

Disease-orientated threshold values as tool for effective early blight control

JUERGEN LEIMINGER & HANS HAUSLADEN

Technische Universität München-Weihenstephan, Lehrstuhl für Phytopathologie,
Emil Ramann-Str. 2, D –85350 Freising-Weihenstephan, Germany

SUMMARY

Potato early blight is a major disease of potatoes. Integrated and targeted early blight control represents a growing challenge for agriculture. Epidemics of early blight caused by *Alternaria solani* and *Alternaria alternata* can cause significant economic damage to potato, if not adequately controlled. Nevertheless, early blight is not an insoluble problem. We developed a disease threshold-based framework to define the optimal timing of fungicide application and to reduce the number of applications. Efficiency of fungicide application against EB could be improved, if treatments were carried out at pivotal times in the epidemic. Fungicide treatments have been adapted to the actual early blight epidemic in the field. Increases in disease incidence or severity were the basis for the initiation and subsequent applications of fungicides. A three-time application with azoxystrobin provided adequate disease control. Targeted applications of fungicides reduced the number of sprayings required to protect starch yield. Using fungicide application thresholds based on disease progress can help to effectively manage early blight.

KEYWORDS

Early blight, disease control, threshold values, fungicide termination, strobilurines

INTRODUCTION

Early blight (EB) can be found in many potato growing regions of the world (Rotem, 1994), and belongs to one of the most common and widespread diseases in potatoes. Due to its high adaptability, EB has the potential to become a serious threat for potato cultivation. Next to the widespread potato disease late blight (LB) caused by *Phytophthora infestans*, EB has become a noticeable problem for German potato production within the last years. A rapid increase in disease severity has been observed for German potato growing areas (Leiminger, 2009). EB is caused by *Alternaria solani* and *A. alternata*, which is also the causal agent for brown spot. EB mainly affects potato foliage and leads to leaf necrosis and premature defoliation. Symptoms include characteristic concentric rings that appear dark and sunken and become papery. Lesions enlarge, coalesce and cause leaf death (Pscheidt, 1985).

Because of its increasing economic importance, EB is in the focus of future integrated pest management strategies. EB is difficult to control because of its capacity to produce huge amounts

of secondary inoculum (Campo Arana *et al.*, 2007; Pasche *et al.*, 2004). In order to suppress EB and to prevent the losses it causes, potato fields are intensively sprayed with fungicides (Horsfield *et al.*, 2010). Fungicides of various chemical groups are currently used in Germany to control EB in potatoes. Until recently, only protectant fungicides were available for the suppression of *Alternaria* species. Since 2007 and 2008, respectively, strobilurine fungicides like azoxystrobin or boscalid in mixture with pyraclostrobin have been registered for control of EB. Because of its improved efficacy against EB these active ingredients have a considerable influence on the course of disease progress of EB. However, optimization of fungicide use on potatoes for the management of EB is still a considerable challenge. In order to control EB properly, many farmers use fungicides frequently from early in the growing season until vine desiccation (Campo Arana *et al.*, 2007; Gent and Schwartz, 2004; Shtienberg *et al.*, 1989). As fungicides are applied regardless of existing disease levels or disease-favourable weather conditions, most fungicide strategies may result in superfluous or ineffective fungicide applications.

The aim of this work was to incorporate a reduced fungicide strategy into EB management and to combine methods to reduce fungicide use in potato. Criteria to optimize the timing of fungicide applications against EB have not yet been established for potatoes in Germany, nor have studies examined the effectiveness of varying threshold values on control of EB disease. Therefore, spraying strategies were evaluated according to thresholds based on disease progress. For this, fungicide treatments were adapted to the actual epidemic in the field. Targeted applications at particular times of the disease progress led to effective control of EB and protection of starch yield. This may allow for a reduction in the number of sprayings per season, and will thus benefit producer, consumer and environment.

MATERIALS AND METHODS

Fungicide field trials

Field trials were carried out in 2005 through 2007. Experimental plots were situated within a commercial potato field, which was naturally infected by EB. Trials were carried out using the potato cultivar Kuras (Europlant Pflanzenzucht GmbH, Lüneburg, Germany), which is a late maturing starch cultivar and highly susceptible to EB. Plant density was 40,000 plants ha⁻¹. Trials were designed as a randomized complete block and were replicated four times. Field plots consisted of four rows (0.75 m between rows) and were 8 m long (24 m²). In 2009, control thresholds were evaluated for practical use. Therefore, selected thresholds were tested at different locations (Aiterhofen and Laberweinting, Bavaria, Germany) in terms of their functionality and practicality. Fungicide treatments were carried out by the farmers themselves, using their in-house equipment. Plot size for each variant was 1,000 m².

Assessment of tuber yield

Beside the quantification of EB disease, potato yield as well as starch content was recorded for all trials and variants. Tuber yield ha⁻¹ was determined from the two rows in the centre of each plot. For this, tubers were dug out, collected by hand and weighed on site. Before the starch content was measured, harvested tubers were stored for four weeks. The starch yield was calculated as the economically relevant measure for starch potatoes. The percentage of yield increase between threshold-treated and EB non-treated (EB control) plots was assessed. Site-specific yield losses were evaluated by comparing the EB non-treated control with treatments applied according to thresholds and healthy controls (weekly fungicide treatments).

Disease rating

Disease progress was observed weekly from potato emergence until vine kill. In each of the replications, 10 plants per plot were monitored for disease progress of EB or other diseases (e.g. LB). For the ratings, each potato plant was divided into three levels (lower, middle and upper leaf section) in order to follow disease development. For each leaf level, one leaflet was examined to determine the percentage of necrotic leaf area. The disease severity per plant was calculated as a mean value. At the end of the season, severity values were plotted against time, and the area under disease progress curve (AUDPC) was calculated for each treatment. The height of AUDPC values, which reflected the intensity of the EB epidemic, was used to assess the individual control thresholds.

Implementation of control threshold values

Thresholds correspond to certain stages of the disease progress and were assessed as disease incidence (DI), or disease severity (DS). They formed the basis for the timing of fungicide sprays, in order to optimize the control of EB. Treatments were carried out after pre-defined threshold values have been exceeded. Applications at early stages of disease development were compared to sprays during the progress of an EB epidemic. As variants of a threshold-based disease control, different (consecutive) stages of EB development were selected.

Threshold value	definition
50% DI _p	50% of plants showing EB symptoms at any leaf section
100% DI _p	100% of plants showing EB symptoms at any leaf section
100% DI _{m.l.}	100% of plants showing EB symptoms at the middle leaf (m.l.) section
1% DS _{u.l.}	1% of the upper leaf (u.l.) area necrotized by EB

EB-specific treatments were applied either alone, at one specific threshold, or as a combination of thresholds, which resulted in fungicide double (two EB-specific applications) or triple (three EB-specific applications) treatments. Therefore, additional applications were chosen at designated stages of disease development. Thresholds were compared to EB untreated plots in terms of their effect on disease control and reduction of yield loss. Fungicide trials included a fully untreated control, an LB-free variant with unrestricted development of EB (EB control), and treated plots for comparing disease severity and yield response. Additionally, fixed date double treatments, applied six and seven weeks after crop emergence, and non-threshold-based weekly applications of azoxystrobin or mancozeb were used for comparison. Threshold values were evaluated with regard to their efficiency of disease control and reduction of yield loss.

Evaluations of selected thresholds were conducted with the active ingredient azoxystrobin. Azoxystrobin was applied according to recommended dose rates with 125 g active ingredient (a.i.) ha⁻¹ (Ortiva® 0.5 l ha⁻¹). The active ingredient mancozeb was integrated as a standard treatment and was applied at a dose of 1,350 g A.i. ha⁻¹ (Dithane Neo Tec® 1.8 kg ha⁻¹). Next to threshold-specific treatments, field trials included variants with weekly fungicide treatments of either mancozeb or azoxystrobin in order to determine the site-specific yield potential. To prevent the development of LB, the fungicide Ranman® (400 g cyazofamid l-1) was applied as a cover spray at a dose of 0.2 l ha⁻¹ every 8 to 10 days. As the disease progress of EB was not affected by the use of Ranman®, EB was allowed to develop naturally during the course of the growing season. All fungicides were applied with a portable overhead backpack-sprayer, using air-mix nozzles (Lechler, air-mix 110-0.4) at a pressure of 190 kpa. The respective fungicides were sprayed in a water volume equivalent to 400 l ha⁻¹ and did not contain any additional spreader, sticker or adjuvant.

RESULTS AND DISCUSSION

Disease progress

EB epidemic was monitored over the years. Based on disease observations, EB appeared as primary foliar disease in potatoes. Heavy EB epidemics occurred in all years of investigation. Initial disease symptoms appeared on lower leaf sections, thus leading to inconspicuous disease onset. As the season progressed, EB symptoms rapidly enlarged and spread onto higher leaf levels. Secondary spread of EB was observed in all years starting from the end of July or beginning of August. A stronger increase in disease severity was predominately observed for leaves from the middle and upper leaf sections. Rapid increase in leaf necrosis weakened potato foliage and reduced photosynthetic area. In EB untreated plots, potato plants were premature defoliated. Here, disease severity increased from less than 5% to more than 90% within 5 weeks, resulting in yield losses. Our investigations showed that EB disease development followed a gradual upward progression. First symptoms were obvious on lower leaves. As disease progressed, EB heavily infected leaves from the middle and upper leaf section (Figure 1), resulting in premature defoliation.

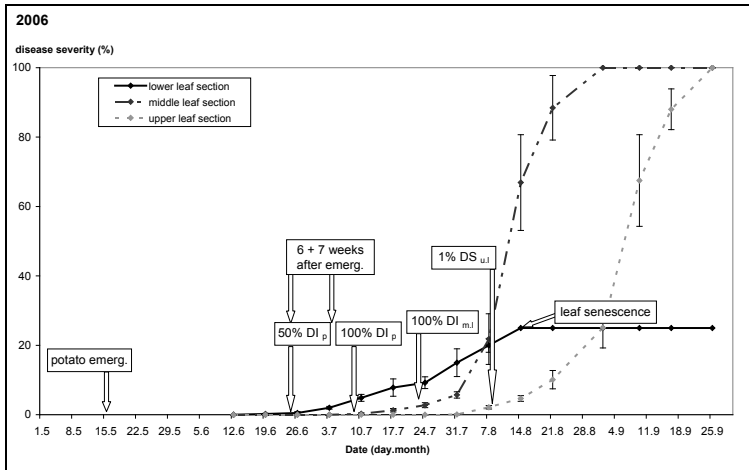


Figure 1 EB disease progress within different leaf layers, and termination of specific threshold, e.g. 2006, cultivar Kuras

Evaluation of threshold values

The control of EB significantly improved foliage health. Threshold values based on certain stages of disease development were highly effective in controlling EB. However, early initial application of fungicides was pivotal for effective disease control and resulted in statistically different levels of effectiveness of EB control. Single treatments with azoxystrobin at early stages of disease progress (50% DI_p or 100% DI_p) significantly reduced leaf blight compared to the untreated EB control. The effect of the time of spray initiation and subsequent fungicide application could clearly be seen throughout the years. Fungicide double treatments, which started early in the course of disease progress, resulted in improved disease control. The adaptation of disease control according to leaf section-specific thresholds was highly effective. Mainly those thresholds achieved satisfying EB control, which were initiated before disease onset or at only marginal disease severities at the specific leaf levels (50% DI_p + 100% DI_{m.l.} or 100% DI_p + 1% DS_{u.l.}). In comparison to treatments, which were applied regardless of the existing disease pressure (6 + 7 weeks after crop emergence), threshold-based treatments resulted in improved disease control.

Already two to three disease-orientated fungicide applications resulted in a significant reduction in disease severity. Among the threshold-based applications, a triple application of azoxystrobin (50% DIp + 100% DI m.l. + 1% DSu.l.) against EB was more effective than double treatments. Here, applications of fungicides according to EB development provided adequate disease control and reduced the number of sprayings compared to unspecific treatments. Our data indicate that proper timing of initial treatments may be of importance (Leiminger and Hausladen, 2012). As EB disease development followed a gradual upward progression in the three-year trials, fungicide sprays should be recommended at early stages of the disease because most of the inoculum for infection of the upper leaves is likely to be formed on lower leaves. The use of fungicides with different modes of action had strong influence on the AUDPC. Applications of azoxystrobin led to a reduction in foliar disease severity and likewise to a delayed disease progress compared to mancozeb. Although weekly treatments with mancozeb led to a reduced disease severity of EB, it was not able to reach the disease control of azoxystrobin.

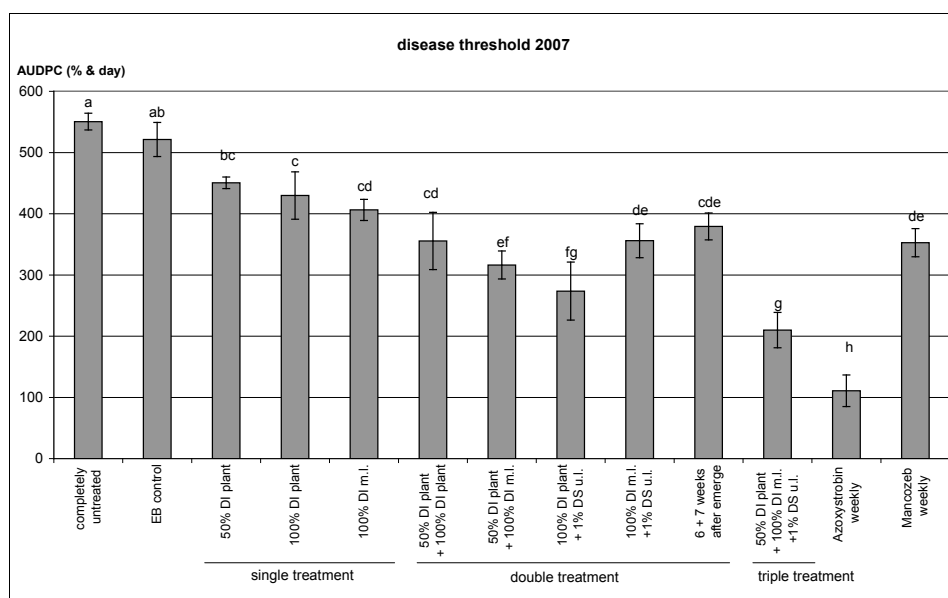


Figure 2 Expression of early blight AUDPC values as a function of fungicide treatments at different control thresholds, cultivar Kurus, 2007

Yield assessment

The estimation of potato yield (2005 to 2007) showed that control of EB resulted in increase of starch yield. According to AUDPC data, most fungicide treatments suppressed foliar blight compared to the EB untreated plots. However, timing of treatments was crucial for the achievement of high starch yields (Fig. 3). In accordance with the results of the disease ratings, the fully untreated control (EB+LB control) generated the lowest yield over all years because of simultaneous infections with *P. infestans* and *Alternaria* species. Single EB treatments did not result in significant yield increase. Distinct differences in potato starch yield depending on threshold-based fungicide applications were observed in 2006 and 2007. When azoxystrobin was applied twice, treatments resulting in particularly increased yield were those applied at thresholds 100% DIp or 100% DI m.l. + 1% DSu.l. Triple applications of azoxystrobin at disease thresholds 50% DIp + 100% DI m.l. + 1% DSu.l. allowed for high starch yields that were similar to those reached after weekly application of

the fungicide. In contrast, applications, which were carried out at fixed time points independently of disease progress (“6 + 7 weeks after crop emergence”), were not significantly different to EB untreated controls or to weekly treatments with mancozeb. The data show that the timing of fungicide treatments influences progress of EB as well as yield. Fungicide applications, which were not adapted to actual disease development, tended to result in lower starch yields. An increase in starch yield was especially evident after application at thresholds, which also reduced AUDPCs according to lower disease severity of EB.

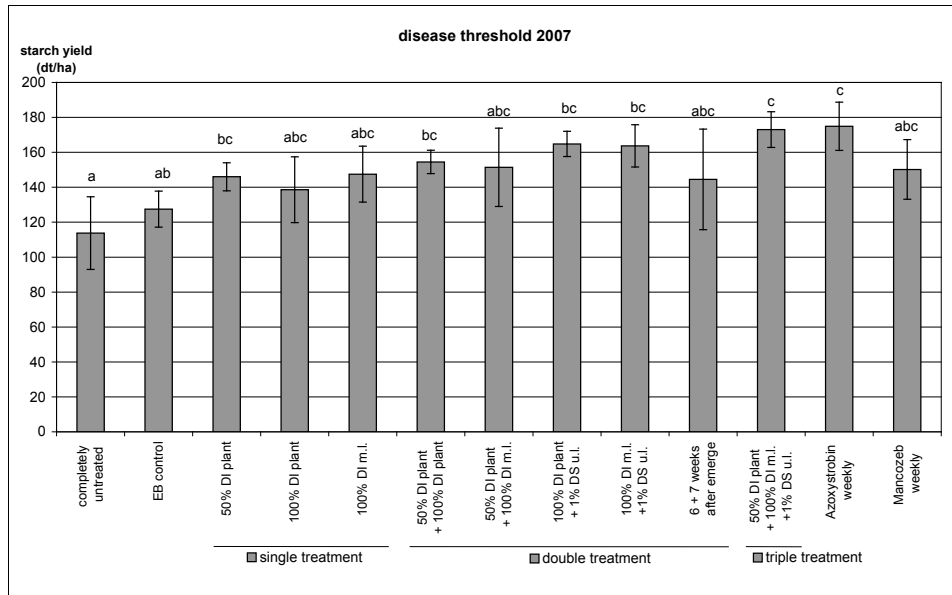


Figure 3 Comparison of starch yields as a function of fungicide treatments at different early blight control thresholds, Kuras, 2007

Practicality of thresholds

According to commercial field trials, the use of disease threshold values was examined in 2009 at different locations. Functionality and practicality of selected thresholds was tested. Differentiated EB epidemics could be observed for the various locations (Figure 4a). Site- as well as cultivar-specific factors had a considerable influence on the development of EB. Due to the distinct development of *Alternaria* species and the corresponding increase in EB, a high disease level (AUDPC) was achieved at both sites Aiterhofen and Laberweinting. At the location Aiterhofen, EB developed quite early, whereby a considerable increase in leaf necrosis was already visible during the course of August. Likewise, at Laberweinting, an increase in EB disease, albeit with a time lag, resulted in the complete destruction of photosynthetically active leaves until the beginning of September.

Depending on the investigated disease thresholds, effective EB control was achieved, if initial applications were carried out at relatively low levels of disease manifestation. Already one single treatment at an early stage of disease progress (50% DIp) significantly reduced EB disease compared to the untreated EB control at both locations.

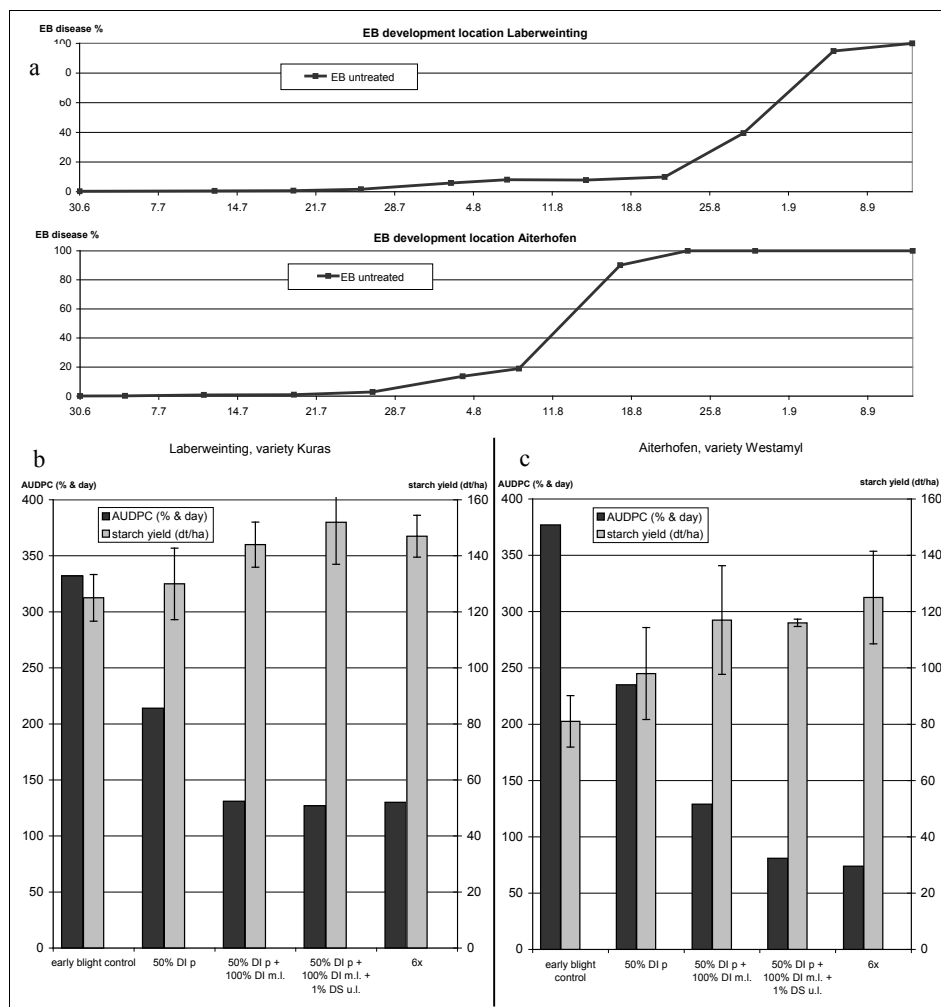


Figure 4a) development of EB disease at different locations (Laberweinting, Aiterhofen), AUDPC value as well as starch yield according to threshold specific EB treatment at b) location Laberweinting and c) location Aiterhofen, 2009

To prevent an uncontrolled increase in EB disease, follow up treatments were tailored according to the specific pathogen development on the plant. Effectiveness of additional treatments was more evident, if EB disease developed strongly. It could be revealed that at the site Aiterhofen, where heavy EB epidemics occurred, a three-fold application according to threshold values was as effective as multiple treatments, which were not adapted to disease development (Figure 4c). Due to the delayed disease progress at Laberweinting, already a two-fold application achieved the best disease control (Figure 4b). Further treatments did not result in improved EB control. Adequate EB control prolonged maintenance of green leaf area as was evident by a reduction in AUPDC values, which likely explains the increase in starch yield. Using disease-orientated thresholds, yield significantly increased over all years. It could be shown that timing of treatments was crucial for the achievement of high starch yields. Targeted applications at particular times of the disease progress led to effective control of EB and protection of starch yield (Leiminger and Hausladen, 2012). At both locations, triple applications of azoxystrobin at disease thresholds 50% DIp + 100% DI m.l. + 1% DS u.l. allowed for high starch yields that were similar to those reached after a six-fold application of

azoxystrobin. Our experiments show, that frequencies of fungicide treatment can be reduced. EB could be effectively controlled, if fungicide application was adapted to the type of epidemic, given that treatments were carried out at pivotal times in the epidemic (Leiminger and Hausladen, 2012). Already two to three fungicide applications based on disease thresholds can protect developing parts of the plant from secondary inoculum. Therefore, the consideration and suppression of EB development on the middle and upper leaf levels is important for a successful EB control. In contrast, calendar-based and “late-initiation” methods were less effective in limiting EB.

SUMMARY

Investigation on EB progress demonstrated the importance of fungicide use for the control of EB in the production of potatoes. Depending on the application frequency of specific EB fungicides and the control threshold used, EB disease could be prevented, and starch yield was safeguarded. Ineffective EB control allowed leaf necrosis, which resulted in reduced green leaf area and premature defoliation. Results show that an effective EB control should start at early disease onset in order to prevent of secondary invasion of the pathogen.

At locations with high disease levels, EB could be efficiently controlled by few fungicide treatments, if they were carried out according to the site-specific disease progress. Especially at locations with less EB disease, non-specific treatments could be prevented, and EB could be controlled by only few fungicide applications. The implementation of control thresholds helped to improve EB control and to prevent yield losses. By this, EB treatments could be restricted to the most necessary. Minimizing the number of applications of a particular fungicide is one of the most effective ways to reduce the risk of fungicide resistance. The development of disease-orientated threshold values as criteria for timing of fungicide applications can be seen as an important tool for farmers to reduce EB epidemics.

REFERENCES

- Campo Arana, R.O., Zambolim L, and Costa, L.C. 2007. Potato early blight epidemics and comparison of methods to determine its initial symptoms in a potato field. *Rev. Fac. Nal. Agr. Medellin.* 60-2:3877-3890
- Gent, D.H., and Schwartz, H.F. 2003. Validation of potato early blight disease forecast models for Colorado using various sources of meteorological data. *Plant Dis.* 87:78-84
- Horsfield, A., Wicks, T., Davies, K., Wilson D., and Paton, S. 2010. Effect of fungicide use strategies on the control of early blight (*Alternaria solani*) and potato yield. *Austral. Plant Pathol.* 39:368-375
- Leiminger, J.H. 2009. *Alternaria spp.* an Kartoffeln – Empirische Untersuchungen zur Epidemiologie, Schadrelevanz und integrierten Bekämpfungsstrategien, Ph-D thesis, Technische Universität München, Druck und Verlag H. Hieronymus, München, 130 pp.
- Leiminger, J.H., and Hausladen, H. 2012. Early blight control in potato using disease-orientated threshold values. *Plant Dis.* 96:124-130
- Pasche, J.S., Wharam, C.M., and Gudmestad, N.C. 2004. Shift in sensitivity of *Alternaria solani* in response to QoI-fungicides. *Plant Dis.* 88:181-187
- Pscheidt, J.W. 1985. Epidemiology and control of potato early blight, caused by *Alternaria solani*. Ph. D. thesis. University of Wisconsin, Madison. 242 pp.
- Shtienberg, D., Doster, M.A., Pelletier, J.R., and Fry, W.E. 1989. Use of simulation models to develop a low risk strategy to suppress early and late blight in potato foliage. *Phytopathology* 79:590-595