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An Integrated Pest Management System in Germany for the Control of Fungal Leaf Diseases in Sugar Beet

The IPM Sugar Beet Model

Only two crops are available for the production of sugar. Sugar cane is the most common in tropical areas, while sugar beet is the source in the more moderate climate conditions of central and western Europe. Currently, approximately 37% of world sugar is produced from sugar beet (3). In Germany, sugar beet cultivation still offers a high monetary return while profits for many other crops are decreasing. The market structure for sugar beet cultivation is based on European sugar beet market quotas, which have the goal of avoiding overproduction by limiting cropping areas and keeping prices stable for European Union (EU)-produced sugar. In Germany, sugar beet is grown on 504,000 ha (24.7% of the European Union sugar beet area). The average German sugar yield in 1997–98 was 7.96 t/ha, rising to 11.1 t/ha in southern Bavaria. The production in Europe, as in Germany, is highly intensive and directed at achieving high yields and quality.

Sugar beet diseases pose serious threats to high production standards (Fig. 1). *Cercospora beticola* is the primary leaf pathogen of sugar beets in Germany, especially in regions with frequent rainfall and average daily temperatures of 20 to 25°C (5,6). Yield losses of 10 to 30% and recoverable sugar yield reductions of up to 50% have been observed for this disease (4,7,13–17,25,26). Economic losses may reach US$1,500/ha. Powdery mildew, caused by *Erysiphe betae*, is also common during hot, dry summers (2,8,10). However, sugar losses (about 5 to 15%) tend to be lower than for Cercospora leaf spot (1). Less important are leaf diseases caused by *Ramularia beticola, Uromyces betae,* and *Phoma betae*. These diseases normally appear late in the growing season or are slow to develop. Therefore, no control measures are required (7).

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In the past, sugar beet leaf diseases were often controlled by applying fungicides on fixed-calendar schedules or growth stages. In many cases, these treatments were applied without regard to cultivar resistance or weather conditions. Additionally, management decisions were often adversely affected by poor disease diagnosis. A new approach was needed to provide adequate disease control while effectively reducing the chemical load on the environment (Table 1). Sugar beet processors, as well as farmers, were interested in achieving high-quality crops because disease incidence increased impurities in molasses that influenced sugar solubility and reduced crystallization of sugar during the production process. After the scientific issues had been established, the sugar beet companies supported the introduction of the integrated pest management (IPM) model in farming (Fig. 2).

Fig. 1. Leaf damage caused by *Cercospora beticola* (right) compared with plot receiving fungicide applications according to the integrated pest management (IPM) sugar beet model (left).

Table 1. Targets of the IPM (**I**ntegrated **P**est **M**anagement) sugar beet model

Principles of development

- Scientific based research
- Useful definitions for practical purposes
- High acceptance by farmers

Impact of introduction into practical farming

- Optimal efficacy and economy of fungicide spraying
- High quality of sugar beet for sugar production
- Reduction of the chemical load on the environment

Disease Diagnosis: A Key Feature of the Model

Proper diagnosis is a key component of the IPM program. Leaf blotches caused by abiotic factors or bacteria may be confused with those caused by the more economically important fungal diseases. Inaccurate diagnoses may lead to unnecessary fungicide applications. Symptom differentiation may be carried out macroscopically, but a hand lens (×10 magnification) is needed to unambiguously identify the causal agent (Fig. 3). Identification is primarily concerned with pathogens such as *C. beticola* and *R. beticola*, which cause foliar necrosis. In contrast, powdery mildew and rust are easy to diagnose.

Steps in IPM Model Development

Our IPM model was developed to allow a flexible response to the variability of disease occurrence from year to year resulting from differences in weather and cultivar selection. For example, Figure 4 illustrates the variability of sugar beet leaf diseases at three locations in Germany during a 3-year study. In 1994, powdery mildew was the dominant disease in northern Bavaria, whereas Cercospora leaf spot was the primary disease in the wetter southern regions. Cultivar selection also influenced disease development in 1994. In particular, the cultivar Ribella was highly resistant to Cercospora leaf spot but was susceptible to powdery mildew. In 1995, both diseases were present at all sites. In 1996, powdery mildew was predominant at all sites, whereas the incidence of Cercospora leaf spot was relatively low.

In addition to accurate diagnosis, three other important steps had to be taken into account during the development of our IPM model:

- The achievement of optimum control by use of epidemic thresholds for timing fungicide treatments (18,19,27,28)
- Setting tolerance limits for disease severity (economic damage threshold) at harvest time (21,23,28)
- Making yield risk forecasts on whether the epidemic would exceed the economic damage threshold (21,28)

Evaluation of Epidemic Thresholds

A goal of our model was to allow flexibility in timing of fungicide applications depending on the epidemic progress. The principles of timing fungicide applications for control of Cercospora leaf spot are illustrated in Figure 5. In general, epidemics were characterized by 3 parameters (22), which mark different phases of disease development (Table 2). In the first phase, disease incidence (DI_{plant}) increased until 100% of the plants were infected. This occurred within a 5-week period relatively early in the growing season. During this phase, disease severity on individual plants remained low.

The second phase of the epidemic was associated with an increase in disease severity on individual plants. The leaf infection rate (DI_{leaf}) increased rapidly when DI_{plant} > 70%. The final DI_{leaf} was limited to a maximum level of 60 to 70%, because the beet plant continued to produce new, uninfected leaves until the end of the growing season. The percent infected leaf area (DS) remained under 1% during the first and second phases of the epidemic. The DI_{plant} = 50% (marked “a” in Figure 5) and DI_{leaf} = 25% (marked “b” in Figure 5) were used to define thresholds for fungicide applications during the first two phases of the epidemic.

During the third phase, DS increased rapidly (up to 15% per week) as DI_{leaf} approached 60 to 70%. Because DI_{plant} and DI_{leaf} were maximized, the parameter DS was used for defining fungicide application thresholds (DS = 2 or 10%) during the latter part of the epidemic. By the end of the growing season, about 60% of the green leaf area was necrotic as a result of Cercospora leaf spot (Fig. 5), but the total amount of necrosis was approximately 90% if the senescence of older leaves was included. At this level of infection, no further yield increases were possible with fungicide applications.

Figure 6 depicts the effects of fungicide applications timed according to the phases of the Cercospora leaf spot epidemic. Overall, fungicides applied early during the epidemic provided the best control. This indicates that fungicides should be applied before DI_{leaf} = 25%. This threshold

Fig. 2. The integrated pest management (IPM) model implementation in Germany is directed by the sugar beet companies.

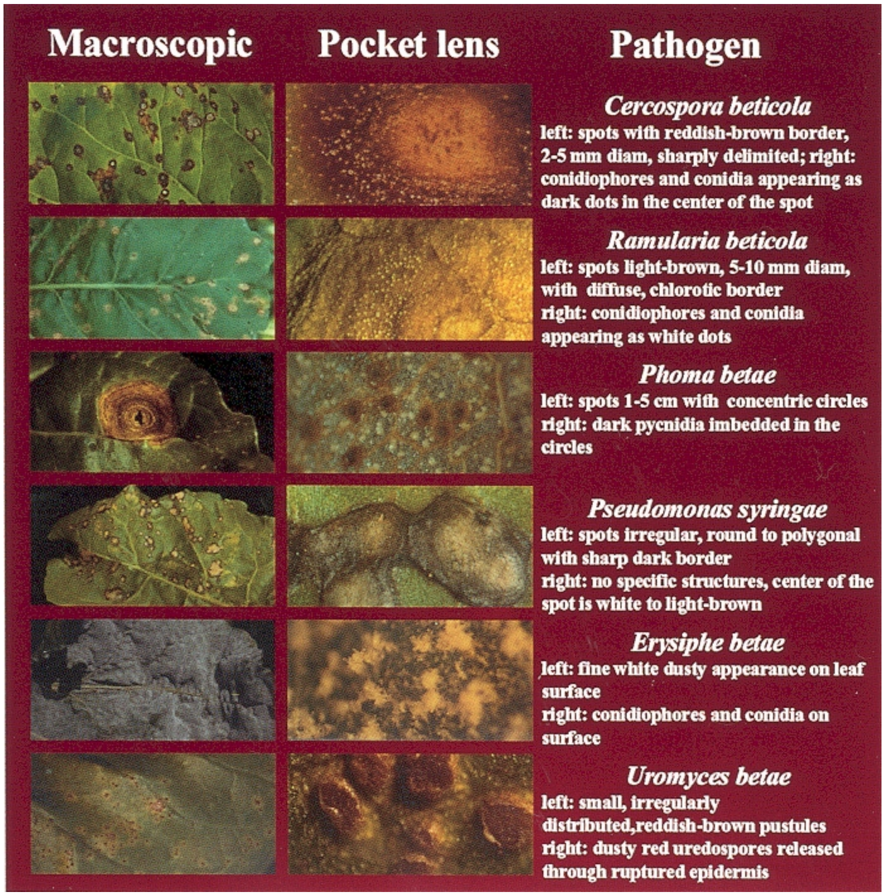

Fig. 3. Diagnosis of foliar fungal diseases in sugar beet by eye (left) and with the aid of a pocket lens (right, ×10 magnification).

corresponds with a DS = 0.2 to 0.4%. Fungicides, including newer generation products such as the triazoles (cyproconazole, difenoconazole, epoxiconazole, flusilazole) and Q_oI inhibitors (azoxystrobin, kresoxim-methyl) were not effective in stopping a highly advanced epidemic. Evaluation of fungicide application thresholds for powdery mildew and Ramularia leaf spot was conducted in the manner described for Cercospora leaf spot, and in general, results were similar.

Of course, the main objective of growers is to minimize sugar losses. To examine effects of Cercospora leaf spot on yield reduction, our field experiments included both untreated and disease-free control plots. The disease-free plots were treated with fungicides at 3- to 4-week intervals. These plots established the maximum yield potential and enabled us to assess the effects of threshold-timed fungicide applications on yield loss. For example, sugar losses caused by powdery mildew were minimized when fungicides were applied at first symptom appearance or at DI_{plant} = 50% (Fig. 7). Even though there was variability among locations, average losses were low (1 to 2%). In determining the effects of powdery mildew on sugar reduction, only those studies with negligible Cercospora leaf spot development (DS values of AUDPC < 1) were included. Sugar losses resulting from powdery mildew ranged from 0 to 15% (Fig. 7).

Evaluation of the Economic Damage Threshold

Despite the success of early fungicide sprays in reducing disease severity, the sprays created a new problem. In almost every case, the threshold for a fungicide application was reached even if the beginning of infection was delayed late into the season. In these cases, disease severity remained low and yield was not affected. In order to maintain a high performance of the model, i.e., applying fungicides only when needed, the tolerance limit of disease severity at harvest was evaluated. This tolerance limit or economic damage threshold was defined as the highest DS level that would not decrease economic profits. The economic damage threshold was deduced from a disease-loss relationship by comparing the decrease of the recoverable sugar yield to DS at harvest (Fig. 8). The parameter "recoverable sugar yield" included quality factors (content of sugar, potassium, sodium, and α-amino-nitrogen) and yield (beet mass). For Cercospora leaf spot, a damage threshold limit of DS = 5% or alternatively an AUDPC = 1 was used. Up to this limit, recoverable sugar losses were negligible. There was a tendency toward slight losses of about 3% at DS < 5%, but the cost associated with fungicide applications outweighed the increases in recoverable sugars. Therefore, DS = 5% was defined as the economic damage threshold and was used as a basis for yield risk forecasts.

The same techniques were used to determine economic damage thresholds for Ramularia leaf spot and powdery mildew. Disease development for Ramularia leaf spot and Cercospora leaf spot were similar in that both caused progressive leaf necrosis. Therefore, the damage threshold DS = 5% was also used for Ramularia leaf spot. In contrast, powdery mildew incidence did not continue to increase during the growing season. Instead, the fungus rapidly colonized leaf tissue during the first part of the epidemic but then slowed as plants matured. Therefore, DS values at the end of the season were not suitable for damage assessment. Instead, the parameter AUDPC = 2 was used for calculating the economic damage threshold.

Forecast of the Yield Risk Potential

The ability to forecast yield risk potential was crucial to a realistic assessment of the necessity of fungicide treatments. In general, fungicide treatment and economic damage thresholds occur at different stages in the epidemic. For instance, Cercospora leaf spot needed at least 4 to 5 weeks to proceed from one phase of the epidemic to the next (22), even under favorable weather conditions and when susceptible cultivars were used (Fig. 9). Early in the epidemic, weekly increases in disease severity (Δ-DS) were slight and increased strongly after the economic damage threshold was reached. Because of the delay between determination of fungicide treatment thresholds and economic damage thresholds, a prediction of the yield risk potential was required. This risk was calculated by regressing the beginning date of the epidemic to the DS at the end of the growing season. The beginning of the epidemic was defined as the time when 50% of the beet plants were infected (DS = 0.01%). We identified three yield risk periods based on when the Cercospora leaf spot epidemic began (Fig. 10). There was high risk of economic damage if the epidemic started in July to mid-August. The resulting disease severity was higher than the economic damage threshold DS = 5% in almost every case. Some risk of exceeding the damage threshold was still present in the period between mid- to late August if harvest was scheduled for October. There was no risk of exceeding the threshold if the first symptoms of Cercospora leaf spot appeared in September. The model was simplified further for making decisions concerning fungicide applications (Fig. 10, bottom), because growers are primarily interested in whether or not they have to spray. There-

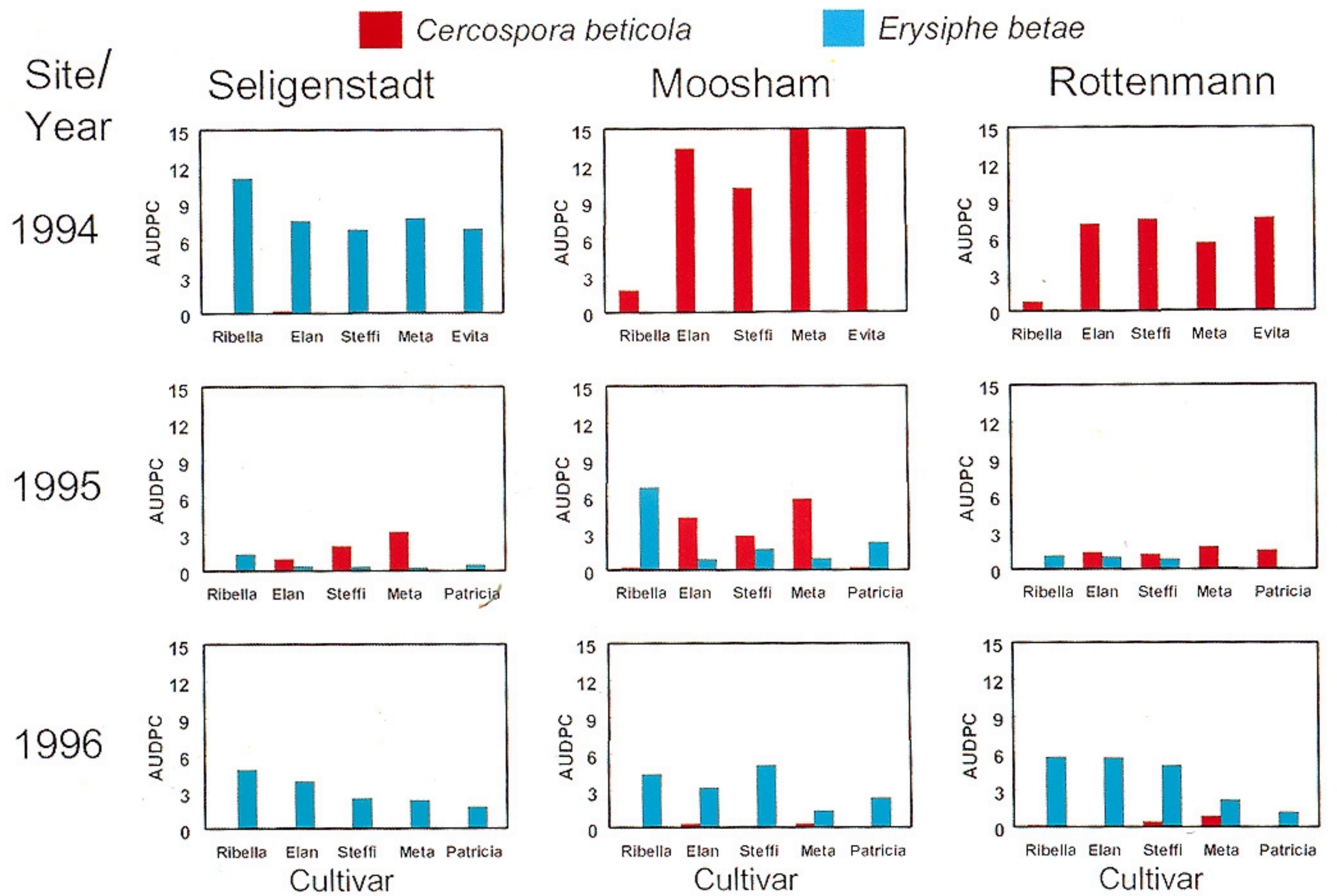

Fig. 4. Development of Cercospora leaf spot and powdery mildew on sugar beet cultivars at 3 locations in Germany, 1994 to 1996. AUDPC (area under disease progress curve) allows expression of entire season's epidemic with one value, calculated by weekly data records (11): $\text{AUDPC} = \sum_{i=2}^{n}(y_{i-1} + y_i)/2 * (t_{i-1} - t_i)$ **where y_i = disease severity (%DS)/100, t_i = date and t_{i-1} = interval of data record (days).**

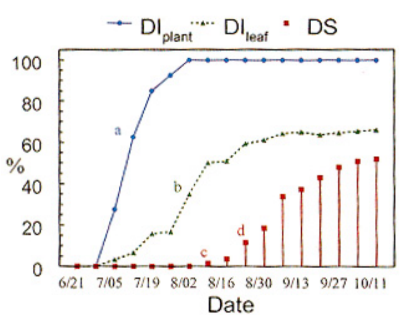

Fig. 5. Epidemic progress of Cercospora leaf spot on the highly susceptible cultivar Carla at Piering, Germany, in 1993 (19). Epidemic thresholds for disease incidence (DI) and disease severity (DS) are: a = 50% DI_{plant}, b = 25% DI_{leaf}, c = 2% DS, and d = 10% DS.

Table 2. Disease incidence parameters

Parameter	Explanation	
DI_{plant}	Disease incidence (plant)	= average percentage of infected plants
DI_{leaf}	Disease incidence (leaves)	= average percentage of infected leaves
DS	Disease severity	= average percentage of infected leaf area
AUDPC	Area Under Disease Progress Curve = % DS/100 * days (11)	

fore, a very simple scheme was developed in which the question of fungicide application was reduced to a "Yes" or "No" answer and was based on when the epidemic started.

The validity of forecasting the yield risk potential was confirmed by comparing the loss of recoverable sugar yield to the date on which the epidemic started (Fig. 11). Sugar losses up to 35% were caused by Cercospora leaf spot when the epidemic started in July (Fig. 11, left). Losses were significantly lower if disease started in August and approached zero if the epidemic began in September. Results for powdery mildew were similar to those for Cercospora leaf spot in relation to initiation of the epidemic. However, the damage potential for powdery mildew was lower (Fig. 11, right), with susceptible cultivars being mainly affected.

Implementing the Model

Negative prognosis. Our objective was to develop an IPM model that could be easily implemented by growers. To this end, we attempted to simplify scouting procedures for determining damage thresholds and timing of fungicide applications. We also tried to minimize the time growers needed to spend scouting their fields by employing a negative prognosis system based on empirical data.

In our studies, symptoms of Cercospora leaf spot were never observed before canopy closure, defined as the time when leaves on 90% of beet plants in adjacent rows began to touch (12,24). Therefore, scouting fields before this period was unnecessary. The frequency of canopy closure followed a Gaussian function and occurred between the 23rd and 28th week (June through mid-July), with most cases in the 25th to 26th week (Fig. 12, top). Cercospora leaf spot epidemics started (DI_{plant} = 50%) after the 26th week in susceptible cultivars and the 30th week in quantitatively resistant cultivars. This demonstrated that the resistance delayed early stages of the epidemic (Fig. 12, middle). However, there was a wide range in time of disease onset in susceptible varieties, indicating that location, meteorology, cropping-measures, and inoculum situation also influenced development. Calculating from the time of canopy closure, the beginning of epidemic may, at the earliest, occur after a period of 3 to 4 weeks in susceptible, and 6 to 7 weeks in resistant cultivars (Fig. 12, bottom). These results were recorded under conditions in southern Germany (72 case studies, 1993 to 1997). Even though canopy closure helped predict the onset of Cercospora leaf spot, considerable variability remained. Sometimes the beginning of an epidemic was delayed 10 to 12 weeks after canopy closure. Even inclusion of climatic factors in the calculation did not

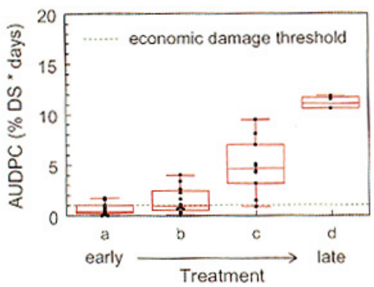

Fig. 6. Efficacy of threshold-timed fungicide applications on development of *Cercospora beticola*. Treatments were applied at the disease incidence (DI) and disease severity (DS) thresholds of: a = 50% DI_{plant}, b = 25% DI_{leaf}, c = 2% DS, and d = 10% DS. Each point represents the mean of one field experiment.

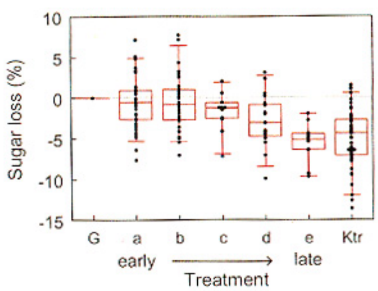

Fig. 7. Loss of recoverable sugar (%) resulting from *Erysiphe betae* infection following a single, threshold-timed fungicide in comparison to untreated control (Ktr) and disease-free (G) plots that received three fungicide applications. Threshold-timed fungicide treatments were: a = first symptom appearance, b = 50% DI_{plant}, c = 25% DI_{leaf}, d = 40% DI_{leaf}, e = 50% DI_{leaf}.

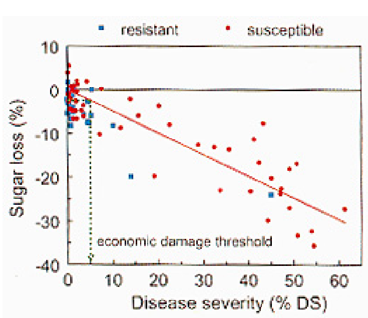

Fig. 8. Disease loss (% recoverable sugar yield) relationship for Cercospora leaf spot where sugar loss (%) = –0.45 * DS, *P* = 0.05, r^2 = 0.80.

satisfactorily explain the remaining variance (24).

The negative prognosis for powdery mildew was derived from an empirical examination, which established the epidemic onset to be probable at mid-July at the earliest. The emergence of first symptoms was also variable, but climatic factors did not explain the remaining variance, possibly because the biology of the fungus is adapted to dry weather conditions. Therefore, the influence of the canopy closure in providing leaf wetness plays a limited role in powdery mildew development. In addition, powdery mildew has not been shown to overwinter in central European climatic conditions. It is likely that the fungus is

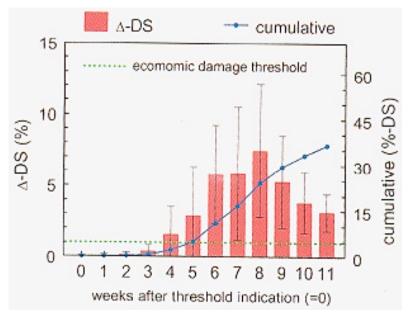

Fig. 9. Progression of disease severity (DS) after exceeding the threshold for an initial fungicide treatment (average of n = 53 field studies), where Δ-DS is the weekly increase and cumulative (%-DS) is the total disease severity.

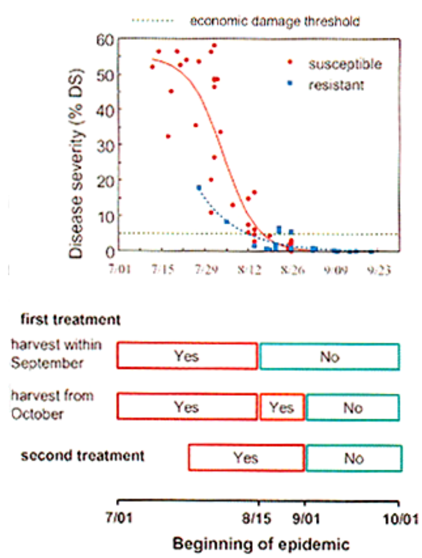

Fig. 10. Relationship between date at which the Cercospora leaf spot epidemic begins and disease severity at harvest. Regression equations for susceptible cultivars, DS (%) = 55.0 * [1 – 1/(1 + 63 * $e^{[-0.181*(x - 194)]}$)], r^2 = 0.82, and resistant cultivars DS (%) = 17.6 * $e^{[-0.079 * (x - 209)]}$, r^2 = 0.77, where *x* = beginning of epidemic (Julian day). The boxes beneath the graph indicate the necessity of fungicide treatments based on the start of the epidemic. Regressions (*P* = 0.05).

introduced every year by windblown conidia from Mediterranean sugar beet growing areas. Hence, the local climate is less important for the timing of the beginning of the epidemic (2).

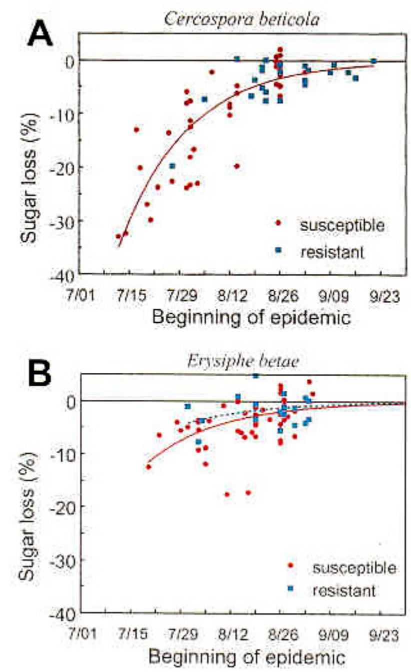

Fig. 11. Forecast of recoverable sugar losses (%) depending on the beginning of epidemic caused by *Cercospora beticola,* A, and *Erysiphe betae,* B. Regression equations for *Cercospora beticola* sugar loss (%) = –35 * $e^{[-0.052 * (x - 194)]}$, r^2 = 0.75, and *Erysiphe betae* on susceptible (sugar loss (%) = –15 * $e^{[-0.05 * (x - 194)]}$, r^2 = 0.30) and resistant cultivars (sugar loss (%) = –8 * $e^{[-0.065 * (x - 194)]}$, r^2 = 0.08) where *x* = beginning of epidemic (Julian day).

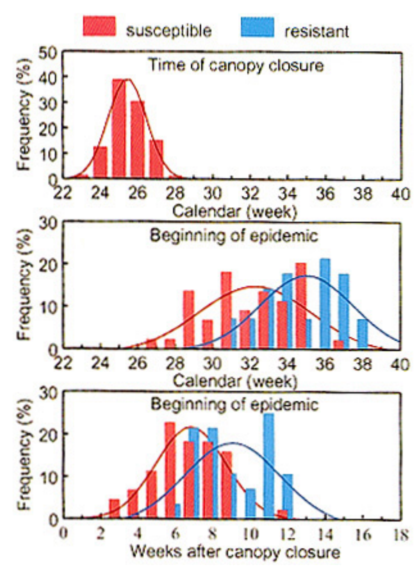

Fig. 12. Frequency of canopy closure (top) and beginning of Cercospora leaf spot epidemic (middle) in relation to date. The beginning of epidemic is calculated from the canopy closure (bottom).

Definition of Thresholds in Practice

In order to simplify field assessment of disease threshold levels, an alternative method of disease scoring was developed. It was based on the percentage of infected leaves in a sugar beet field. Disease incidence was determined by inspecting one leaf from the middle of 100 plants while walking diagonally through the beet field (Fig. 13). With this procedure, the recorder notes only whether leaves are infected. In order to accommodate this sampling procedure, the established thresholds needed to be changed. We developed this system by using regressions for calculating the alternative threshold levels (28). Figure 14 illustrates the decision system for fungicide treatments based on leaf sampling.

The model predicts that if 5% of leaves are infected before mid-August, a fungicide should be applied. This strategy is valid for all of the foliar diseases. If thresholds are exceeded from mid- to late August, the damage risk is conditional on time of harvest for Cercospora leaf spot and powdery mildew. If harvest is scheduled before the beginning of October and the cultivar is resistant to these diseases, then further fungicide applications are not needed. In case of later harvest, Figure 15 shows that there is still a risk of achieving the tolerance limit of DS = 5% by *C. beticola* if the $DI_{leaf} > 25\%$ (DS = 0.2 to 0.4%) in the second half of August. This threshold corresponds to 40 to 50 infected leaves from a sample of n = 100. If this threshold level is exceeded in September, no fungicide application is necessary. This threshold level is also used for determining whether a second fungicide application is required. Based on our experience, a second treatment is usually not required unless the epidemic begins in July.

The application of fungicides based on the IPM model effectively limited Cercospora leaf spot severity to levels below the tolerance limit of AUDPC = 1 (Fig. 16). Average sugar losses were less than 4% when compared with the fungicide-treated, disease-free control plots. These losses result mainly from the reduction of α-amino-nitrogen contents as side effects of the fungicides, even if there is no or only a slight disease incidence. The disease-free control plots required three fungicide applications, whereas the mean number of applications in the IPM plots was <1. The slight loss in sugar was offset by the reduced number of fungicide applications, which cost about US$60 to 80/ha.

Disease Monitoring

Despite the practical aspects of the forecasting model, we were concerned that the system would not gain wide acceptance among farmers. The farmers are loosely organized, vary in educational background, and have many problems other than plant protection to consider. Therefore, in 1994, the University of Kiel in cooperation with the state advisory service established a disease monitoring service (25). Since 1996, monitoring in Germany has been organized by the sugar companies and supported by the German state advisory service. The model was also introduced in Austria in 2000 by the Novartis-Agro GmbH (now Syngenta) as a service for beet growers. Monitoring is conducted by scouts (200 in Germany, 40 in Austria) trained in diagnosing and scoring diseases. The disease monitoring is initiated as soon as the negative prognosis cannot exclude the beginning of an epidemic (Fig. 17). The weekly records are specified for each

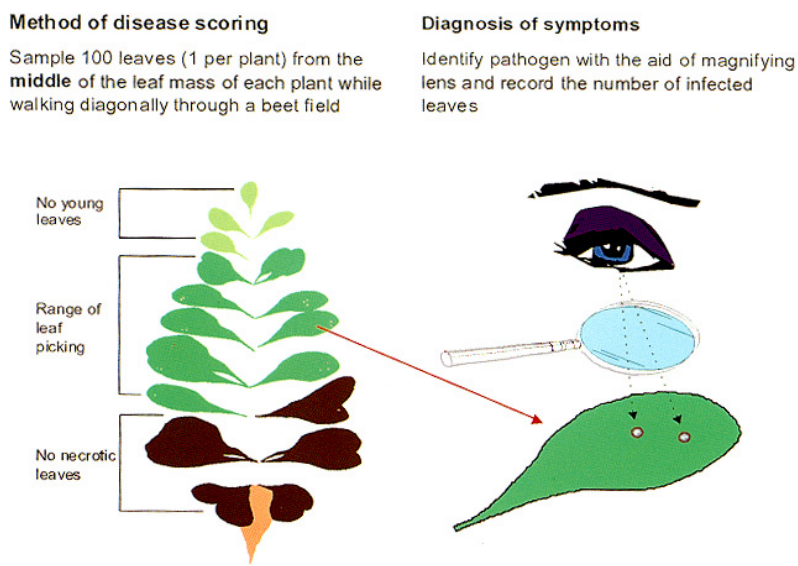

Fig. 13. Method of diagnosis and disease scoring.

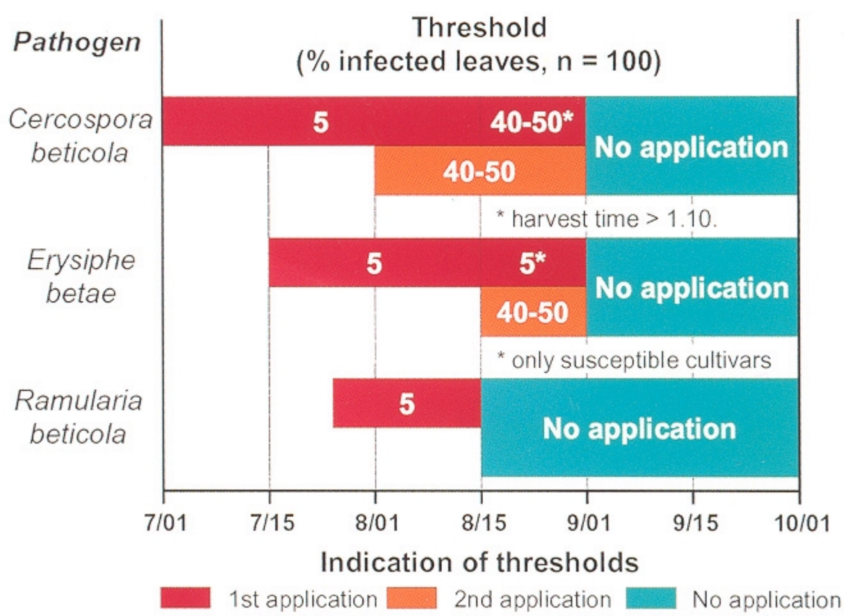

Fig. 14. Scheme for determining timing of fungicide applications.

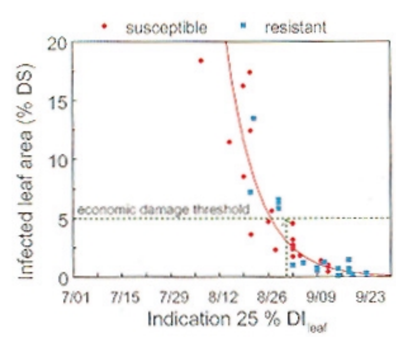

Fig. 15. *Cercospora beticola*: Forecast of infected leaf area (% DS) at harvest depending on the time of exceeding the epidemic stage DI_{leaf} = 25%. The regression equation is DS (%) = $25 * e^{[-0.11 * (x - 225)]}$, $r^2 = 0.75$, where *x* = day of exceeding 25% DI.

region with differing climatic conditions. The scouts are instructed to sample 100 beet leaves in selected fields on Friday or Saturday and determine disease incidence. The results are then transmitted by fax or internet on Monday morning for data evaluation. Where thresholds are reached, warnings (warning letter, publication in journals, internet) are given to farmers who may then scout their own fields. Since 1998, Südzucker AG and Syngenta-Austria have provided an internet site displaying the sugar beet foliar disease situation on a weekly basis. For example, Figure 18 illustrates the foliar disease situation during mid-September in southern Germany. The map displays the distribution of various foliar diseases and warns of potential outbreaks of Cercospora leaf spot. The colors of the different regions define the actual warning situation. In this example, almost every region received a first warning for Cercospora leaf spot development. At the end of the season, the regions are colored rose, because these warnings are older than 1 week. Actual warnings for a first fungicide spray would be indicated by red color. Some areas that had been treated with a fungicide earlier in the season received a second warning (slight blue color), while others received no further warning. These warnings indicated that a fungicide application would be needed in many locations. Nevertheless, the final decision to apply a fungicide was left to the farmers.

Conclusions and Outlook

The implementation and acceptance of our sugar beet IPM model was based on the ability to accurately diagnose foliar diseases and to transmit the disease warn-

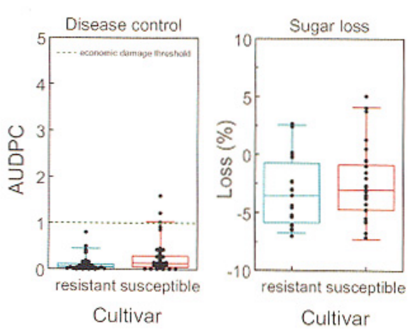

Fig. 16. Efficacy of fungicide sprays (left disease control, right loss of % recoverable sugar yield), based on the integrated pest management (IPM) model.

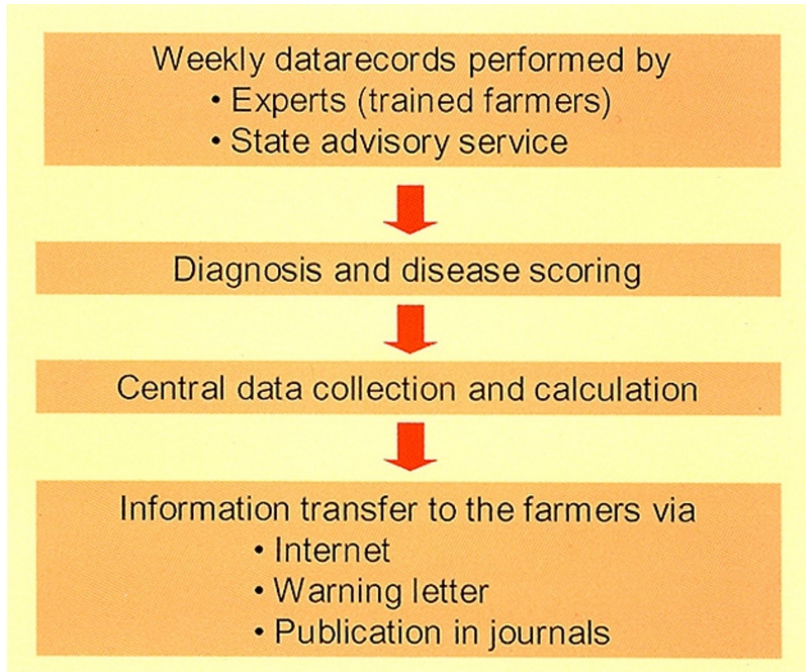

Fig. 17. Organization of disease monitoring system.

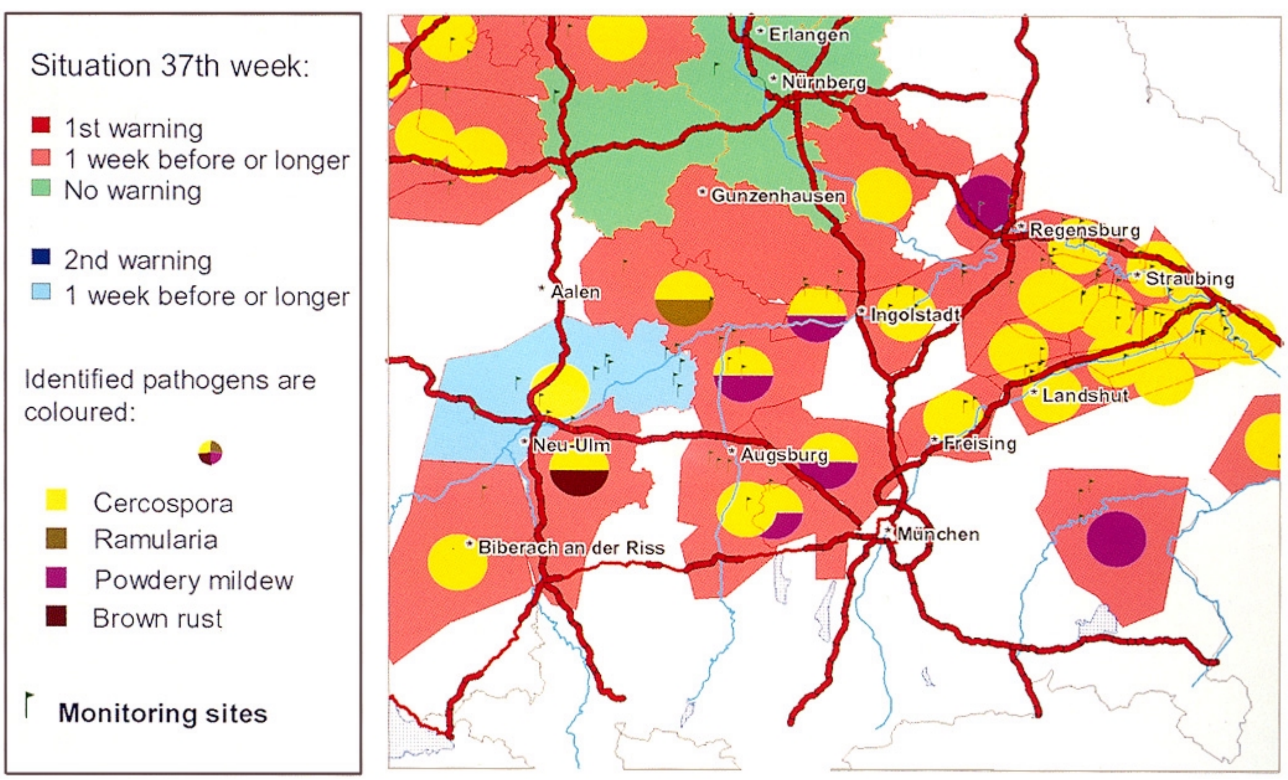

Fig. 18. Example of a disease forecasting map for monitoring sites in southern Germany in 2000.

ing system to the farmer in a user-friendly system. In the past, misidentification of foliar diseases, particularly between leaf blotching caused by *Pseudomonas syringae* and Cercospora leaf spot, often resulted in unnecessary fungicide treatments. Symptoms associated with *P. syringae* are already common in June but are temporary and originate from physical injuries such hail. Fungicide applications are neither necessary nor do they have any effect against the bacterium. Hence, accurate diagnosis at early stages of the epidemic is very important. The scouts were able to accurately diagnose diseases after an initial training and now have developed a reliable routine over six seasons. The most important advantage of the model is the potential for reducing or eliminating fungicide applications. It must be conceded, however, that many farmers view a warning as a signal to start spraying without further monitoring on their own farms. Nevertheless, there is still an advantage compared with past systems in that farmers are fully informed and take action only in a time of real risk. A future goal must be to improve farmer training so that the benefits of the model and how to use it become more apparent.

The scientific innovation of our model is the linking of the fungicide treatment and damage thresholds to develop forecasts of damage risk. The damage threshold alone is not suitable for optimization of timing fungicide applications, because even the new generation of fungicides is not effective in suppressing disease development once the damage threshold is reached. Therefore, there is a need to define special thresholds that allow optimum fungicide efficacy (18,19,27). The yield risk potential forecast takes this into account. In the future, the possibility of including weather data in the forecasting model will be considered. However, the question is how to make best use of these data. There currently is little advantage in including weather information in determining damage-potential forecasts. The risk calculation is necessary at the time a threshold is reached. The period between deciding on a fungicide spray (beginning of epidemic) and the end of the growing season is at least 4 to 5 weeks. Currently, weather forecasts are not reliable over this length of time.

Almost the same factors we used in developing our IPM sugar beet model are employed in the “Cercospora leaf spot model for sugar beet” developed by Windels et al. (9,20). Their model, which is used in Minnesota and North Dakota, already has a history longer than 10 years and involved the cooperation of the sugar beet industry, producers, and university personnel. They also emphasize the importance of accurate diagnosis. Based on the results of Shane and Teng (16,17), thresholds for fungicide sprays are given with a successive adaptation to the calendar. These are nearly the same as those in our IPM model. The thresholds refer to different action zones, where, for instance, no fungicide has to be applied as long as the disease progress remains within the “safety” zone. There is a slight difference in determining the tolerance limit of disease severity (economic damage threshold) at 3% instead of 5%. Furthermore, the Cercospora leaf spot model takes into account the weather conditions during calculation of daily infection values (DIV), and disease monitoring is considered to be suitable for implementation.

Weather data may be able to describe the probability of infection. But the target of predicting the onset of an epidemic in an individual beet field is difficult to achieve, because the influencing factors seem to be complex (24). From this point of view, the evolution of single beet fields and therefore the disease development differs greatly, even in the same region with similar weather conditions. Additional local effects from rivers, forests, or the geographical inclinations of beet fields cannot be taken in account, because in such cases it would be necessary to have a weather station in every beet field. Overall, the different interactions result in a wide spread of epidemic onset times. This means that, in the final analysis, it is necessary to have a field-specific approach to fungicide treatments in order to achieve the target of flexible fungicide management with high economic and ecological efficacy. In order to reach this goal, field observations are indispensable.

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