A CONCEPT IN INTEGRATED PEST MANAGEMENT (IPM) OF FUNGAL LEAF DISEASES OF CEREALS AND SUGAR BEETS

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1 ABSTRACT

Current efforts by scientists have focused on developing IPM concepts in order to balance the benefits of pesticides with the ecological concerns of pesticide residues contaminating the environment. With regard to fungal leaf diseases, only synthetic fungicides offer the probability of interfering with an actual epidemic to secure yield and quality of the crop. Therefore, the IPM concepts should include the use of fungicides, but are considered as an "ultima ratio", which means applications are only allowed in the presence of a real risk. The goal thus is to avoid superfluous treatments as a consequence of following routine or precautionary systems.

In the development of IPM models, consideration should be given to the specific host-parasite implications as well as the efficiency of available fungicides. Concerning fungal leaf diseases in cereals and sugar beet, initial stages of the epidemic cause neither a reduction of yield nor quality and cannot be controlled by systemic or curative fungicides. Therefore, in our approach, the actual epidemic situation in the field serves as the key criterion for flexible handling of fungicide treatments, since forecast of diseases has been found to lack sufficient accuracy to serve as the basis for implementation of plant protection measures.

For cereals, decision systems were preferred that mainly operate with certain threshold values that correspond with initial disease incidence levels of the epidemic. When a threshold is exceeded within a specific risk period, the likelihood of yield losses is indicated and therefore, the application of fungicides is justified. The aim is to interfere with the epidemic during the most sensitive stages, to minimize the chemical load on the environment and to optimize the economic benefit as well.

A holistic concept, involving four elements of IPM, has been developed for sugar beets. The system may be characterized as quaternary where the single tools are linked and only the combination provides a complete system. The calculation of daily infection values is used for a negative-prognosis (first tool), which determines the disease free period. Once infections cannot be excluded, a field monitoring has to follow. Diagnosis and disease scoring substantiates the reduction of acting thresholds (second tool). The economic damage threshold (third tool) defines the tolerable disease level at harvest. The loss prognosis (fourth tool) gives insight into whether the future progress of an epidemic will lead to thresholds having exceeded by scheduled harvest time and therefore, whether or not a fungicide treatment is necessary.

For implementation in practice, simplification of the scientific issues is required for acceptance by advisory services and on the farmers' side. Transfer of knowledge, how to use the model as well as information about the current disease situation (monitoring, negative prognosis) has been found to be very useful.

2 INTRODUCTION

Integrated pest management (IPM) systems are generally considered to be keys to promoting sustainable agricultural land use systems, particularly, with increasing recognition of environmental problems which are associated with synthetic pesticide applications [1]. The worldwide production of crop protection products increased considerably, from US$0.9 billion in 1960 to more than US$ 26 billion in 1990 (Fig. 1). Since then, the pesticide market has nearly stalled. Although regulation by governments has directed pesticide development toward active ingredients with minor environmental impact, a risk remains, as the environmental fate of the comparably large amounts used today cannot be estimated accurately. A restriction of pesticide application is therefore increasingly demanded by governments as well as non-government environmental organizations worldwide.

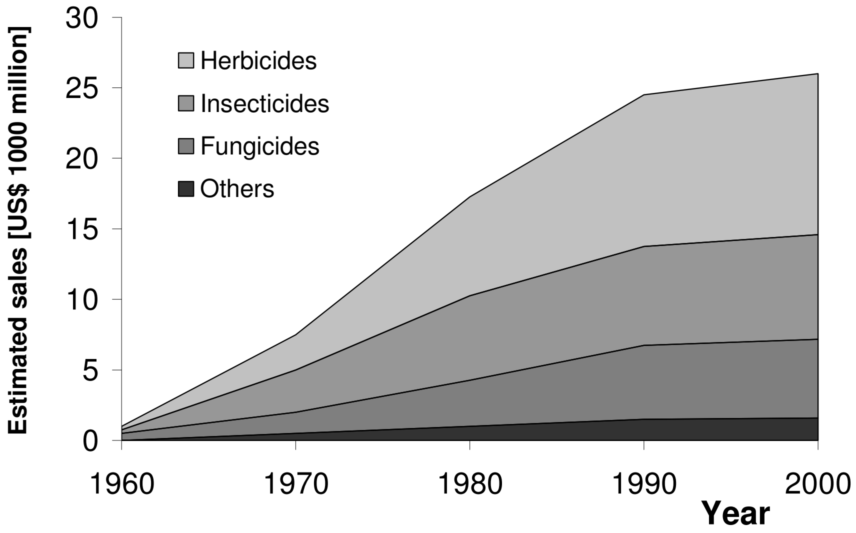


Figure 1: Trends in expenditure on crop protection products (based on trade prices) from 1960 to 2000 (Data from CountyNatWest WoodMac, 1992, FAO 2002).

Among the diverse range of measures which are aimed at protecting crops from fungal leaf pathogens, e.g. sugar beets and cereals, only fungicides provide efficient interruption of a current epidemic and thus secure crop yield and quality. The integrated crop protection approach thus explicitly includes fungicide applications, taking into account that even by applying all available preventive measures (crop rotation, soil cultivation, resistant cultivars, etc.), fungicide applications can generally not be replaced by other measures to optimize crop yield and quality [2]. However fungicide applications are only justified when yield losses are anticipated with a high probability from disease monitoring data.

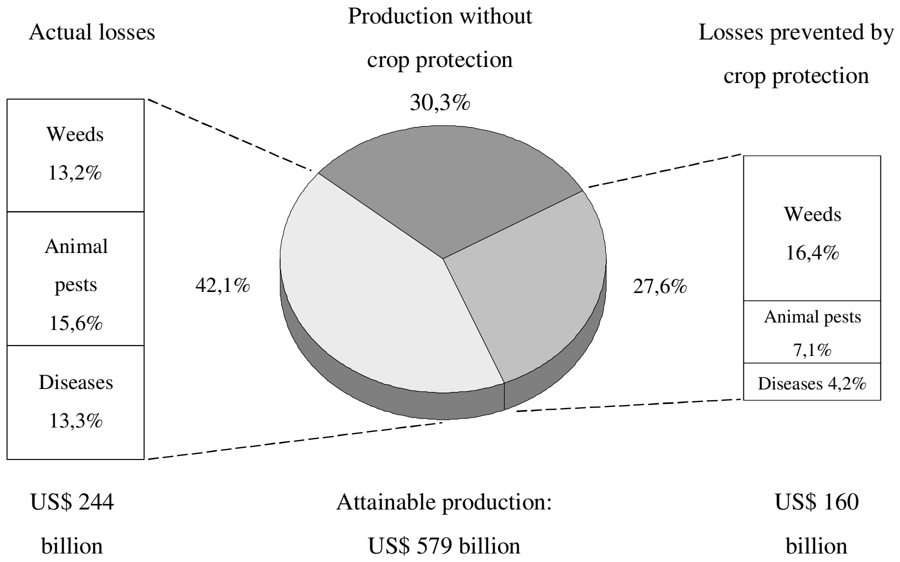


Figure 2: Estimation of the effect of crop protection on the yield of the eight principal food and cash crops, 1988-1990 (After Oerke et al., 1993).

Without any chemical crop protection, global yield losses would approach 69.7%, whereas this proportion is reduced by the currently applied crop protection methods to 27.6% [3]. Plant pathogens cause yield losses of 17.5%, and 4.2% are prevented by the application of direct control methods (Fig. 2). The potential yield losses can, depending on crop and regional factors, increase significantly, especially under high-intensity crop production conditions combined with susceptible crop cultivars. Despite the current plant breeding efforts to create resistant cultivars, and even by applying molecular breeding techniques, this situation will probably not change in the near future. In addition, resistance is unstable, as pathogens evolve with their hosts by genetic recombination and evolution of pathogen races [4, 2]. Fungicides will thus, at least in the near future, continue to play an important role in pest management.

The occurrence of plant diseases is a common annual phenomenon, at least in the maritime and temperate climatic zones, but their annual sequence, severity and the course of the epidemic may vary significantly between years. Precautionary pest management systems which are based on routine measures with timing of fungicide treatments being oriented to fixed calendar schedules are therefore rarely suitable to minimize pesticide use.

Our aim is to move from a habitual to a flexible management of plant protection measures which is adapted to the specific pathogen situation in the field. The basics of an epidemic-oriented management of fungal pathogens were substantially formulated by Hoffman [5, 2]. They were integrated into the IPM models for wheat [6, 7, 8], barley [9, 10, 11, 12] and sugar beet [13, 14, 15, 16, 17]. Integration of IPM-systems cannot successfully be carried out without at least knowledge of some basic principles. In particular, diagnostic capacities and insights into the life cycle, epidemiology, and economic impact of specific pathogens on one hand and into the efficiency of a specific pesticide that is interacting with the epidemiological stage on the other hand, are required. The basic concept is completed by prediction of disease severity and economic losses under the condition that their accuracy and their applicability in practice are assured.

3 PRINCPLES OF IPM SYSTEM DEVELOPMENT

3.1 Diagnosis

Diagnostic methods include the identification of disease symptoms and their causes, which can either be biotic (viruses, bacteria, fungi, or animal pests) or abiotic (e.g. nutrient or water deficiencies). They are surely key factors of any IPM-system (Figs. 3, 4). Among the basic factors of IPM-model design, field studies of pathogen progression, which also include assessment of the economic losses, are essential. The resulting data form basis for the determination of control and damage thresholds as well as for the development and validation of disease prediction models. In this context, the different IPM elements require a reliable identification of the disease-causing pathogens to guarantee the validity of the data. Without a correct diagnosis, an IPM-model can neither be developed nor be successfully implemented [18, 6, 17, 19, 16].

Diagnosis and scoring of disease severity, which is based on the evaluation of necroses or remaining green leaf areas in many cases is inappropriate (Fig. 4). In particular, pathogens that cause symptoms in wheat and barley have to be differentiated from symptoms of senescence or from other inducers of leaf spots or necroses [19]. For instance, necrotic lesions may be the consequence of defense mechanisms (hypersensitive response), increased susceptibility against own pollen as well as from phytotoxicity after the application of fertilizers or herbicides [4]. The identification of the causal agent may be performed macroscopically or by the naked eye in the case of pathogens which form visible structures on leaf surfaces, for example white to grayish dots or patches of the ectoparasitic fungal genus *Erysiphe spp.* The rust fungi belonging to the genera *Puccinia spp.* or *Uromyces spp.* respectively may be recognized by the appearance of brown to reddish spots or pustules breaking up the epidermis. Leaf necrosis-causing pathogens, on the other hand, can in most cases only reliably be diagnosed microscopically by identifying specific morphological structures like mycelium, pycnidia, sporeocarps, or conidia (Fig. 3, left part; Fig. 4).

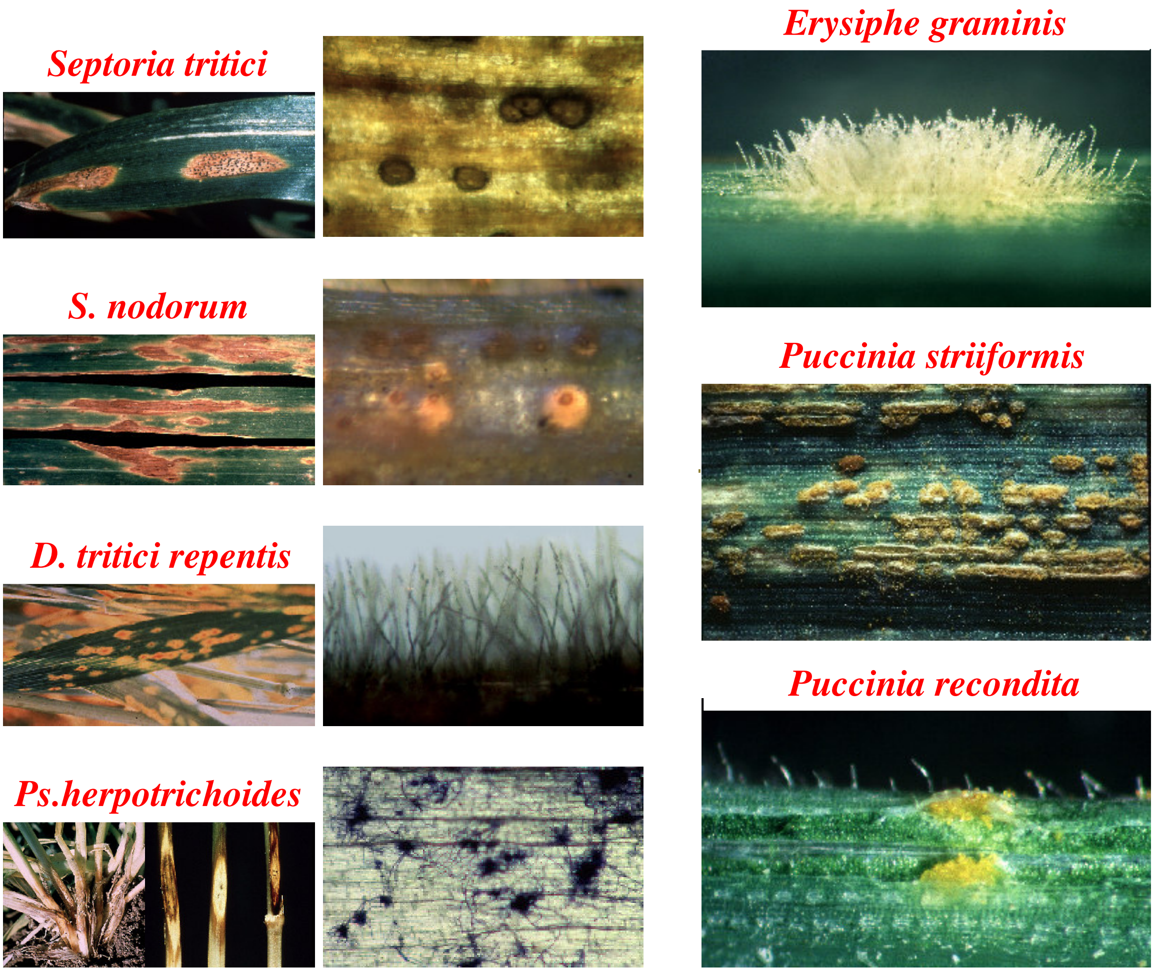


Figure 3: Symptoms of diseases caused by wheat pathogens; identification by hyphal structures/propagules of necrotic spot diseases (left), obligate parasites on leaf surface (right), (After Verreet and Klink, 2000).

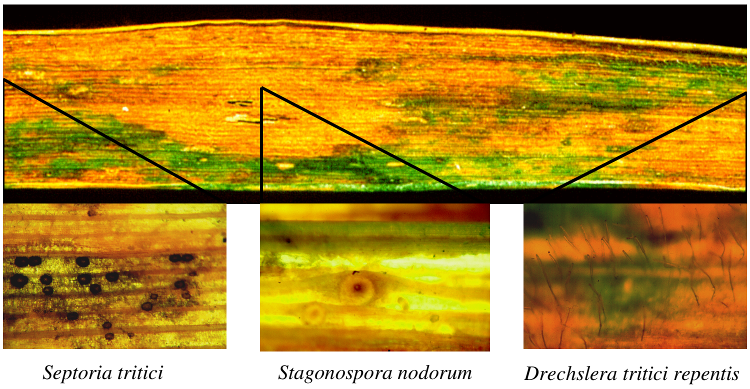


Figure 4: Unspecific necroses (top) and identification of the causal agent by asexuel propagules (bottom), (After Verreet and Klink, 2000).

3.2 Case studies of pathogen behavior in the field

Essential elements of IPM-model development are case studies of pathogen epidemics in natural ecosystems. This is primarily performed by an empirical description of the specific composition, sequence and dynamic of the population development, which is in turn determined by site-specific factors. Ideally, data should be collected for several years at different locations and under cropping systems to determine the spectrum and extent of variation within the pathogen.

The suitable parameters should be recorded to determine the progression of pathogens in an epidemic. To determine the onset, course and severity of an epidemic, data must be collected from such determinants as cropping factors (e.g., seeding time, cultivar resistance, fertilization, pest management, etc.), the phenologic development by the growth stage (GS) of the crop plant, and records of the predominant climatic factors. Finally, the effects of epidemic yield quality and losses must assessed.

3.2.1 Quantitative diagnosis, disease scoring

Beside pathogen identification, a quantitative diagnosis is required which has to be performed over the duration of a potential epidemic. For this purpose, the entire spectrum of diseases has to be monitored for possible interactions between the leaf pathogen and potential antagonists. Weekly recordings of activities of the pathogen, which have to take specific crop morphology into consideration, are typically sufficient. For wheat and barley, e.g., the height of the leaf insertions should be considered [6, 7]. Single beet leaf monitoring, on the other hand, can be performed counter-clockwise following the leaf age, beginning with the oldest leaves to the center of the leaf rosette [20, 16].

The evaluation of data has to be adapted to the pathogen. Pathogen-specific traits have to be differentiated from those which are related to leaf chloroses and necroses. Thus, disease scoring of visible pathogen structures already includes diagnosis. On the other hand, incidence of necrosis by pathogens may be estimated by infected leaf area. However, in addition, there is frequently a need for identification of the causal agent of the symptoms via their generative organs in order to ensure that the data records are related to the pathogen. This is specifically appropriate for the perthotrophic cereal pathogens *Septoria tritici*, *Stagonospora nodorum*, *Drechslera spp*. and *Rhynchosporium secalis* and for the sugar beet pathogens *Cercospora beticola*, *Ramularia beticola*, *Phoma betae* and *Pseudomonas syringae.* Unspecific necroses in these cases have to be verified additionally by quantification of the inoculum through for example the number of pycnidia or conidia per leaf or plant [6, 7].

A pathogen-specific epidemic may be characterized by single leaf monitoring from which the disease incidence (DI) is calculated, i.e., by evaluating the percentage of infected leaves (DI/L) or plants (DI/P) that show disease symptoms. The disease incidence parameters DI/P and DI/L are rather suitable for the description of early phases of an epidemic, its horizontal and vertical spread in the field respectively. Horizontal spread in this context refers to the progress of infection from plant to plant. For example, case studies of *Cercospora beticola* in sugar beet show that the horizontal transmission of the pathogen (DIP) takes three to four weeks until every plant shows at least one symptom (Fig. 5A, B, C). The vertical transmission (DIL) describes the progression of lesion. from older to younger leaves. As soon as the maximum is reached, disease severity begins to increase significantly. Disease severity (DS) is related to the percentage of infected leaf area. This parameter characterizes the extent of an epidemic and is of specific importance for loss judgments. The year-specific weather conditions result in a significant shift of the different phases of an epidemic, in turn affecting the disease severity at the end of the season which is of most importance for evaluating the extent of damage and economic losses [15, 16].

3.2.2 Evaluation of acting thresholds for fungicide treatments

Acting thresholds correspond with certain stages of the epidemic progress such as frequencies of infection (% infected plants or leaves), or severity of disease (% infected leaf area, number of pycnidia etc.). They form the basis for the timing of fungicide sprays, in order to optimize the control of pathogens as well as the economic benefits. These acting thresholds are to be interpreted as limit values of a disease or population development that pinpoint the optimum time for a fungicide application. The disease incidence levels corresponding with the threshold values signify a very early phase of the epidemic that frequently precedes the stage of epidemic that causes significant yield losses. Consequently, the fungicides must be applied in most cases long before the actual occurrence of yield losses. As an example, during determination of threshold values for *C. beticola* in sugar beets (Fig. 5), spraying times were strictly linked to the epidemiology and therefore were held flexible, in accordance with the actual exceeding of threshold values. In 1994 (Fig. 5A), thresholds were exceeded relatively early compared to the growing seasons of 1995 (Fig. 5B) and1996 Fig. 5C).

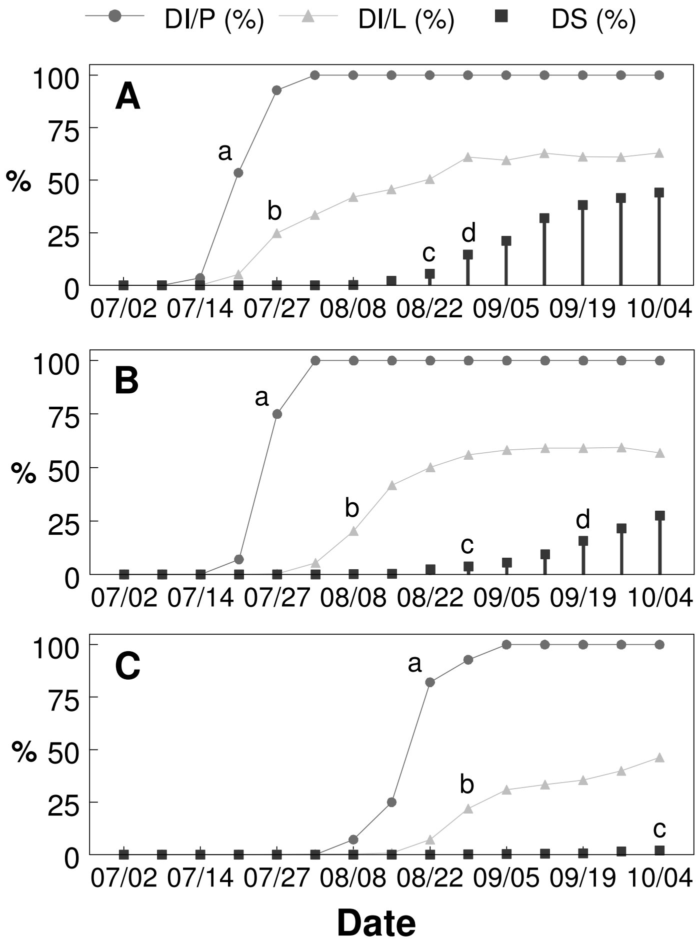


Figure 5: Epidemic progress of *Cercospora beticola* in 1994 (A), 1995 (B) and 1996 (C) at site Regensburg, cultivar "Elan", and exceeding times of epidemic thresholds (After Wolf and Verreet, 2000).

Thresholds:
a = 50 % disease incidence per plant (DI/P) according to ~0.01 % DS
b = 25 % disease incidence per leaf (DI/L) according to ~0.2% disease severity (DS)
c = 2 % disease severity (DS)
d = 10 % disease severity (DS)

A further scheme for evaluating the efficacy of thresholds was by assessing the relationship between real disease situations and irreversible reduction of crop yield. Our field trials thus consisted of untreated (C = control) and treated plots for comparing disease incidence and yield response. In addition, every case study included a variant that was treated 3-5 times (H = healthy variant) in order to determine the site-specific yield potential without any disease incidence. This variable, for which the treatments were performed at intervals of three to four weeks, enables an accurate assessment of the efficacy of particular thresholds, and the efficacy relative to the number of treatments is the crucial point [6, 21, 19, 22].

As an example, figure 6 shows the biological and economical effects of threshold oriented fungicide sprays, carried out from early through later epidemic progression stages of *Cercospora beticola* in sugar beets. The exceeding of thresholds and therefore, the prompting of a fungicide spray, is linked to the progress of disease severity (Fig. 6A). The result of reducing the amount of disease (Fig. 6B) as well as yield response (Fig. 6C) indicate higher spraying efficiency of early epidemic stages, when used as thresholds. It is further evident that a single treatment was not sufficient. However, threshold-based treatments at initial stages of the epidemic (Fig. 6A: 0.01/0.2 = first treatment: 0.01% DS, second treatment: 0.2% DS) showed similar efficiency compared to the healthy variant (H) treated three times.

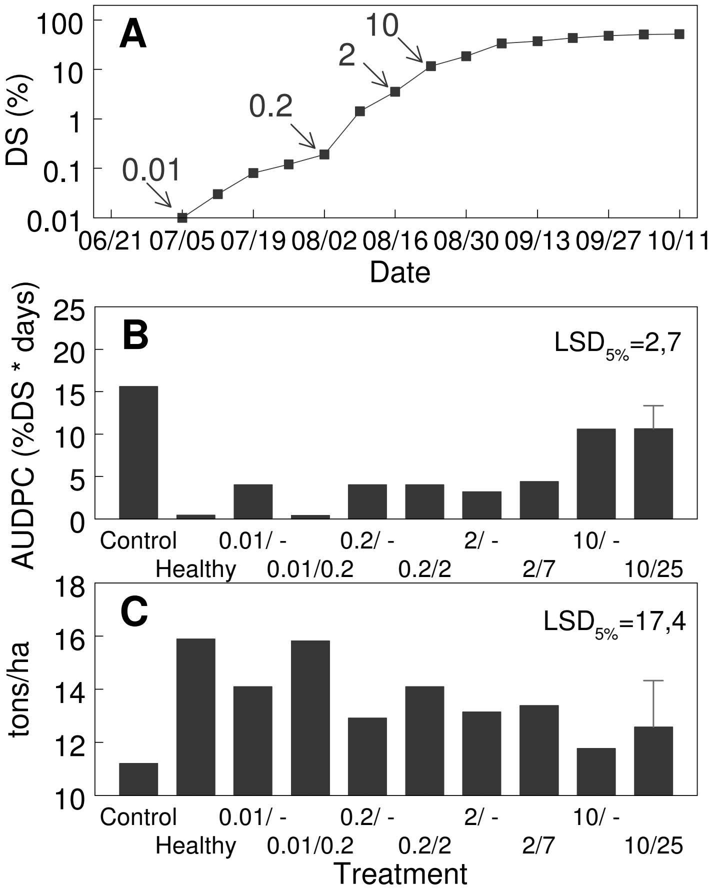


Figure 6: Case study of *Cercospora beticola* in sugar beet: Exceeding of epidemic thresholds according to the progress of disease severity (A), disease control (B) by reduction of AUDPC (area under disease progress curve) and yield response (C) of different threshold-oriented treatments (numbers on x-axis = DS of 1st / 2nd treatment, - = no 2nd treatment) in comparison to the control (untreated) and healthy (3 sprays) (Data from Weis, 1998).

3.2.3 Evaluation of the disease severity

The site-specific potential yield losses may be evaluated in field experiments that integrate treatments with non-disturbed pathogen development (untreated control), threshold-oriented variants, and healthy variants (treated three to five times). The extent of losses (loss (%) = 100 – yield of the untreated control / yield of the healthy variant • 100) is the result of the site-specific disease occurrence and the epidemic dynamic. It should be linked with the disease severity of an entire vegetation period. Depending on the pathogen, either the ultimate severity or the sum of severity values on defined leaves may better reflect the actual situation (Fig. 7). In other cases, the AUDPC (area under disease progress curve) value is preferable as it reflects the disease course during an entire season [23]. Figure 7 shows the relation between tan spot infection and yield loss, exemplified by leaf spot development on the upper three leaves [24]. According to the regression curve, one leaf spot causes a loss of 17 kg/ha. The determination of disease and yield loss relations requires adequate field trials that include variations which range from weak to severe epidemics. A regression curve could be used to establish the magnitude of losses which do not impact the yield or from economic aspects, fall within the limit of tolerance at harvest time. Economic damage thresholds are important determinants in the development of loss predictions. In contrast with complex diseases as occur often in cereals, disease-loss relationships are only of limited value [2]. This is due to the interactions between the pathogens as well as varying infection times and disease tolerances that depend on weather conditions.

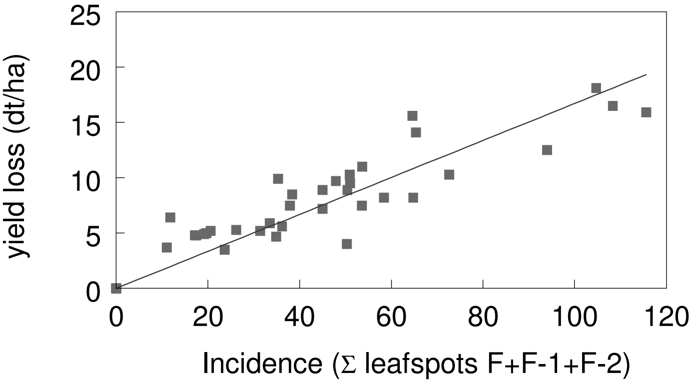


Figure 7: Tanspot (*Drechslera tritici-repentis*) in wheat: Disease-loss relationship calculated from the sum of leafspots on the upper three leaves and yield loss (Data from Wolf, 1991).

3.2.4 Fungicide efficacy

The threshold-oriented method generally implies a tolerance of early infections. The availability of adequate curative and eradicative fungicides thus is a precondition to control the infections that are defined by threshold values. The selected fungicides, in addition, should provide adequate control of the predicted pathogen spectrum. In the evaluation of the fungicides, the efficiency of each and combined active ingredients should be considered from epidemiological aspects [2, 7, 19].

3.2.5 Disease prediction

Frequently, the prediction of disease is considered the most important element for developing guidelines relating to the optimization of pest management methods. Nevertheless, their integration into IPM concepts depends on their precise implications on the specified host-parasite system (Fig. 8). In particular, the extent to which early infections may be tolerated has to be assessed by practical examination. For a number of pathogens there is little tolerance of early infection because of their impact on food quality or lack of fungicides for control even in the early stages of an epidemic. This is in particular true for apple scab (*Venturia inaequalis*) where there is a demand for quality fruit or for potato late blight (*Phytophthora infestans*) due to the lack of efficacy of the available fungicides. For application of protective fungicides, under these circustances, weather data-supported disease prediction remains the only viable method that offers flexible time for application under the prevailing risk of infection. Other crops at least in the initial phase, tolerate infections without significant yield or quality loss and, in addition, fungicides can efficiently control the early stages of an epidemic. This is particularly relevant for fungal caused cereal and beet leaf diseases for which decisions concerning fungicide applications are primarily based on threshold values and prognoses provide only additional information.

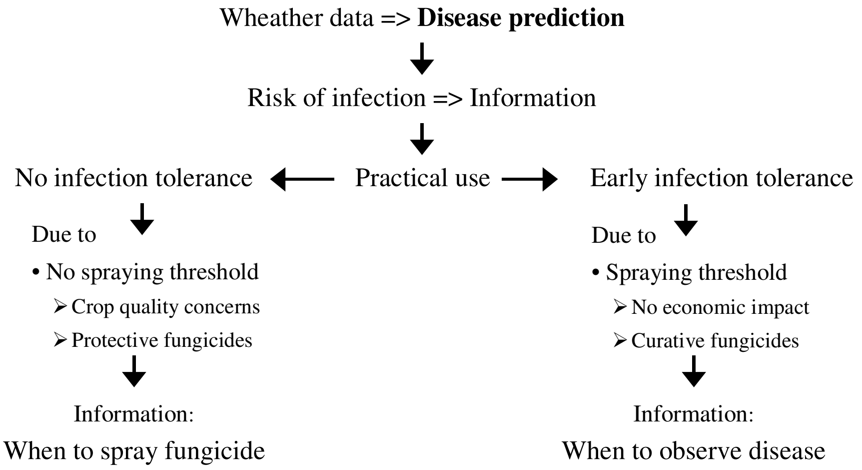


Figure 8: Practical use of disease prediction, dependent on crop specific tolerance of infection.

Epidemiological case studies are required on one hand, for the development of disease prediction models and essential for their validation with regard to practical implementation. The relationship between the influence factors and the epidemic onset is crucial here. Evaluation of influence factors is important as proper explanation about variations in occurrence of the pathogen can provide a greater chance for reliable prediction of the epidemic onset.

On the other hand, disease progression data and simulation of future disease development could provide good information, in particular, for an estimation of disease severity at harvest time. The risk of yield and quality losses can be assessed by comparing the economic damage threshold and predicted disease progress.

4 DECISION MODELS FOR FUNGICIDE TREATMENTS IN WHEAT AND BARLEY

4.1 Basic considerations

These decision models are based on epidemic thresholds for the precise timing of fungicide sprays. After performing qualitative and quantitative diagnosis, the user is able to decide on appropriate plant protection measures, which are optimized according to IPM demands, i.e., justified from both ecological and economic points of view [2].

The integrated management of fungicide applications is primarily oriented toward the epidemic of a pathogen (Fig. 9). It is based on the knowledge that the sequence and the disease severity of pathogen species is the consequence of interactions all among complex factors. [5, 2, 6, 7, 17]. Compared to prediction models that are primarily based on weather parameters, integrated decision models seek to reduce the probability of errors to a minimum providing that a reliable pathogen diagnosis is conducted. Extensive epidemiological studies which focus on critical pathogen populations that result in a high probability of an epidemic outbreak and in economic losses are required to establish such decision models. Epidemic thresholds have to be determined selectively and directed at the specific implications of any given pathogen. The aim of these models is to control the pathogen at the early, sensitive stages of an epidemic, resulting in an epidemic delay of several weeks. This is in many cases the period of transition from primary to secondary inoculum, which is followed by an increased risk of secondary infections. Thus, fungicide sprays intervene with the transmission of infection from basal to yield essential upper leaves. This strategy is focused on providing an optimum effect with a minimum input. Even so, the availability of effective fungicides is required. Thus IPM systems integrating decision models are intended to give field-specific guidance for the management of fungicide sprays by the farmer [2].

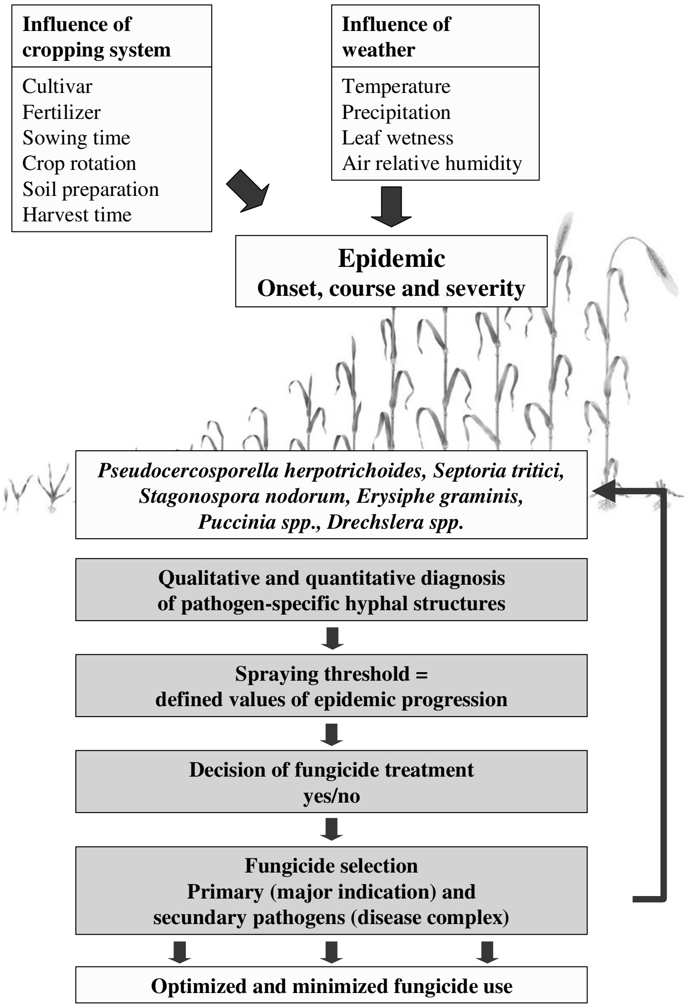
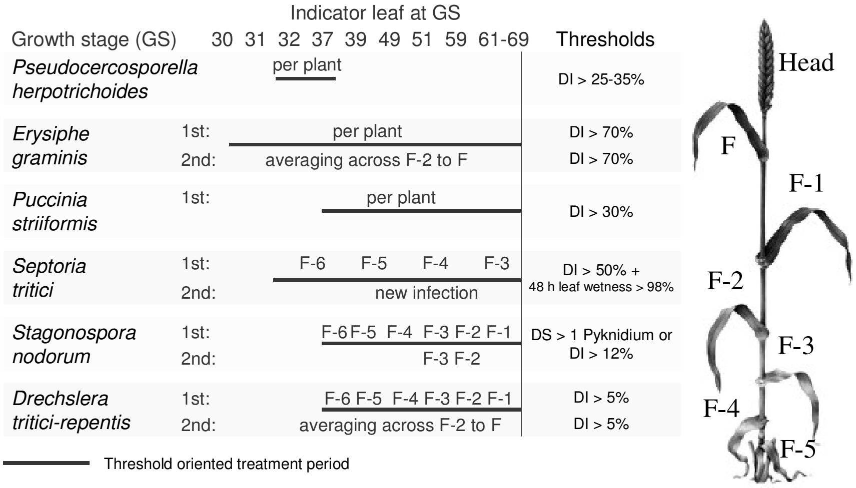


Figure 9: Schematic description of the decision model ”IPM wheat model“ for an optimum control of wheat diseases by minimized input of fungicides (Modified after Verreet, 1995).

4.2 Practical use of threshold-oriented decision systems

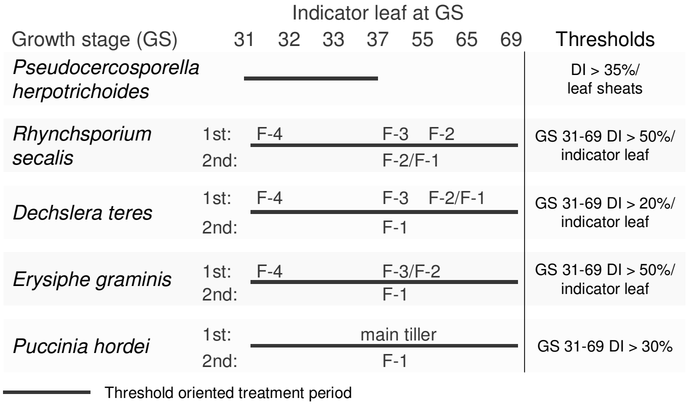
The effectiveness of the IPM models is best appraised with the aid of untreated monitoring plots (spraying width x 10-15 m). The remaining area of the field is treated according to the model. The success of the integrated approach can thus be assessed by comparing IPM model treatments with untreated controls with regard to the extent of an epidemic and the efficiency of the pathogen control method. For disease scoring purposes, incidence parameters have to be monitored on 30 randomly collected plants from the beginning of the risk period. A reliable assessment of the pathogen situation in the field involves the determination of the plant growth stage and leaf insertions, especially before the appearance of the flag leaf [6, 7, 19].



Growth stage (GS)		Indicator leaf at GS 30 31 32 37 39 49 51 59 61-69	Thresholds
Pseudocercosporella herpotrichoides		per plant	DI > 25-35%
Erysiphe graminis	1st:	per plant	DI > 70%
	2nd:	averaging across F-2 to F	DI > 70%
Puccinia striiformis	1st:	per plant	DI > 30%
Septoria tritici	1st:	F-6 F-5 F-4 F-3	DI > 50% + 48 h leaf wetness > 98%
	2nd:	new infection	
Stagonospora nodorum	1st:	F-6 F-5 F-4 F-3 F-2 F-1	DS > 1 Pyknidium or DI > 12%
	2nd:	F-3 F-2	
Drechslera tritici-repentis	1st:	F-6 F-5 F-4 F-3 F-2 F-1	DI > 5%
	2nd:	averaging across F-2 to F	DI > 5%

Threshold oriented treatment period

Figure 10: Decision scheme for threshold-oriented control of wheat diseases according to the IPM wheat model in Germany (Modified after Verreet and Klink, 2000).



Growth stage (GS)		Indicator leaf at GS 31 32 33 37 55 65 69	Thresholds
Pseudocercosporella herpotrichoides			DI > 35%/ leaf sheats
Rhynchsporium secalis	1st:	F-4 F-3 F-2	GS 31-69 DI > 50%/ indicator leaf
	2nd:	F-2/F-1	
Dechslera teres	1st:	F-4 F-3 F-2/F-1	GS 31-69 DI > 20%/ indicator leaf
	2nd:	F-1	
Erysiphe graminis	1st:	F-4 F-3/F-2	GS 31-69 DI > 50%/ indicator leaf
	2nd:	F-1	
Puccinia hordei	1st:	main tiller	GS 31-69 DI > 30%
	2nd:	F-1	

Threshold oriented treatment period

Figure 11: Decision scheme for threshold-oriented control of barley diseases according to the IPM barley model in Germany (Data after Appel, 1996).

Decisions regarding fungicide treatments are based on specific epidemic thresholds which were developed for the most important pathogens of wheat and barley through field experiments [25, 26, 12, 9, 27, 7, 28, 11, 29]. The implementation phases are defined by specific stages of the pathogen which pose risks for potential economic yield loss, provided that the early phase of an epidemic has commenced and the threshold value has been exceeded. In general, the threshold oriented risk periods are oriented to the growth stage (GS) of cereals [30]. The decision regarding the periods of implementation for cereal eyespot (*Pseudocercosporella herpotrichoides*), as an example, spans the growth stage two nodia (GS 32) till emergence of flag-leaf (GS 37) for wheat and from one nodium (GS 31) till GS 37 for barley (Figs. 10, 11). Fungicides should be applied only when the disease incidence on a certain leaf sheath has exceeded values of 25-30 % for wheat and 35 % for barley, respectively. A risk for other cereal pathogens is indicated with the beginning of stem elongation phase (GS 32-37) when secondary inoculum is appearing and therefore the risk of infections on higher leaves increases. In wheat and barley primarily, the yield essential leaves must be protected, which for wheat are the upper three to four leaves and for barley the centrally located leaves F-1 to F-4. Therefore, the monitoring period in barley is beginning at GS 31 (Fig. 11), whereas in wheat in most cases at GS 37 (Fig. 10). Only cereal mildew (*Erysiphe graminis*) has to be monitored from GS 30/31 on, because, from a small primary inoculum, a sudden transition to the epidemic phase may occur. The criterion for fungicide applications is here the occurrence of mildew pustules on 50 % (barley) or 70 % (wheat) of the plants. With the exception of cereal eyespot, the period of fungicide applications ends at the end of flowering phase (GS 69). When thresholds are exceeded later, fungicide applications are economically not justified.

4.3 Fungicide strategy

The fungicide strategy is directed primarily at major indicators of the pathogen which had first exceeded the threshold [19], for instance in many years powdery mildew or *Septoria tritici* is the major indicator. In addition, minor indicators of the pathogens, for example diseases caused by *Puccinia spp.* have to be observed, i.e. the entire disease spectrum including an outlook for future development and potential yield loss should be considered. Furthermore, assessment of the risk of secondary infections under the existing state of occurrence of the disease is needed to determine the choice of fungicides, i.e. active ingredient combinations to determine optimum efficacy. A threshold-oriented initial fungicide application typically inhibits the progression of the epidemic significantly obviating field monitoring over the following two weeks. Further epidemic progressions cannot be excluded, especially in the case of spraying before GS 41/49. Under favorable weather conditions, a spread of infection mostly to the upper leaves could be induced again. Subsequent treatments must therefore be based on observations of threshold exceeding on higher leaf positions.

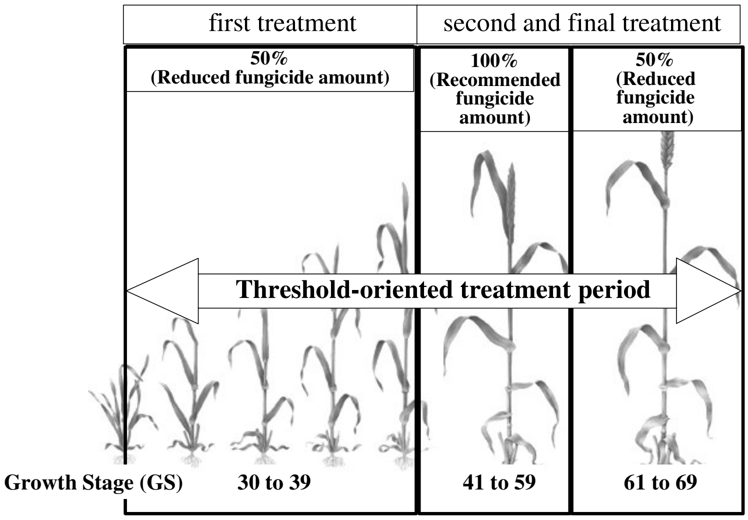


Figure 12: Fungicide strategy of the IPM wheat model (After Verreet and Klink, 2000).

Dosage of fungicides may be held flexible in accordance with the pathogen spectrum and the crop growth stage [19]. From early phases of the plant development to GS 39, fungicide doses often can be reduced to 50 % of the recommended dosage, particularly, when fungicide sprays are based on the thresholds and the epidemic is still in its initial phase (Fig. 12). The same system of applying reduced fungicide dosage could be applied for ensuing treatments from GS 61 onward. However, primary applications between GS 41 and GS 59 should be done at the recommended dose to achieve a prolonged fungicide effect, to avoid additional fungicide applications, and especially to protect the important period of kernel filling (GS 71-85). Furthermore, fungicides generally cannot be applied from these growth stages onward for adherence to waiting periods. But again, when thresholds for a primary treatment are reached initially at GS 61 on, 50 % of the recommended doses can be applied. The epidemiological data show the however slight effect of reduced fungicide doses on yield, which can be controlled with, even under conditions that are favorable for the pathogen. Nevertheless, the reduced doses provide effective control only under the regime of strict adherence to the threshold values.

4.4 Integration of climatic factors into the decision system

In addition to the threshold-oriented concept, under suitable conditions, IPM-models that include climatic factors can be developed. This has been accomplished for *Septoria tritici*, the major wheat pathogen in Northern Germany, and for *Rhynchosporium secalis*, ranked beneath *Drechslera teres*, as one of the major leaf spot diseases of barley. The weather-related fungicide strategy for both pathogens is based on the incubation time, i.e., the period from inoculation to the appearance of the first symptoms.

The initial infection period for *Septoria tritici* depends primarily on sowing time, soil cultivation (minimum tillage, ploughing), crop rotation (monoculture) and weather conditions [31, 29]. Dispersal of the asexual pycnospores depends on precipitation and temperature. Infections are predictable after precipitation >10 mm for three consecutive days or >5 mm over 48 hours with continuous moisture on the leaf surface [27, 32, 33, 19]. Consequently, an outbreak of symptoms could be observed within four weeks (Fig. 13). Only when the two criteria are fulfilled, i.e., the threshold of DI >50 % on leaf F-6 has been surpassed, followed by an infection phase of uninterrupted moisture on the leaf surface for >48 hours, will fungicide application be required [29, 19].

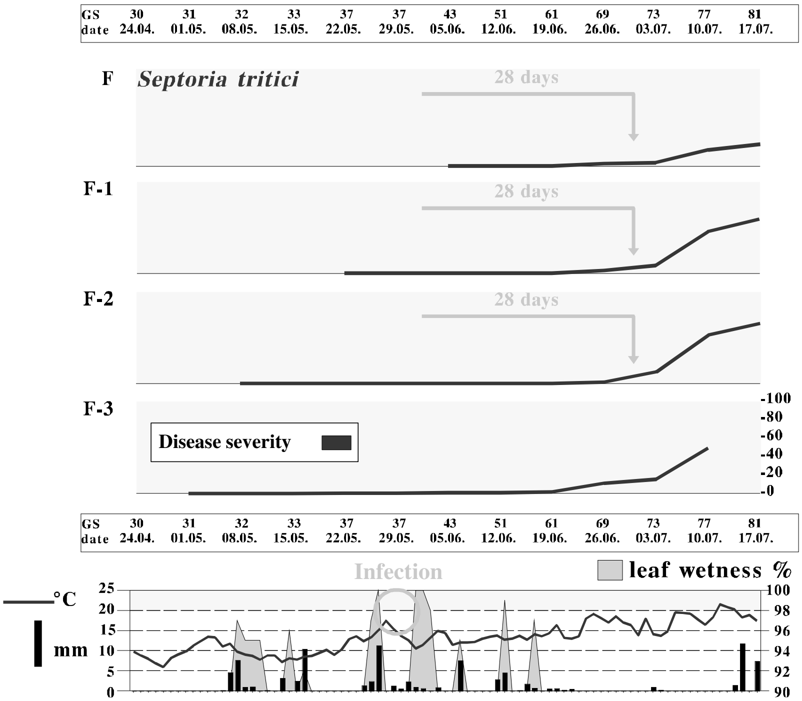


Figure 13: Dynamics of the latent period (28 days) and disease severity of *Septoria tritici* in relation to the infection conditions (leaf wetness period >48 h and relative humidity >98%) on the leaf positions F-3 (fourth from top) to F (flag leaf) in the untreated control; variety Pepital, site Klausdorf/Fehmarn, 1995. Disease severity of *Septoria tritici* = number of pycnidia per leaf, sampling period from growth stage GS 30 to GS 81 (After Verreet and Klink, 2000).

Leaf wetness data record provided by datalogger “Septoria-Timer” (Thies, Göttingen).

Regarding *Rhynchosporium secalis*, it was found that a period of 200 °C days (Sum of average °C/day) after precipitation was required for initiation of spore germination and symptom expression [11]. In addition, DMI- (demethylation inhibitor) fungicides like Tebuconazole, Flusilazole and Epoxiconazole offered a significant remedial effect which provided nearly complete suppression of the development of symptoms, until a sum of 120 °C-days (Fig. 14). Thus, fungicides need not be applied immediately after a threshold has been exceeded, but may be delayed until the additional weather criteria is met, leading frequently to a reduction of fungicide sprays. The determination of the °C day values was simplified for the farmers with the aid of a simple flow chart which substituted complex techniques of temperature measurement (Fig. 15). The chart is based on averaged data determining the limit of fungicide waiting times for different periods within a season. For instance, under the weather conditions of Southern Germany, the remedial effect concerning *Rhynchosporium secalis* is established between eight and sixteen days, depending on the season from mid-April to the end of May.

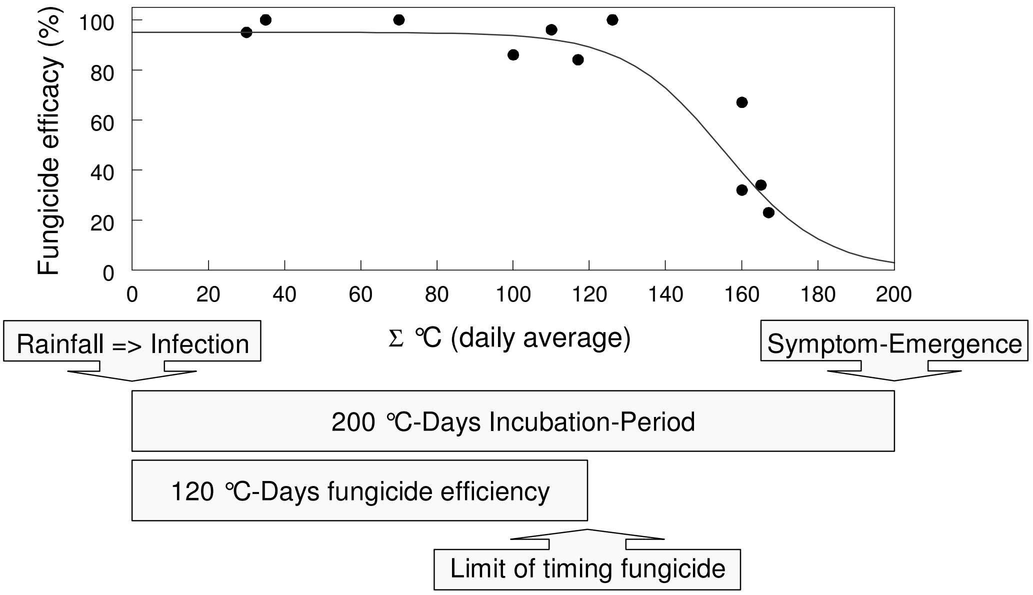


Figure 14: *Rhynchosporium secalis*: Dependence of fungicide effects on the incubation time determined by the sum of daily average °C (Data from Appel, 1996).

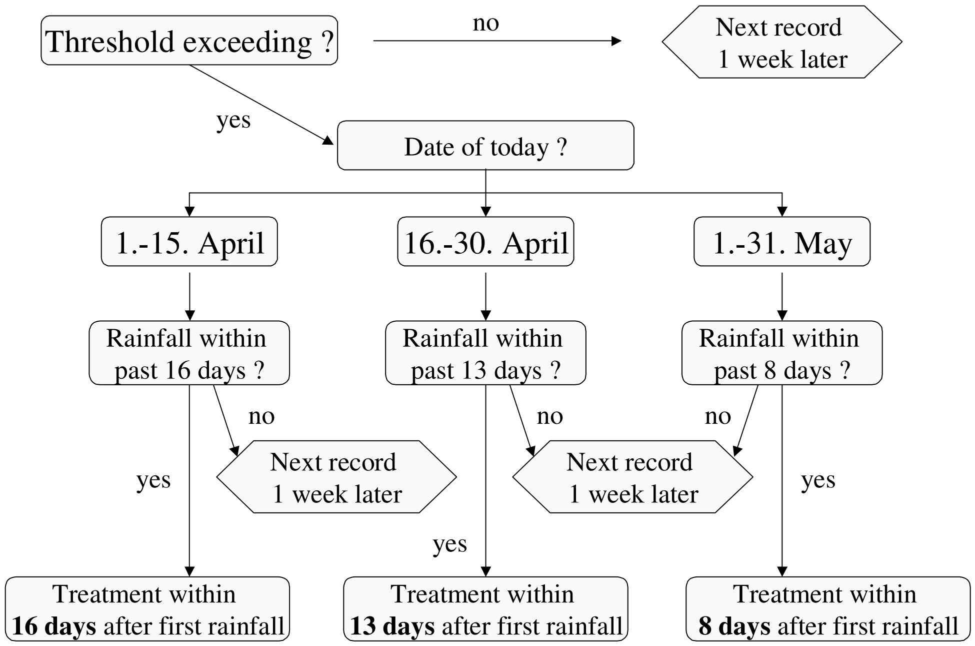


Figure 15: Decision scheme for the fungicide control of *Rhynchosporium secalis* in barley based on threshold values and weather data exceeded (After Appel, 1996).

5 QUATERNARY IPM SYSTEM FOR SUGAR BEETS

Leaf diseases affect crop yield and quality of sugar beet (*Beta vulgaris ssp. vulgaris*), especially after canopy closure during late periods of the growing season. In most growing areas, *Cercospora beticola* is the most important leaf spot disease of sugar beets [34, 35, 31]. Powdery mildew (*Erysiphe betae*) is more adapted to arid zones [36, 37] whereas *Ramularia beticola* is more adapted to the humid climate [38, 35]. The risks of losses caused by these pathogens require the application of fungicides in several sugar beet growing regions. However, as in cereals, the damage potential is highly variable depending on year, location and cropping measures [15, 16, 17]. Some unique characteristics of sugar beets which must be considered in developing IPM systems. Sugar beet is a biennial species that usually flowers in the second year. However, as a crop beets are harvested at the end of the vegetation period of the first year. The ontogenesis thus shows a successive exposition of leaves with a relative absence of leaf senescence except other than older leaves [17]. The objective of cropping measures in sugar beets is to attain high sugar content and reduced impurities. The following concept focuses on *Cercospora beticola*, but it may also be applied to other host-parasite systems under similar conditions.

5.1 Current disease prediction concepts

Because sugar beets usually are free of fungal leaf diseases during their early phase of development, there should be a good outlook for predicting the onset of an epidemic. In the past, some prediction-models were presented for *Cercospora beticola* which were mainly based on weather conditions. The question is whether these models are able to predict the epidemic onset satisfactorily in order to decide on plant protection measures directly.

Rossi et al. [39, 40, 41] presented a model "CERCOPRI" (*Cercospora* primary infections) where weather related infection probabilities are calculated under addition of daily average temperature >5°C or relative humidities >60%. The totals were calculated from the beginning of the year and percentiles of disease appearance were primarily deduced from relationship of the temperature totals to higher and lower relative humidity (RH). Symptoms became evident within a range of 1000–1700°C-days (Fig. 16). Hence, this model defines the extent to which the outbreak of disease is likely after exceeding a minimum degree-day value. The authors emphasize that the model was applicable primarily in the region where it was developed.

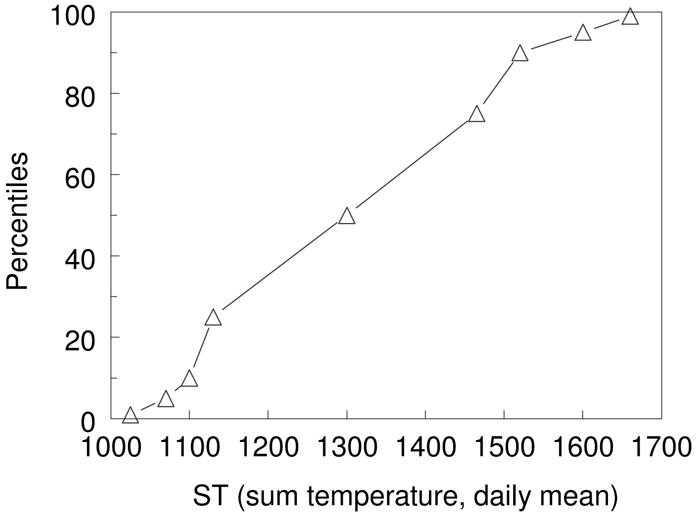


Figure 16: Appearance of primary infections of *Cercospora beticola*, computed with sum temperature, daily mean (ST), western Emilia, Italy (After Rossi et al., 1991).

Results from greenhouse trials in combination with published data [42] formed the basis of the *Cercospora* infection model that was developed by Shane et al. [43, 44]. This model was further modified by Windels et al. [45], with emphasis on effective introduction into practical farming. Daily infection values (DIV) are derived from temperature and relative humidity. DIV range between 0 and 7 and are calculated based on the number of hours per day with RH ≥90% and the average temperature during these hours (Fig. 17). For the *Cercospora* prediction, the DIV for two consecutive days are taken and summed together. If the DIV sum was < 6, the infection probability was low; a sum of 6 represented "marginal" infection probability and sums from 7 to 14 signify favorable conditions. The authors concede that the DIVs sometimes did not account for the incidence of *Cercospora* leaf spot observed in the field and recommend an additional field monitoring

hours/day ≥90 % RH	Daily Infection Values																																		
24	1	2	4	5	5	6	6	6	6	6	6	6	6	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	3
23	1	2	3	4	5	6	6	6	6	6	6	6	6	6	6	6	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	3
22	1	1	3	4	5	6	6	6	6	6	6	6	6	6	6	6	6	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	3
21	0	1	2	4	4	5	5	5	5	5	5	6	6	6	6	6	6	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	3
20	0	1	2	3	4	5	5	5	5	5	5	5	6	6	6	6	6	6	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	3
19	0	0	1	3	4	5	5	5	5	5	5	5	5	6	6	6	6	6	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	3
18	0	0	1	2	3	4	4	4	4	4	4	5	5	5	5	5	5	6	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	3
17	0	0	1	2	3	4	4	4	4	4	4	4	5	5	5	5	5	5	6	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	3
16	0	0	0	2	3	4	4	4	4	4	4	4	4	4	4	4	5	5	6	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	3
15	0	0	0	1	3	4	4	4	4	4	4	4	4	4	4	4	4	5	6	6	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	3
14	0	0	0	1	3	3	3	3	3	3	3	4	4	4	4	4	4	4	5	6	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	3
13	0	0	0	0	3	3	3	3	3	3	3	3	4	4	4	4	4	4	5	6	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	3
12	0	0	0	0	2	3	3	3	3	3	3	3	3	4	4	4	4	4	4	5	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	3
11	0	0	0	0	2	3	3	3	3	3	3	3	3	3	3	3	3	3	4	5	6	7	7	7	7	7	7	7	7	7	7	7	7	7	7	3
10	0	0	0	0	2	2	2	2	2	2	2	3	3	3	3	3	3	3	4	4	6	6	7	7	7	7	7	7	7	7	7	7	7	7	7	3
9	0	0	0	0	2	2	2	2	2	2	2	2	2	2	2	2	3	3	3	4	5	6	6	6	6	6	6	6	6	6	6	6	6	6	6	3
8	0	0	0	0	1	2	2	2	2	2	2	2	2	2	2	2	3	3	3	3	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	3
7	0	0	0	0	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	3	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	3
6	0	0	0	0	0	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	3	4	4	4	4	4	4	4	4	4	4	4	4	4	4	3
5	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
4	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
3	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
2	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
°C	16	.	.	.	.	18	.	.	.	.	21	.	.	.	.	24	.	.	.	.	27	.	.	.	.	29	.	.	.	.	32	.	.	.	.	35

Figure 17: Daily infection values (DIVs) for *Cercospora* leaf spot on sugar beet calculated from the number of hours per day (24 h) with relative humidity (RH) ≥90% and the average temperature during those hours (After Windels et al., 1998).

The IPM sugar beet model also includes a concept for predicting the epidemic onset of *Cercospora beticola* [17]. For validation purposes, the definition of epidemic onset was the time when ≥50% of beet plants showed at least one lesion on one leaf instead of first symptom appearance, which is very hard to determine.

The effect of temperature was quantified by the latent period (LP) which is defined here as including the entire period from inoculation, germination of conidia, infection, symptom emergence towards the production of conidia. This LP was determined under controlled conditions in growth chambers [46]. The quantitative effect for temperature is expressed by the proportion of LP_x (latent period at current temperature x) and LP_{opt} (latent period at optimum temperature) and calculated hourly as DIV, which ranged between 0 (no infection possible) and 1 (optimal conditions).

Condensation on the leaf surface is obligatory for infection and occurred under field conditions with 75 % probability when relative air humidity was >90%. Therefore, the temperature dependent calculated DIVs were set to 0 in cases of relative air humidity <90% and absence of precipitation, because infections being rather unlikely under these conditions [17].

In order to express the relationship between disease onset and weather conditions, cumulative DIV (c-DIV) was introduced and determined by adding the daily DIVs [17]. The procedure is illustrated in Figure 18. From the time of row closure till epidemic onset, DIV ranged from 0.06 to 0.61 (Fig. 18A). Higher DIV values correspond with higher humidity and precipitation (Fig. 18B). In this field study, a c-DIV of 9.8 was determined. The period of c-DIV is held flexible from canopy closure to disease onset. The flexible start of c-DIV takes into consideration the effect of crop development on microclimate due to a longer period of accumulation of condensed water on the leaf surface and relative humidity within the crop after canopy closure [47, 46]. This formula was confirmed by the appearance and observation of first symptom three weeks after canopy closure at the earliest [15, 16]. Thus, it must be assumed that infection takes place mainly after closure of beet rows and, therefore, weather events prior to this event may be relatively unimportant.

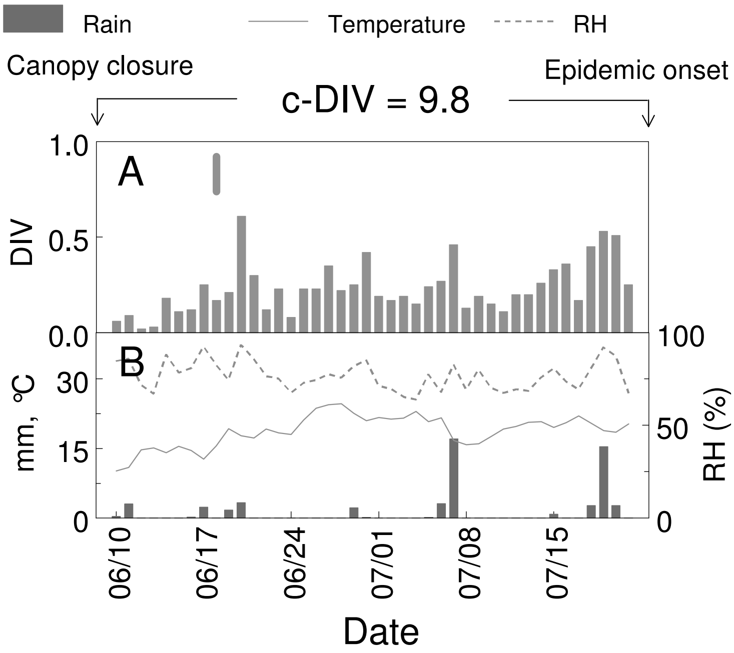


Figure 18: Calculation of daily infection values (DIV) from canopy closure till epidemic onset (A) in relationship to weather conditions (B) (After Wolf, 2002).

The next objective was to explain the differences in times of disease onset, which appeared in the field studies over different years, cultivars and sites. This was done by comparisons of c-DIV and the expectation that the extent of variance will be small. This examination is crucial in order to assess the accuracy of disease prediction. In the first result, cultivar resistance had a big impact on c-DIV and therefore has to be considered as an important determinant (Fig. 19). The most important observation was the difference between minimum and maximum values of c-DIV, which ranged between 7 and 19 for highly susceptible cultivars and 12 to 25 for cultivars with a lower susceptibility. These values indicate a relatively high variance and, therefore, do not explain the epidemic variances of past field experiments satisfactorily. Consequently, this approach was also considered to be unsuitable for predicting the precise time of epidemic onset in future growing seasons.

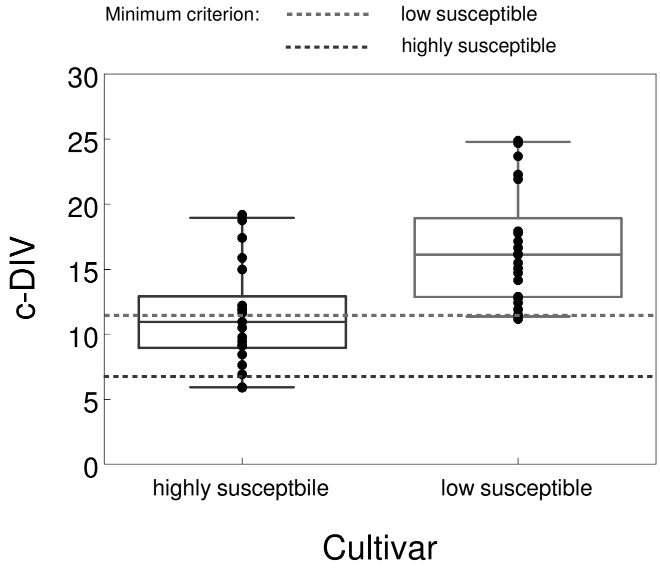


Figure 19: Variation of c-DIV (cumulative DIV) and deduction of minimum criteria for Negative-prognosis; highly susceptible varieties, left (n=22), varieties with lower susceptibility, right (n=21) (After Wolf, 2002).

Legend for Box-Whisker graph:
The box shows the range between the 25th and 75th percentiles, the horizontal line indicates the median value, the whiskers extend from the edge of the box to the 5th and 95th percentiles.

Overall, the models discussed here are able to describe weather dependent risk of infection, but seemingly fail to predict the exact time of disease onset. They have to be considered as approximations of reality. In addition, they are only valid under defined conditions such as a distinct regional cropping situation (climate, growing density, cropping measures and techniques). Most models lack proper information about the inoculum potential because a field specific analysis of soil contamination is expensive. Besides, the above-presented models provide not a proper basis for direct decisions on plant protection measures.

5.2 Improvement through combination of IPM tools

It is obvious that a single tool like disease prediction is not adequate to fulfill the demands of IPM, e.g. the reduction of fungicide input to a minimum while optimizing yield factors. The most distinct innovation of our model lies in the effective combination of IPM tools (Fig. 20). The model may thus be characterized as quaternary as it involves four elements, which are i) negative-prognosis of disease incidence [17], ii) acting thresholds [21, 20, 22, 16]], iii) the determination of the economic damage threshold [48, 16, 17], on which iv) the prediction of yield losses is based on [16, 49]. The diagnosis has a key-function, as no IPM-tool mentioned here is working without an exact identification of disease symptoms. Overall, the principle of combining IPM tools may be applied to many other host-parasite systems, in particular to those with tolerable initial infection.. This is the case when quality and yield of the crop are not affected at the disease level of a acting threshold and when fungicides are available that are highly effective in controlling diseases at initial epidemic stages. The following presentation is mainly focused on the arguments as to why IPM tools must be linked.

Because attempts at predicting the exact time of the epidemic onset have failed, another option is to attempt forecasting periods with a high probability that no infection will occur. By this negative-prognosis efforts in disease observation may be saved and information when monitoring should begin are provided. It is the first tool to be applied during a growing season. The disease-free period can be determined by setting minimum values of c-DIV when a disease onset occurred (Fig. 19). The threshold value here is established at 7 for highly susceptible varieties, while in the case of less susceptible varieties, the disease onset was not observed until a total c-DIV of 12. When these thresholds are exceeded, disease onset cannot be excluded anymore and has to be expected with increasing probability. For these definitions, the best approach in starting addition of DIV, the flexible origin of c-DIV by canopy closure, is applied [17].

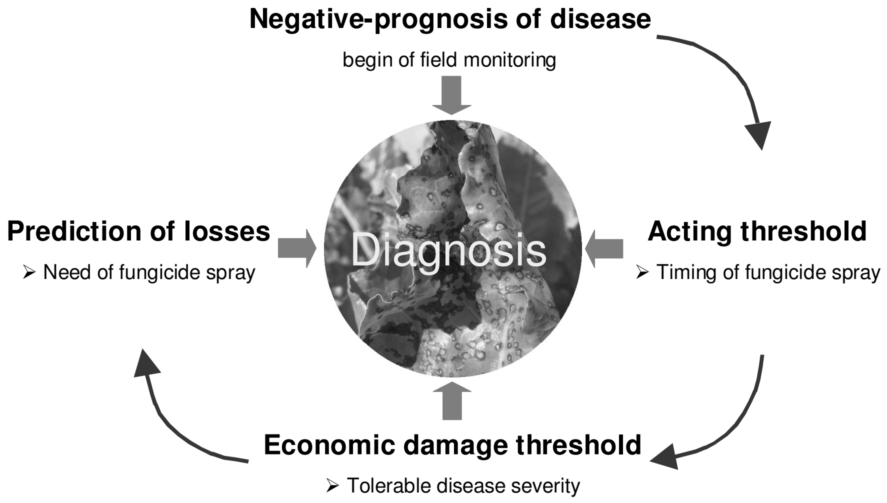


Figure 20: Innovative combination of IPM tools and their sequential use in a growing season.

The system and use of the negative-prognosis are demonstrated in Fig. 21. Based on the weather conditions (Fig. 21A), the daily infection values from canopy closure on are calculated (DIV, Fig. 21B). The date when disease onset of *C. beticola* can no longer be ignored is deduced from the c-DIV (Fig. 21C). This is revealed at the crossing point of c-DIV and minimum criteria, i.e., in this case July 13 for susceptible varieties and August 9 for less susceptible varieties. The monitoring of the crop has to start then in order to determine the actual disease onset.

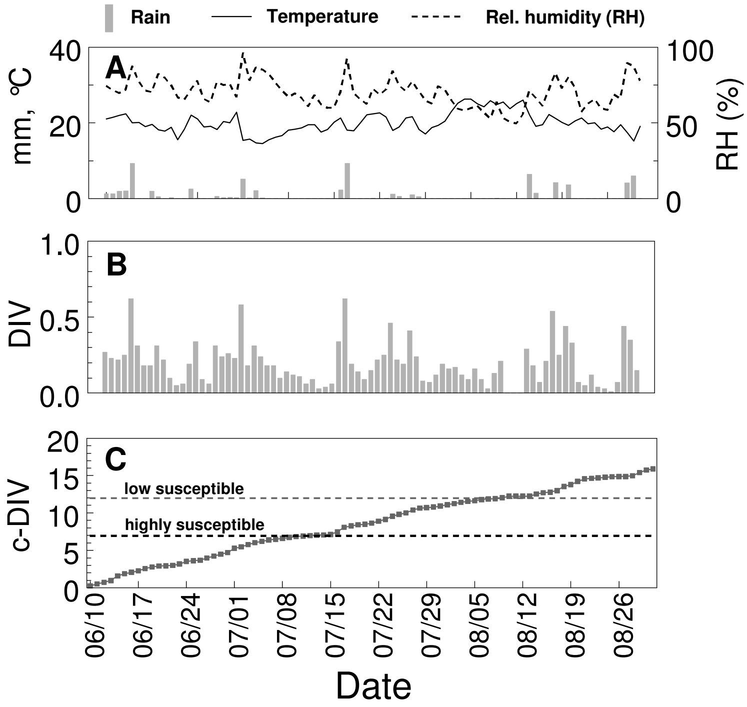


Figure 21: Weather conditions (A), daily infection values (B) and negative-prognosis (C), in cases when the minimum criterion is exceeded by c-DIV and field monitoring is recommended.

5.2.2 Acting thresholds

Acting thresholds determine the optimum date for fungicide applications. Crucial components of monitoring are the diagnosis and quantification of diseases as well as assessment of fungicide sprays oriented to acting thresholds. In order to reach the objective of optimizing the efficiency of fungicide sprays, successive stages of the epidemic were assessed for thresholds to determine the precise time for application. The results show that sprays at the onset of disease epidemic are most effective and suitable for a practical application [21, 20, 15, 22, 16]. Applications should be carried out at a disease severity between 0,01 and 0,2% of infected leaf area. Later applications decrease the efficacy to less than 80 % (Fig. 22). Even modern DMI- and QoI-fungicides are not effective enough to stop a highly aggressive epidemic. Nevertheless, epidemic thresholds as a single tool are not sufficient to accomplish above-mentioned objectives of IPM. Despite the utilization of threshold values as the basis for the fungicide spraying schedule, incidences of lack of yield response to spraying have been observed, in particular when the epidemic was delayed in the later periods of the growing season. The reason is that a acting threshold is indicative of the time for a highly effective spray but not decisive in determining economic damage.

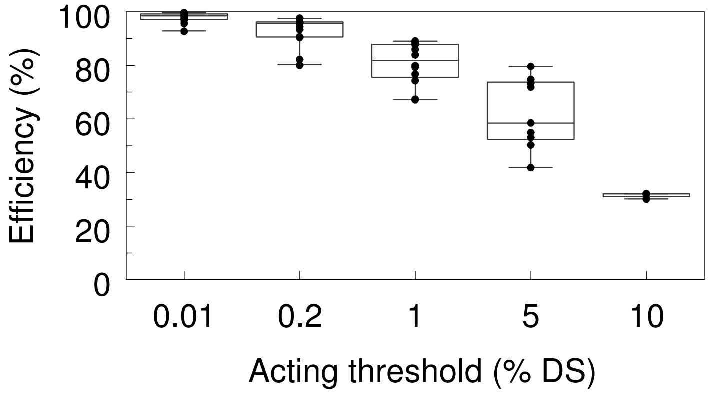


Figure 22: Efficiency of disease control by using disease severity (DS = % infected leaf area) as acting threshold for the timing of fungicide sprays. Each single point (mean of 4 replications = plots) is representing the result of one field experiment, for instance of one year, site and cultivar (Data from Weis, 1998). Efficiency (%) = (1-$\text{AUDPC}_{\text{acting threshold}}$ / $\text{AUDPC}_{\text{control}}$)*100.

5.2.3 Economic damage threshold

Unlike the acting threshold, the economic damage threshold is related to the tolerable disease level at the end of the season [48, 16]. At this disease level, application costs would equalize the benefits of disease control. The definition of the economic damage threshold is based on a disease loss relationship (Fig. 23) and follows the principles which were presented in chapter 3.2.3. The relationship between the disease severity at the end of the season and the sugar loss shows a linear character. Sugar losses ranged from 0-35% depending on disease severity. The economic damage threshold is a degree of disease severity (DS) 3-5% infected leaf area beyond which percent sugar is linearly related.

5.2.4 Prediction of losses

Once the acting threshold is surpassed, loss prediction must occur as the disease level at an acting threshold does not correspond with actual damage. Depending on site-specific conditions, the epidemic requires a period of at least five to ten weeks to proceed from the disease level at the acting threshold (0.01% DS) towards the economic damage threshold (3-5% DS)

[48, 16]. Hence, the importance of the time at which the threshold is exceeded, cultivar resistance, and scheduled harvest time for the prediction of yield losses is obvious. A fungicide application is necessary when the predicted disease severity exceeds the damage threshold before the scheduled harvest time. The weather is not considered because predictions are to be implemented over a period of four weeks, and weather forecasts are not reliable over such duration.

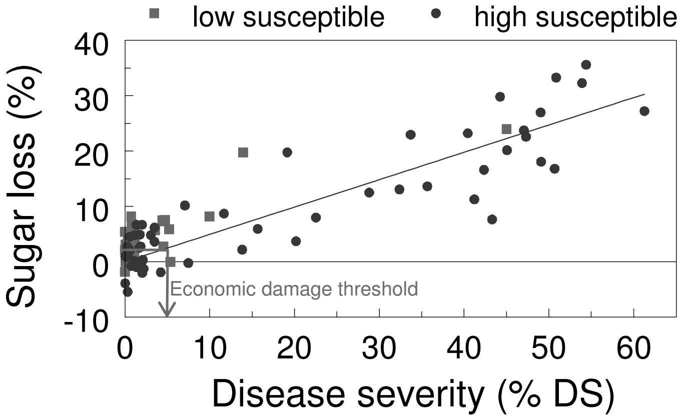


Figure 23: Disease-loss relationship of *Cercospora beticola* in sugar beet; definition of the economic damage threshold = 5 % DS, corresponding loss of recoverable sugar = 2-3% (After Wolf and Verreet, 2002).

Regression ($p=0.05$):
Sugar loss (%) = 0.45 * DS; $r^2 = 0.80$

Loss prognosis is based on real case studies of disease progression in the field. The model is therefore empirical on one hand and deterministic on the other [49]. It is deterministic because the prognosis depends on the input of the actual date to be precise; disease incidence per leaf (% DI/L in the range of 3-50%, sample n = 100 leaves) and cultivar resistance, which determine the prediction of future disease progression. The loss prediction is developed through selection of case studies, which depend on the date (calendar week) of epidemic onset and resistance of cultivar (high and low susceptibility). The mean, minimum and maximum of selected disease progressions were calculated and forecast of disease progression was performed by the mathematical model:

$DS = DS_{min} + DS_{max} / (1 + \exp(-(CW-a)/b))$,

where DS = disease severity, DS_{min} = minimum disease severity, DS_{max} = maximum disease severity, CW = calendar week, a and b = variables which depend on actual DS and cultivar resistance. Figure 24 illustrates three examples of different threshold-exceeding times. For instance, if the acting threshold is reached on July 23, a highly progressive epidemic is predicted to develop. There is an absolute need for fungicide application because harvest time mostly takes place in the period from October till November, at least in Central Europe. Fungicide application is only conditional if the acting threshold is exceeded on August 6. Disease progression is rather moderate, and whether there is a yield risk depends on harvest time. In this example, fungicide applications can be avoided if harvest takes place before October. However, in the case of threshold being surpassed on August 20, no fungicide application is necessary. The progression remains below the damage threshold up to the end of the season.

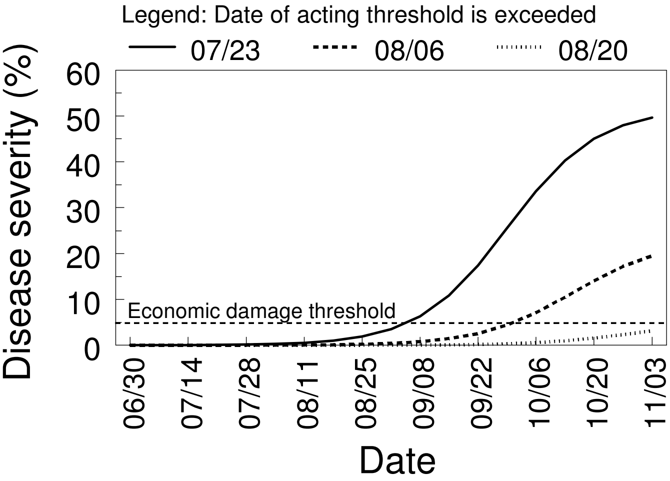


Figure 24: Prediction of disease progression in dependence of threshold exceeding time (acting threshold = 0,01 % DS, cultivar low susceptible); a fungicide spray is necessary, when the economic damage threshold is exceeded before the scheduled harvest time.

6 IMPLEMENTATION INTO PRACTICE

The development of IPM models originates from basic scientific research, where the results and definitions are typically hard to communicate to farmers. In addition, application of plant protection measures under the concepts of IPM is not possible without knowledge gained from efforts in field observation and assessment of disease incidence. Despite the practical nature of the IPM models, it is conceivable that implementation will not be successful without simplification and transfer of information on how to use the models. Farmers vary in their management styles and have a range of priorities in addition to plant protection, and are extremely diversified in their educational backgrounds.

6.1 Simplification of models

Simplifications of the models are frequently possible without a loss of precision. Such a simplified decision scheme for fungicide treatments in sugar beets that includes all required information is presented in Figure 25.

The bars represent risk periods when a threshold has been exceeded and the left margin of the upper bar in relation to the calendar, when disease monitoring is to be initiated. The latter refers to the earliest time of epidemic onset which is based on a simple negative prognosis from empirical observations. For example, the epidemic onset of *Cercospora beticola* was observed at the beginning of July at the earliest. Therefore, before this date, the exceeding of the acting threshold can be excluded with high probability and observations are not necessary. The method of leaf scoring is also simplified while diagnosis is not abandoned. The thresholds are now defined as percentage of infected leaves (DI/L) instead of estimations of infected leaf area and are based on a sample of 100 beet leaves that were picked from the middle of the leaf mass (Fig. 26). Loss prediction is included since application of fungicides will not be required after threshold exceeding has taken place, and that period indicated by the light gray bars (Fig. 25).

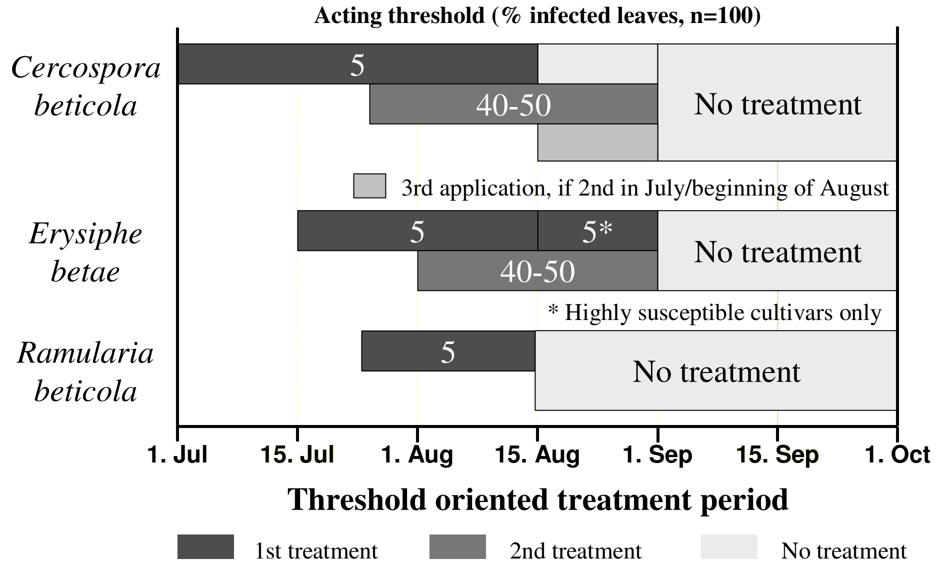


Figure 25: The IPM sugar beet model in summary for *Cercospora beticola*, *Erysiphe betae*, and *Ramularia beticola*. The numbers in the bars represent the thresholds oriented to the frequency of infected leaves (DI/L). The columns indicate the threshold oriented treatment periods related to a yield risk when a threshold is exceeded and therefore a fungicide spray is required. (Modified after Wolf and Verreet, 2002).

6.2 Monitoring and transfer of information

Despite simplifications, we assume that only a few farmers would be willing to put efforts into weekly observations and disease scoring. The likelihood of putting the concept into practice is low, because of a demonstrated preference by farmers for simple prescriptions for action.

Field monitoring, carried out by advisory services with well-trained staff or trained farmers familiar with diagnosis and disease scoring could provide a suitable solution to this problem. Considering the stage of the crop's growth and location, a weather-based negative-prognosis may indicate when monitoring should begin. The negative-prognosis show the current risk of disease onset and may be published via the internet (Fig. 27). Data on disease monitoring which provides the real-time information in the field is currently available on internet sites of sugar or chemical companies as well as advisory services. Newsletters sent directly to the farmers or publications in journals complete the means providing information to the farmers. Nonetheless, this information only provides an assessment of the current situation and still may deviate from the aim of field specific treatment. Even within given geographical regions with identical climate and cropping systems, the onset of epidemics of diseases may vary in a wide range. Thus, the farmer is still responsible for monitoring his or her fields and deciding on the necessity of a fungicide treatment.

7 SUMMARY

The concept of IPM includes preventative measures such as crop rotation, soil preparation, cultivar resistance, etc. in order to interrupt the chain of infection. Despite the acknowledgment of these principles and their practical application, the occurrence of losses from disease epidemics may not be precluded. Fungicide treatments remain the only means of interference with an current epidemic and thus, secure yield and quality of the crop. Concerns over the impact of synthetic chemicals in the environment have directed attention of scientists toward developing concepts that reduce the chemical load on the environment on one hand while optimizing the economic benefits on the other hand.

Method of disease scoring

Sample = 100 leaves (1 per plant) from the **middle** of the leaf mass, picking up whilst going diagonally through a beet field

Diagnosis of symptoms

through identification of hyphal structures by the aid of a lens

Naked eye **Pocket lens**

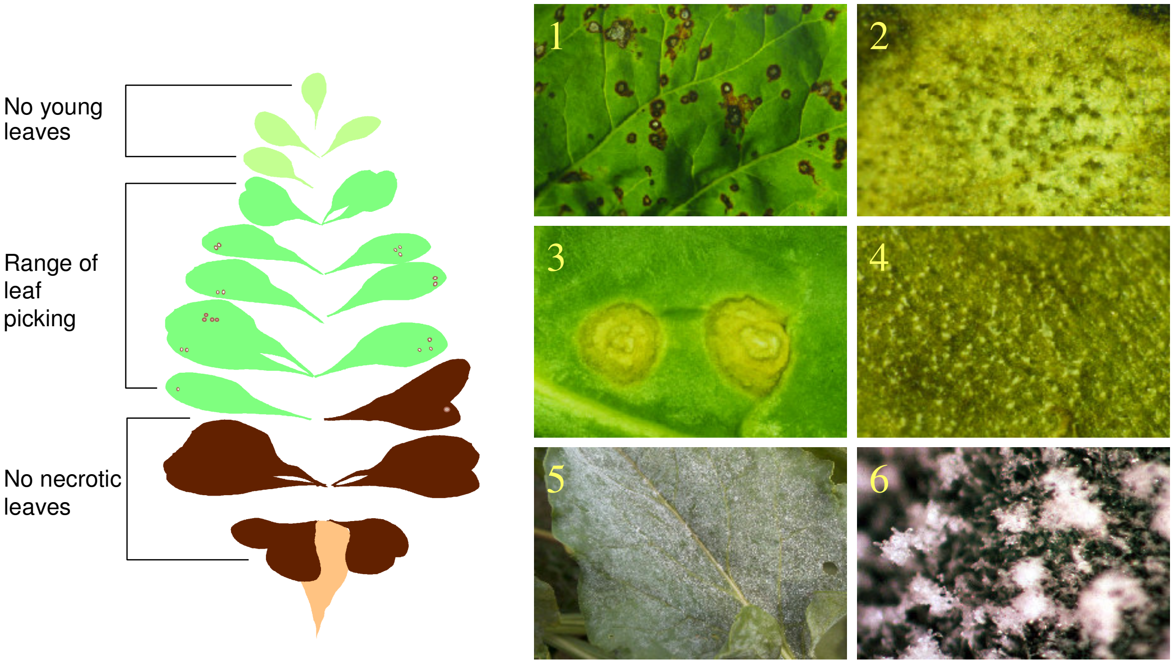


Figure 26: Implementation of the IPM sugar beet model into practice; method of disease scoring (left), diagnosis by naked eye and identification of hyphal structures with pocket lens (right). Pictures: *Cercospora beticola* (1,2), *Ramularia beticola* (3, 4), *Erysiphe betae* (5,6) (Modified after Wolf and Verreet, 2002).

Management of fungicide treatments under the principles of IPM is not possible without insight into the epidemiology of diseases and knowledge of their diagnosis. Therefore, IPM requires efforts in disease monitoring as well as accurate assessment of symptoms of the causal agent.

Analysis of different IPM-tools has shown that the weather-based prediction of diseases is quite difficult. The models described here present complex processes in nature which are not always adequate and therefore may be considered to be more or less approximations of real situations.

How to use predictions in practical farming depends on the specific host-parasite system. If disease incidence isn't tolerable at all, fungicide are to be applied preventative and disease prediction may serves as the only basis for the timing of treatments in a flexible manner. On the other hand, where at least the initial stages of an epidemic may be acceptable, the likelihood of infections may serve as information about the risk of epidemic onset, especially in determining when to begin field observations. During field monitoring, the exceeding of pathogen-specific thresholds serve as crucial indicators because they pinpoint the proper timing for fungicide sprays. Threshold oriented treatment periods signify a yield risk in case of a acting threshold being exceeded. Loss prognosis, which is based on computation of disease progression in relations to the economic damage threshold, may define the yield risk. Only when disease progress is predicted to exceed the economic damage threshold before the scheduled harvest time a fungicide treatment is necessary.

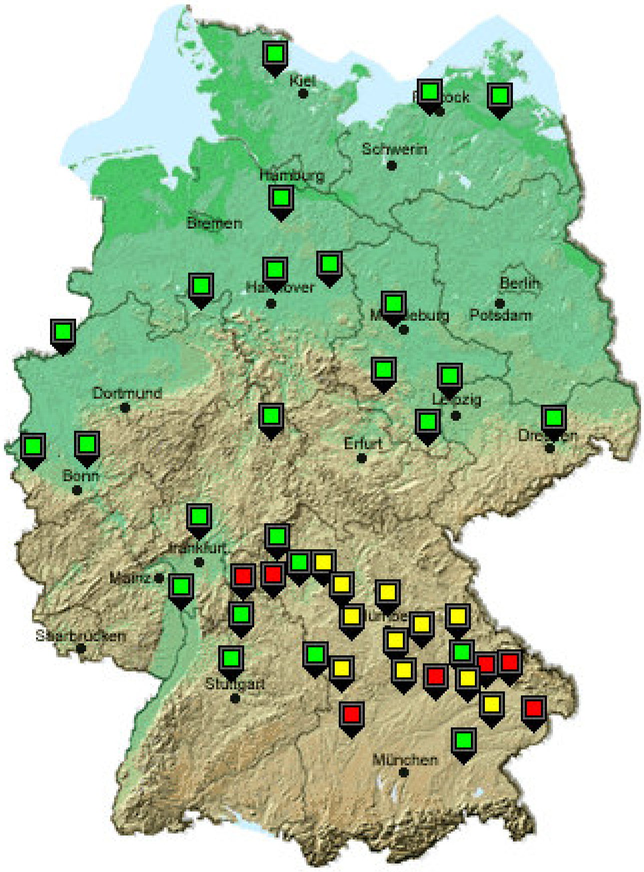


Figure 27: Negative-prognosis of *Cercospora beticola* in Germany, displayed by the internet (**www.ips-zuckerruebe.de**); every pin marks one site with a weather station where different colours indicate the risk of epidemic onset: green colour = no risk, yellow = low risk, red = high risk.

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