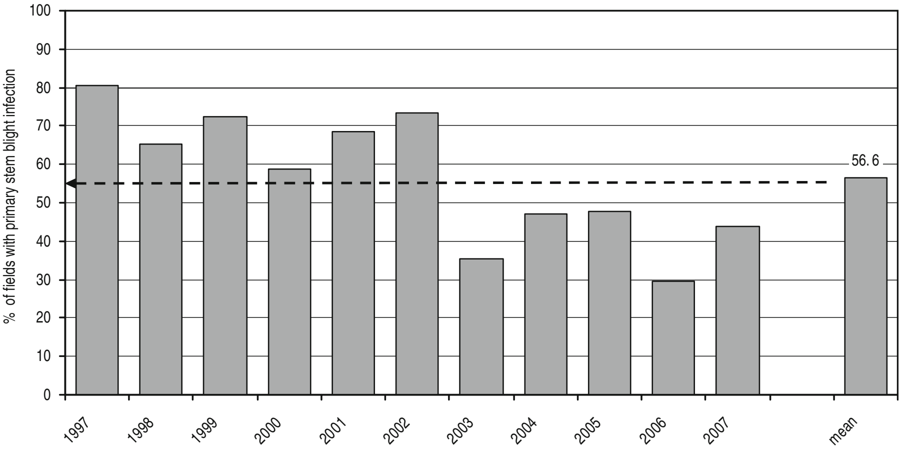
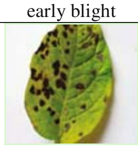


Fig. 1 Incidence of stem blight on potato crops in Poland

conditions high regional losses of up to 45% were recorded, caused by early blight. However, most of these high losses were associated with cultivars with recognized susceptibility to this disease (Kapsa and Osowski 2004). In midwestern regions of the USA early blight is considered of more economic importance than late blight (Gudmestad and Pasche 2007). The research conducted in Poland and eastern and southern Germany in the years 2002–2006 revealed a more frequent occurrence of *A. alternata* (Hausladen et al. 2004; Hausladen and Leiminger 2007; Kapsa and Osowski 2007). In other countries, such as USA and the Netherlands, *A. solani* is dominating (Johnson et al. 1986; Shtienberg et al. 1996; Bouwman and Rijkers 2004; Wiik 2004). The relative impact of both species varies and depends on the climate conditions (Hausladen and Leiminger 2007). Both *Alternaria* species differ also in some morphological features such as mycelium colour and mycelium growth rate on the media, spore structures and temperature requirements (Table 3).

Table 3 Characteristics of two *Alternaria* species, the causal agents of potato early blight

Fungal species /synonyms	Host plants	Disease symptoms	Optimum temperature °C[a]	Spore morphology[b]
Alternaria solani *Macrosporium solani* *A. porri* f.sp. *solani* *A. dauci* f.sp. *solani*	plants from *Solanaceae* except *Datura*	 early blight	Sporulation - temp. 26-28 °C Mycelium growth & spore germination 18-22 °C	
Alternaria alternata *A. tenuis* *Torula alternata*	about 40 plant species	 brown leaf spot	Sporulation - temp. 25-26 °C Mycelium growth & spore germination – 22-26 °C	

[a] Dorozkin and Bel'skaja 1979

[b] Hooker 1990

Spores of *A. solani* are usually borne singly and spores of *A. alternata* are formed in chains. In the course of disease development the morphological symptoms are difficult to distinguish; therefore they are evaluated jointly as early blight.

According to Gudmestad and Pasche (2007) factors that are conducive to disease occurrence are alternating wet/dry periods, which favour spore formation and disease development provided by dew and/or irrigation and irrigated potato soils, light-textured, sandy, low in organic matter. The causal agents of early blight are typical examples of necrotrophic organisms, i.e. a pathogen infecting weaker and older plants (Rotem 1966). Potato plants infected with some viruses are more susceptible to early blight infection (Hooker 1990).

Black Dot

High air temperatures and alternating dry and high humidity periods are conducive to the occurrence of infection with *Colletotrichum coccodes*, the causal agent of black dot appearing on potato plants and other plants in the potato family—tomatoes, eggplants, and peppers. The pathogen often invades plants that are weakened by other diseases, and the infection may induce earlier death of the haulm already infected with *Verticillium, Pectobacterium* and even *P. infestans*. Black dot occurs most frequently on plants grown in coarse-textured soils under conditions of low or excessively high nitrogen fertilization, high temperature, or poor soil drainage.

Bacterial Diseases

The increase in the global air temperature has created conditions favouring development of pathogens recorded previously only in the regions of the Mediterranean Sea and northern Africa. The recent records have shown that *Pectobacterium (Erwinia) chrysanthemi*, the bacterium causing soft rot under the conditions of high temperatures, is identified more frequently than others already known as causal agents of black leg and bacterial soft rot, i.e., *Pectobacterium carotovorum* var. *carotovorum* and *Pectobacterium atrosepticum,* respectively. *P. chrysanthemi* is responsible for increasing incidence of black leg in central and northern Europe. In 2005, when temperatures were high during the growing season, *P. chrysanthemi* was responsible for 50–100% of black leg cases in France and the Netherlands. Also in 2006, the relative incidence of potato diseases caused by *P. chrysanthemi* was high (Tsror et al. 2007; van der Wolf et al. 2007). The first symptoms are wilting of the upper leaves and this moves towards the lower parts of a plant. Usually discolouration of the vascular system at the stem base is observed. Discolouration becomes darker when the disease progresses. At high infection severity the whole plant can dry out. The symptoms on above-ground parts of plants are often associated with wet rot of mother potato tubers and occasionally daughter tubers.

P. chrysanthemi has been renamed recently and various strains are now distributed among six different *Dickeya* species. According to van der Wolf et al. (2007) various species of *Dickeya* have been identified on potato crops in Europe such as *D. dianthicola*, *D. dadantii* and *D. zeae. D. dianthicola* might be causing black leg but there are other species, known as “warm climate *Dickeya* species”, that appear more frequently under conditions of higher temperatures. *D. dianthicola* is able to survive in soil or various surfaces only for a short time. However, some data showed that *D. dianthicola* was found frequently in river water. It might be concluded that water is a good environment for longer survival of that species (Laurila et al. 2007). Nevertheless, if river water is used to irrigate potato fields it could pose a high risk of spreading out bacterial strains of high virulence within potato plants.

New Pathogens

In recent years the records revealed an occurrence of new pathogens previously hardly ever observed in northern and eastern Europe. The most common are *Ralstonia solanacearum*, which causes brown rot of potato and *Verticillium dahliae* and *Fusarium solani* f. sp. *eumartii* pathogens inducing wilting of potato plants.

The fungus *Verticillium* can survive in soil for a long time. Cold weather conditions are conducive to infection but high temperatures favour development of symptoms. *Verticillium* colonizes the vascular system and interferes with water transport in the stems, so injury is most severe during periods of hot weather when plants are stressed for water. The symptoms of *Fusarium* wilt are similar to those caused by *Verticillium* and they intensify in severity at high temperatures and insufficient water level. Laboratory analysis of infected plant tissue is usually necessary to determine the causal agent. In most areas *Verticillium* wilt is more common than *Fusarium* wilt.

Viral Diseases

Viruses are a group of organisms that are very important for potato production, particularly seed production. Virus diseases reduce plant vigour and yield potential of seed tubers. The most important virus diseases are those caused by leafroll virus and potato virus Y, especially Y^N. Viruses are transmitted by seed potato. In the field they are usually transmitted by aphids (PLRV, PYV), sometimes by contact (PXV and PSV) or by nematodes (tobacco rattle virus).

Insects

Reduced tillage system generates new problems, for instance accumulation of harmful pest species of economic importance. Global warming favours also the development of insects on potato fields. High temperatures and periods of dry weather occurring during the growing season accelerate their development and cause overlapping of the particular stages of the insects. This has been observed among soil insects such as larvae of wireworms from the family *Elateridae* that gnaw on underground parts of the plants and can cause severe damage. If the injuries appear at once on the root system and tubers the entire field might be destroyed already in spring. Larvae tunnel through the tubers, leaving small, round holes on the surface and narrow tunnels running into the tuber flesh making a large part of the crop unmarketable.

Another group of soil pest dangerous for potato are larvae of *Nuctuidae*. Cutworms tunnel also through the tubers, filling tunnels with excrement and webbing on which disease organisms (fungi) grow. Such potatoes are unsightly and of little food value. Soil pests are usually found attacking crops planted in soil that has not been planted for several years or planted in poorly drained lowlands.

Faster development of the Colorado potato beetle (CPB) has also been observed. Larvae are the most damaging stage but adults also feed on the foliage. Due to larva feeding, leaflets have holes of varying sizes usually starting around the margins. The leaf blades are eaten often leaving a skeleton of veins and petioles behind. This results in defoliation. In numerous countries because of the weather changes CPB undergo complete metamorphosis twice each year and adult beetles of the third generation overwinter deep in the ground.

Pathogen/Pest Management Strategy

Plant protection as an integrated part of plant production will also be influenced by climate changes. Plant protection aimed at prevention of pest occurrence and suppression of disease development faces various problems, connected with effect of climate changes, such as pathogen variability, pest distribution and migration.

Potato is planted, harvested, stored and consumed mainly in the vegetative form—the tuber. In this respect the potato crop is different from most major arable crops and brings up unusual crop protection problems. What are the basic principles of potato protection against all pathogens? There are three aspects that should be taken into consideration:

- Correct number of plants in a row (avoiding losing plants due to bacterial soft rot and silver scurf and protection of sprouting tubers and young plants against *Rhizoctonia*)
- Maintenance of full assimilation leaf surface allowing the plants to produce the best tuber yield (protection of above-ground plant parts against diseases and pests)
- Protection of tubers during the growing season against the insects and during storing (skin and rot diseases).

Management of persistent and recurrent diseases of potato requires the integration of many control measures to achieve an efficient crop protection. The protection of potato starts very early before planting.

Decisions Before Planting

Decisions about potato cultivation regarding development of diseases have to take into account the selection of suitable field first.

Crop Rotation It is necessary to avoid planting potatoes in the same field year after year. Proper crop rotations enhance soil fertility, help maintain soil structure, increase soil organic matter, conserve soil moisture, and reduce certain pathogen/pest problems (*Rhizoctonia* stem canker, powdery scab, potato cyst nematode, weeds;

wire worm may occur in old grassland or weedy cereal land). Rotations of potatoes for three or more years may be beneficial on some infested sites. Use of non-composted manure from animals that have fed on tubers infested with pathogens should be avoided as well.

Soil Type of soil can induce development of some diseases. It has already been proven that heavy and not well drained soils favour tuber infections with late blight and black leg, thus it is highly recommended to avoid planting more susceptible varieties on this type of soil. On the other hand, light and sandy soils create conditions that are conducive to the development of common scab or early blight.

Fertilization To improve both plant conditions and crop quality it is necessary to apply accurate fertilization. The correct doses enhance plant growth and increase plant resistance to pathogens. Potassium fertilization plays an important role in control of *Rhizoctonia* by inducing better resistance in potato plants against the pathogens. At higher nitrogen doses plants develop more delicate tissues and consequently they become more susceptible to the pathogens. In addition to that, nitrogen fertilization prolongs the growing season so the plants are longer exposed to pathogen infections. Higher nitrogen doses also favour development of late blight and tuber infections not only with the late blight but also with black scurf as well. The pH of soil affects the growth of plants too. Increases in rate of $CaCO_3$ result in higher tuber infection with late blight. High pH may affect the incidence of common scab or the occurrence of manganese deficiency as well.

Weed Control Well supervised potato cultivation including control of the weeds is essential not only to keep potato crops clean but also to reduce the number of unwanted plants growing on a field that become potential competition for crop plants. Higher density of plants changes humidity within a row and creates conditions favouring development of *Rhizoctonia* and late blight. The weeds play also a role in inter-crop survival of pathogens or pest vectors (aphids transmitting potato viruses).

Choice of Cultivar Cultivars with high genetic resistance are the “cheapest” form of protection in control of pathogens occurring in the field. The features taken into consideration are resistance/susceptibility to diseases (early and late blight, common scab, virus diseases and powdery scab, storage diseases), nematodes, abiotic and meteorological factors (external damage and internal bruising, drought) and herbicide tolerance. There are no elements associated with plant resistance to *Rhizoctonia solani* species. In some cases the genetic resistance is an essential element when evaluating cultivar usefulness for cultivation under the conditions of high risk of disease occurrences and rapid disease development. Chemical products are applied less frequently on the fields with cultivars of high genetic resistance (late blight, early blight), when pathogen appearance is rarer, and nematode density is lower. The producers are confronted with a choice between planting more resistant cultivars to avoid early epidemics of diseases and the demands of the market (commercial or consumption). The latter becomes more crucial as providing material easy to sell is a good guarantee of high incomes.

Control Activities During Planting

Seed Health Most pathogens causing potato diseases of economic importance are transmitted to the next growing season by tubers (bacterial ring rot, black leg, common scab, late blight, potato viruses, powdery scab, *Rhizoctonia*, root knot nematodes, silver scurf, and wilt diseases). Stem cutting and micropropagation techniques have been developed to obtain pest-free potato plants for propagation and production of certified seed tubers. Certified seed tubers are not guaranteed to be disease free. The allowable level of symptom expression for each pest or disorder is a tolerance level, and these levels vary in different countries. A zero tolerance exists for quarantine pests, such as bacterial ring rot and root knot nematode.

Earlier Sprouting of Potato Plants on the Fields Reduced tuber yields collected from fewer plants/stems might result from sprout pruning caused by rhizoctonia. *Rhizoctonia* stem canker can be reduced by practices that favour rapid emergence, such as pre-sprouting of seed tubers before planting, planting tubers at a relatively shallow depth, and avoiding early planting dates when soil temperatures are low and to cut down the period of tubers developing underground to the minimum. Sprouts growing faster underground are less exposed to the pathogen infection.

All cultivation processes resulting in faster growth of potatoes are part of the plant protection programmes of potatoes against late and early blight. More rapidly growing plants produce more tubers before an occurrence of diseases destroying in most cases assimilation area of plants. Planting of already sprouting tubers is one way to do that. Another cultivation technique is to apply foliage fertilizers that accelerate plant growth.

Seed and/or Soil Treatments Potato tuber treatments or treatments of the field with soil incorporated pesticides prior to or at the time of planting are fundamental principles in integrated pest management. Tuber treatments help to control an occurrence of *Rhizoctonia* stem canker. Treatments applied in spring provide better conditions for uniform growth of plants during sprouting and result in better tuber yield. Some tuber treatments control appearance of silver scurf and common scab as well. Some insecticide tuber treatments protect potato plants from infestation with aphids, Colorado potato beetle and wireworms.

Control of Diseases and Pests During Growing Season

Elimination of Sources of Pathogens and Pests

Potato Dump Hygiene Uncontrolled outgraded piles on farms are the biggest source of late blight inoculum for potato crops. Sprouting and infected tubers left after spring sorting near potato fields are also an important source of bacterial diseases. Zero tolerance to any green growth on the pile should be practiced. Unwanted tuber piles should be destroyed by covering with soil or plastic (before growth starts), or application of fast-acting herbicides.

Control of Volunteer Potatoes Observations from recent years with winters with higher temperatures than before showed that potato tubers left in fall on the fields survive more often and become the sources of inoculum of *P. infestans* causing early infections. Moreover, these tubers develop into self-sown plants that are uncontrolled and get infected with all types of pathogens and insects. Potato tubers left in the ground are a source of inoculum not only of *P. infestans* but also of several other pathogens such as black scurf, black dot, powdery scab and are hosts for aphids.

Negative Selection Removing of plants infected with black leg and *Rhizoctonia* stem canker during the growing season. Eradicating infected plants is important for field sanitation and conditions of other plants. Sick potato plants should be taken out from the field to avoid accumulation of pathogen inoculum.

Protection of Earlier Maturity Crops Crops of early cultivars are an additional source of inoculum of late blight for late plantings and thus they should be very carefully protected by several applications until tuber harvesting. The control programme should prevent mass occurrence and spreading out of spores of *P. infestans* or *Alternaria* spp. into adjacent fields.

Irrigation

Availability of soil water is a major factor that determines yield and quality of the potato crop. Too little water reduces yields, induces tuber malformations, or increases severity of common scab or *Verticillium* wilt after infection has occurred. Maintaining high soil moisture (80–90% of available water storage) during tuber initiation and the 6 to 8 weeks that follow, reduces the severity of common scab and usually controls the disease adequately. Over irrigation may reduce yields and quality, and can cause several disease problems in the field (powdery scab, black leg), in storage (soft rot), or leach nutrients from the root zone. Fluctuations in water availability favour disorders such as second growth and internal necrosis.

Chemical Control of Pests and Diseases

Chemical control is very essential when the potato crops have a full canopy cover. Its role is to maintain plants at high production level by protection of haulm from destruction. The growing season is essential for potato production as then the tubers are formed and each factor affecting the assimilation area affects tuber development. For instance pathogens caused diseases such as late and early blight, black leg, and larvae of Colorado potato beetle can reduce tuber formation and, as a result, the final yield. In most European countries with high potato production a very intensive chemical protection of potato crops against potato late blight is conducted (Table 4).

Application of appropriate fungicides controls *Alternaria* spp., the causal agents of early blight. Preventive fungicide applications are recommended to provide acceptable control of late blight and early blight as well. Effectiveness of these treatments is dependent upon several factors such as cultivar resistance, disease

Table 4 The estimated use of fungicides for *Phytophthora infestans* control on potato in a few European countries (years: 1997–2006)

Country	Year									
	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
Belgium	14–15	12–14	11–15	13–16	11–13	12–16	11	15	16	12–16
Denmark	5.5	8	7.5	7–8	8–9	8–9	7	7–8	7–8	5–16
Finland			2–6	5–9	4–8	4–8	3–7	5–9	4–8	1–5
France	10–14	?	15	16–17	10–19	12–13	10–14	?	8–13	8–16
Germany	7–9	3–10	4–5	2–14	2–16	3–14	3–11	2–10	1–10	4–12
Latvia			?	2	4	2	1–2	5–6	4–5	2–5
Netherlands	7–15	7–15	7–16	15–20	10–18	8–16	12–13	10–15	8–14	6–20
Norway			5–6	6–7	5.5	6–8	6–7	4–8	3–8	2–8
Poland	1.7	1.7	2	2	1–8	1–5	1–6	1–10	1–12	1–8
U. Kingdom	4–18	8–15	4–16	8	8–12	8–14	9.9	11–12	10–11	8–12

Source: www.euroblight.net, Schepers 2004, Schepers and Spits 2006, Hansen et al. 2007

scouting and forecasting prior to beginning of protection, order of fungicide applications in relation to mode of action. Accurate estimation of timing of the first chemical application is very important and often affects the following treatments and their efficacy. Unfortunately this decision is frequently made too late and the farmers are not able to make up for these losses.

Monitoring and Forecasting Many attempts have been made to forecast blight or provide systems that support the spray decision and replace routine preventive spraying. All forecasts are based on determining the probability of weather conditions (temperature, humidity) that will favour disease development and assume the existence of primary late blight infection source. Changes in the *P. infestans* population influence the time when potato late blight appears in the potato crop. The late blight monitoring system makes it possible to evaluate reliability of the forecast provided by decision support systems that are applied in potato protection and consequently defends in practice potato crops from earlier appearing infections (Kapsa and Hansen 2004). Currently late blight is more dangerous to potato production than in the past and its control is more difficult. Genetic changes within the pathogen population raise the question whether the current computer based systems of warning and forecasting are reliable, particularly those developed from results collected prior to the occurrence of new pathogen populations (Hansen et al. 2003).

Decision Support Systems (DSSs) DSSs used in control of potato late blight in potato crop protection help to determine an accurate date of first treatment and the following applications—only when necessary. This allows decreasing the number of fungicide treatments and plays a significant role in cost-effectiveness of chemical protection and also in environment protection. Many European countries use variations of blight maps as a decision support tool, including Ireland, Denmark, Germany, Netherlands as well as many Scandinavian and eastern European countries.

One of the decision support systems used in some European countries is NegFry developed in Denmark in the years 1992–1993 (Hansen 1993; Hansen et al. 1995).

Table 5 Effect of protection system on control efficacy of late blight (Poland, years 2002–2006)

Year	Cultivar[a]	Protection system	Haulm destruction (%)	Control efficacy (%)	No. of treatments
2002	Łucja (B2)	Control	88.5	–	–
		Routine	13.1	85.2	7
		NegFry	13.4	84.9	4
2003	Bekas (B1)	Control	7.0	–	–
		Routine	1.1	84.3	5
		NegFry	1.1	84.3	3
2004	Irga (B1)	Control	99.6	–	–
		Routine	7.1	92.9	5
		NegFry	4.1	95.9	4
2005	Irga (B1)	Control	99.1	–	–
		Routine	18.3	81.4	7
		NegFry	14.9	84.8	7
2006	Irga (B1)	Control	88.5	–	–
		Routine	0.2	99.8	9
		NegFry	0.2	99.8	6

[a] Cultivar resistance: B1—very susceptible, B2—moderately susceptible

The NegFry model is based on two existing earlier models, the "negative prognosis" for forecasting the risk of primary attacks (Ullrich and Schrodter 1966) and a model for timing subsequent fungicide applications during the season (Fry et al. 1983). The NegFry model used for timing the chemical control of potato late blight was validated in field trials at Bonin in Poland, in the years 2002–2006 (Table 5).

In these trials the number of fungicide treatments recommended by NegFry was one- to three-fold lower than the number of treatments in a routine spraying scheme. This reduction was mostly the: result of a delay in the time of the initial fungicide application and longer spraying intervals recommended by NegFry. Compared with routine treatment schemes, the number of fungicide applications was reduced significantly by using the NegFry: in Denmark, Sweden and Norway about 50% (Hansen et al. 1995), in Estonia, Latvia and Lithuania from 25% to 50% (Hansen et al. 2000). Using NegFry, it is possible to obtain satisfactory control against late blight and at the same time to reduce the number of fungicide treatments compared with a routine protection model (Kapsa et al. 2003).

Programmes of fungicide sprays should commence well before blight is established in the field. Product selection can be steered by crop growth stage. Development of plants during the growing season might be divided into four main stages. Each stage demands a specific attitude towards protection.

1. Germination and sprouting. Plant protection role at the beginning of the growing season is to prevent plant infection. During conditions favouring occurrences of diseases (higher humidity) systemic or locally systemic fungicides are recommended while during cold spring when the plants grow much slower, the applications of contact or locally systemic fungicides can provide sufficient protection.
2. Stem elongation and leaf growth stage is a period of sudden development of aboveground plant parts. The fungicides applied at that time aim at the protection of new developing parts of plant and thus systemic fungicides quickly moving

within stems are the most efficient. These products are also highly recommended for control of the late blight with stem lesions occurring on potato plants.

3. Flowering, steady haulm growth. At tuber formation leaf development is rather slow, however, rapid accumulation of tuber mass takes place. The fungicides used at that time continue protection of plant foliage.
4. Tuber ripening and drying out the plants. This is the last stage of plant protection and its main focus is on tuber protection. The products recommended at that time should destroy zoospores and protect tubers against late blight and early blight as well. Their mobility is not important as far as type of fungicide is considered.

Haulm Destruction The last treatment during the growing season called haulm desiccation is very important as its correct application helps to avoid development of tuber diseases during a storing period such as late blight, *Rhizoctonia*, and viruses. In addition, well performed haulm destruction leaves the crop better prepared for harvesting and tubers are often of better quality and less damaged. The decrease in mechanical damage is particularly important regarding the risk of infection with pathogens during storage (gangrene dry rot), but this risk is increased if the interval between the haulm destruction and harvesting the crop is excessive.

Chemical desiccation should be carried out on tubers for long-term storage and also seed tubers. In the years of high infection pressure it is also advised to combine a fungicide with a desiccant to destroy potential sources of infection.

Harvesting

Preventing bruising and mechanical damages is one of the most important considerations in a well-managed harvest operation. Blackspot and shatter bruise can seriously affect marketable yield if precautions are not taken to reduce them. Several factors are important in controlling bruising: soil moisture, soil temperature and equipment operation.

Potato Storage Management

A large part of the potato crops is stored for fresh market or processing during winter and spring. All seed tubers are stored.

Potato storage facilities can vary but have controls for temperature, humidity, and ventilation. Ventilation is essential during storage. To reduce the risk of rot developing and spreading during the storage season, wet or rotting tubers should be removed from the incoming conveyors when filling a storage unit. The storage period consists of three phases: curing, holding, and warming.

Integration

Integration of various methods to achieve better results in control of plant diseases became more popular in the recent years and allows decreasing the number of chemical treatments that plays a significant role in cost-effectiveness of chemical protection and also in environment protection, and protection of people's health. Some of these combined techniques were described above. It has been suggested that about 80% of crop protection for potatoes depends on sound planning and 20% on decision making after the crop has been planted (Gunn 1990). It is essential to remember that each element of good management that enhances potatoes' condition increases plant resistance to their "enemies". All efforts undertaken by farmers to eliminate pathogens/insects and reduce the losses caused by their infection/infestation allow only reducing their presence to some extent as total eradication of them is almost impossible.

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