INNOVATIVE COMBINATION OF IPM (INTEGRATED PEST MANAGEMENT) TOOLS - THE IPM SUGAR BEET MODEL -

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BACKGROUND AND OBJECTIVES

In many parts of the world, *Cercospora beticola* is the most important leaf spot disease of sugar beets. The frequent risk of losses caused by this pathogen demands the application of fungicides in many regions of sugar beet growing. However, the damage potential is variable to a big extent, dependent on year, site and cropping measures. Therefore, we developed an IPM-System, which is reacting flexible, according to the present epidemic development (6, 8, 9). On the primary, the innovation of our model lies on the effective combination of IPM-tools (Fig. 1). Conversely we found, that a single tool is not able to fulfil the demands of Integrated Pest Management of reducing the chemical input by fungicides to a minimum, but to optimise yield factors. Hence, the model involves the prediction of incidence (7, 8), spraying thresholds (4, 6, 8, 9), the determination of the economic damage threshold (5, 8), where the prediction of yield losses is based on (10). The diagnosis is outstanding due to it's key-function, because definitely, there is no IPM to be conducted without exact identification of disease symptoms. Or in simple words, the tools are not working, if the symptoms are ignored or confused. In general, these principles of combining IPM-tools may be applied for many other host-parasite systems as well, in particular, where an initial infection is tolerable. This is the case, if quality and yield of the crop is not affected at the disease level of a spraying threshold, and, on the other hand, if fungicides are available, high effective in controlling disease at initial epidemic stages.
The presentation, following now, is mainly focused to the reasons why IPM-tools have to be linked with each other. Therefore, detailed insights in modelling of the different parts may be allowed to be neglected and substituted through reference of citations, where more detailed information is provided.

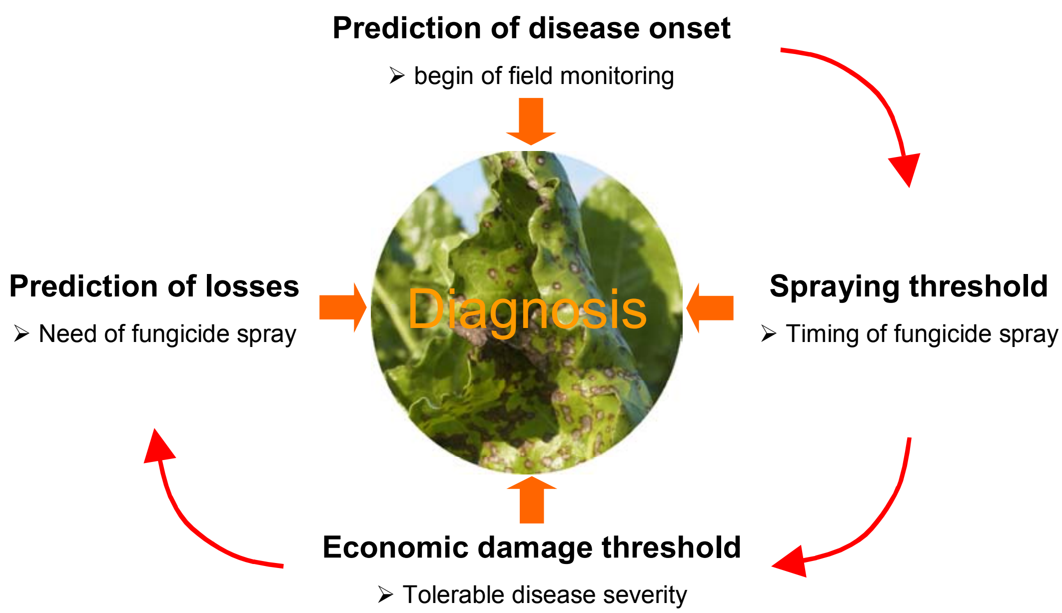

Figure 1: Innovative combination of IPM-tools and the order to use them during in a growing season.

MATERIALS AND METHODS

Field experiments

The program involved trials in a randomised block design with multiple factors (block n=4 replications, cultivar n=1-5, fungicide treatment resp. thresholds n=4-12). The data set (n=109 field experiments) consists of a six years study (1993-1998, 11 sites) in Southern Germany. Disease severity was recorded from the beginning of June until October. On first recording date, fourty beet plants (10 per plot) were randomly selected. At weekly intervals, the number of green and dead leaves as well as the percentage of necrotic leaf area was established on selected plants. Necrosis estimation of single leaves was performed by using a rating scheme (1). Based on single leaf records, mean calculation of plant/leaf infection frequency as well as disease severity was performed. If diagnosis was not sure, the causal agent of leaf spots was fixed through the occurrence of hyphal structures.
Efficiency of epidemic oriented spraying thresholds was compared to relatively disease free plots (3 fungicide sprays fixed by calendar schedule). Yield was measured after a machine harvest of three rows in the centre of a plot (11 rows, 7 m). Yield analysis was supported by sugar industry and involved measurements of yield mass, sugar content as well as contents of impurities (αAmino-Nitrogen, Sodium, Potassium).
Collection of weather data was provided by electronic stations (temperature, precipitation, air relative humidity), either after “Weihofen” (Thies, Göttingen) or “Lambrecht” (3).

Model description

Negative-Prognosis. Epidemic onset (target variable of negative-prognosis) was defined as the time when ≥50% of beet plants were infected, resp. showed at least one lesion on one leaf. The influence of weather on the epidemic onset was assessed through the calculation of daily infection values (DIV) (7, 8). The influence of temperature was expressed by proportions relative to the optimum of the latent period, found under greenhouse conditions. Leaf wetness is obligate for infection and existed with 75 % probability, if air relative humidity was higher than 90%. Therefore, the calculated values were set to 0 in cases of air relative humidity ≤90%. Each epidemic onset of fieldstudies (n=48) was set in relation to the cumulative DIV (c-DIV). Start of DIV-subsummation was the variable time of canopy closure and therefore flexible, in order to match the differing canopy development. Time of canopy closure has a distinct impact on epidemic onset due to the changes of microclimate, resulting in longer leaf wetness periods and higher air relative humidity. Resulting c-DIV’s from fieldstudies (n=42) showed a relatively high variability, not suitable to predict the precise disease onset time. Therefore, a “Negative-Prognosis” was defined by using the minimum sum of c-DIV as a threshold, where, when exceeded, the occurrence of incidence cannot be excluded anymore.

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 hand. Deterministic, because prognosis depends on data input of actual date, actual disease incidence (% infected leaves in the range of 3-50%, sample n=100 leaves) and cultivar resistance, which determine the forecast of future disease progression. First step of development was selection of case studies depending on the date (calendar week) of epidemic onset and resistance of cultivar (highly and low susceptible). The mean, minimum and maximum of disease progression was 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 of disease severity, DS_{max} = maximum of disease severity, CW = week of calendar, a and b = variable depending on actual DS and cultivar resistance.
In addition, loss prognosis (yield mass, sugar content, recoverable sugar yield) is calculated, depending on scheduled harvest time and expected yield. This prognosis is based on the rela-

tionship of AUDPC (Area Under Disease Progress Curve) (2) and loss (relative difference of untreated and healthy).

RESULTS

Combination of IPM-tools

1. Prediction of disease onset is the tool to save efforts in disease observation and gives information, when to start**.** During a growing season, it's the first tool to be applied. The weather dependant probability of infection is quantified by daily infection values (Fig. 2, top) and the risk of disease onset by the cumulative DIV (c-DIV). The question is now, how to use the c-DIV, in order to pinpoint the exact time and necessity of a fungicide spray. The problem is, that the daily infection values did not explain the variance of disease onset times satisfactorily. Comparing the c-DIV's from different years and sites, a relatively high variability was evident. Thus, disease prediction, as defined by c-DIV's, is not able to pinpoint a fungicide spray. On the other hand, the c-DIV may be used to calculate a risk of disease incidence. This is done by a Negative-prognosis, where conversely the disease free period is calculated by the minimum c-DIV (susceptibility: high Σ DIV=7, low: Σ DIV=12), when a disease onset occurred (Fig. 2, bottom). As soon as this criterion is exceeded, disease incidence cannot be excluded anymore and a disease monitoring, i.e. field observations, has to follow, to establish the actual disease situation. Figure 2 presents an example, where this is revealed at the crosspoint of "c-DIV" and minimum criteria, i.e. in this case July 15 for susceptible varieties, August 4 for less susceptible varieties.

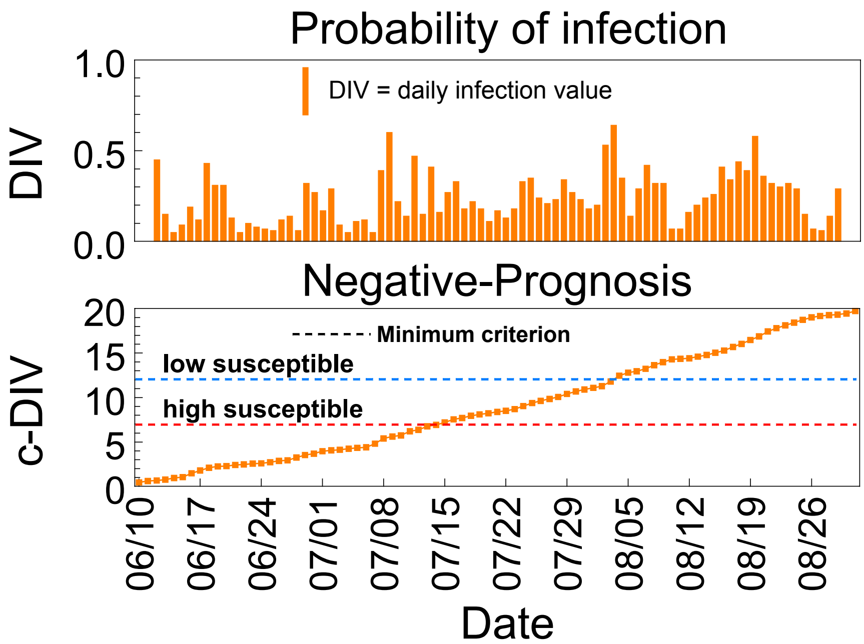

Figure 2: Weather dependent probability of infection (top), Negative-Prognosis depending on cumulative DIV (c-DIV); field observations are recommended, when the minimal criterion is exceeded (7 => highly susceptible cultivars, 12 => low susceptible cultivars).

2. Spraying thresholds are setting the timing of fungicide sprays to the optimum. During the monitoring, the crucial point is, to diagnose and quantify diseases as well as to proof, whether the spraying threshold is exceeded. In order to match the target of optimising the efficiency of fungicide sprays, successive stages of the epidemic were assessed for thresholds, pinpointing the exact time of application. The result was here, that only sprays during the epidemic onset of disease are effective and suitable for a practical use. Applications should be carried out at disease severity in the range of 0,01 up to 0,2 %. Later timed applications are decreasing efficacy to less than 80 % (Fig. 3). Even the potential of modern Azol- and Strobilurin fungicides is not effective enough, to stop a high progressive epidemic. But during the evaluation of thresholds, a new problem appeared. The problem was, that the sugar beet is far away to be damaged at the time, when the spraying threshold is reached. Despite orientation of fungicide sprays to thresholds, cases without any yield respond appeared, in particular when the epidemic was delayed in later periods of the season. That was the consequence, because a spraying threshold is indicating the time for a high effective spray but not the significance of an economic damage.

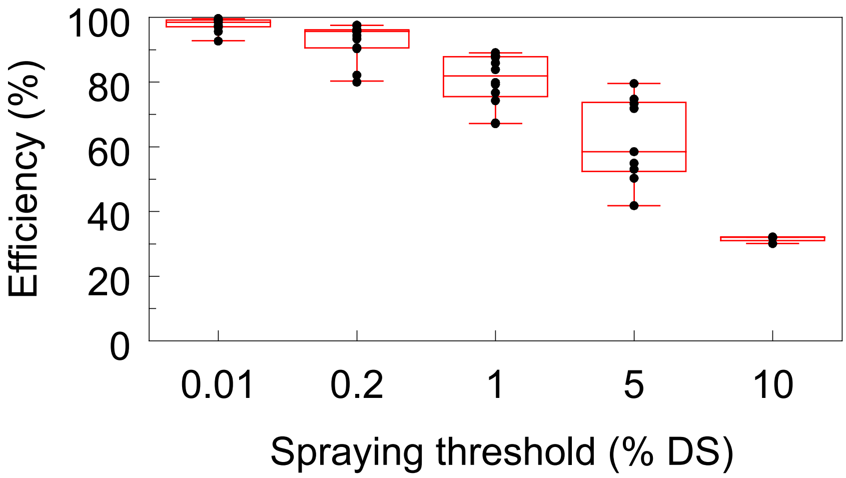

Figure 3: Efficiency of successive stages of the epidemic as thresholds for the timing of fungicide sprays. Each single point (mean of 4 replications = plots) is representing the result of one field experiment, for instance of one year, site and cultivar.
Legend for Box-Whisker graph:
The box shows the range between the 25^{th} and 75^{th} percentiles, the horizontal line indicates the median value, the whiskers extend from the edge of the box to the 5^{th} and 95^{th} percentiles.

3. The **Economic damage threshold** defines the tolerable disease level at the end of the season, unlike the spraying threshold. The definition of the economic damage threshold is based on the relationship of disease severity and sugar loss. The disease-loss-relationship shows a linear character. Sugar losses resulted to a big extent from 0-35% (Fig. 5), but 3-5 % of infected leaf area (DS) may be accepted at the end of the season. At this disease level, losses of sugar are 2-3 %, where application costs would equalise the benefits of disease control.

4. The **Prediction of losses** is necessary, just when the spraying threshold is exceeded. The need of prediction is the consequence, because the disease level of a spraying threshold is without an actual damage. The necessity of a fungicide application is indicated, if the predicted disease severity exceeds the damage threshold before the scheduled harvest time. The weather is not referred to, because predictions are to be done for more than 4 weeks and weather forecasts are not reliable for such a long time.

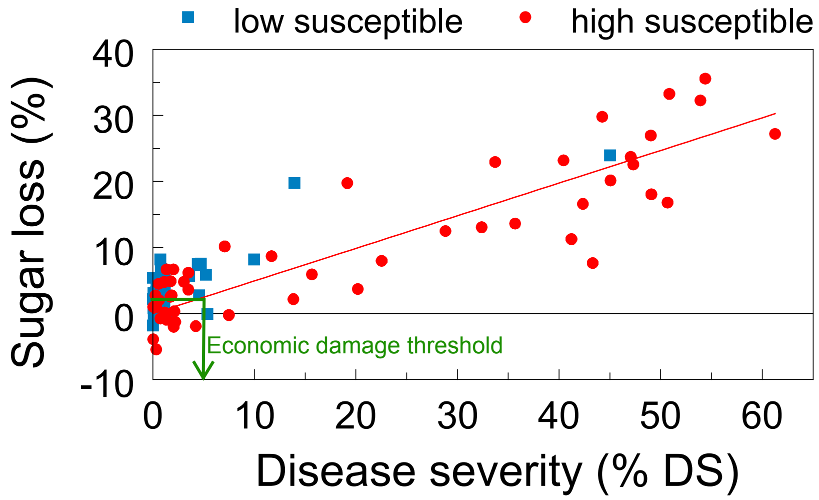

Figure 4: Disease loss relationship; definition of the economic damage threshold = 5 % DS, corresponding sugar loss = 2-3% (recoverable sugar yield)
Regression (p=0.05): Sugar loss (%) = 0.45 * DS $r^2 = 0.80$

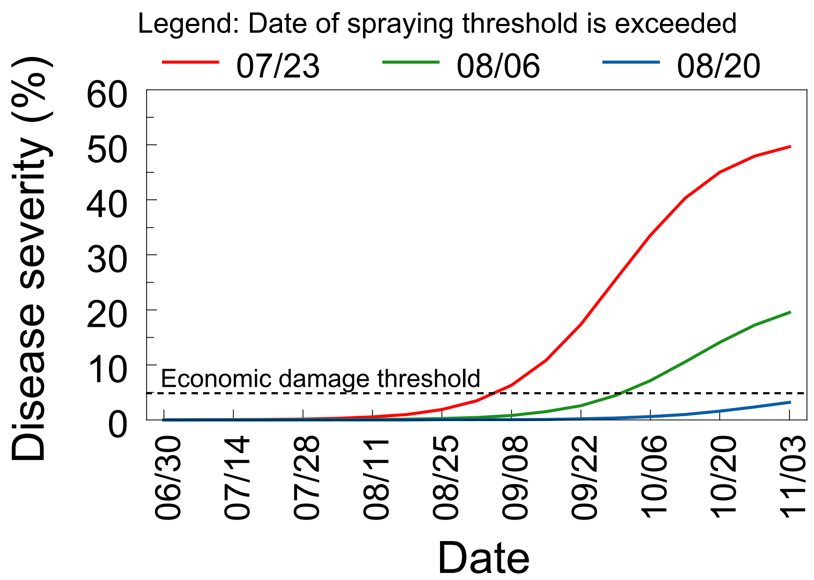

Figure 5: Prediction of disease progression dependent on the time of threshold excision (threshold = 0,01 % DS, cultivar low susceptible); a fungicide spray is necessary, if the economic damage threshold is exceeded before the scheduled harvest time.

Figure 5 displays 3 examples of different threshold exceeding times. For instance, if the spraying threshold is exceeded on the July 23 (red line) a high progressive epidemic is predicted to develop. There is an absolute need of fungicide application, because harvest time normally begins later, at least under conditions in middle Europe. The need is only conditional, if the spraying threshold is exceeded on August 6 (green line). Disease progression is rather moderate and it depends on harvest time, whether there is a yield risk. In this example, fungicide applications can be avoided, if harvest takes place before October. The blue line marks the progression after exceeding the spraying threshold on August 20. In this case, definitely no fungicide application is necessary. The progression remains below the damage threshold up to the end of the season.

CONCLUSIONS

The principles of the IPM sugar beet model may be used for many other host-parasite systems as well, for instance in cereals or even in other crops. Of course, the special implications of the crops have to be considered in adapted modifications. In this paper, as an example, the innovative combination of IPM-tools is focused to *Cercospora beticola*. The same procedure is applied to *Ramularia beticola* and *Erysiphe betae* (8, 9). The goal of the IPM-system lies on reducing fungicides input as much as possible and on the other hand optimising yield response. In order to have a successful approach, we found, that the weather dependant prediction of incidence is not sufficient to pinpoint fungicide sprays. The causative factors are more complex, even though canopy development and cultivar resistance is referred to.

Only a negative-prognosis is possible, which defines the beginning of a field monitoring. Therefore, disease observation in the field is unalterable. By doing this, knowledge about diagnosis and identifying symptoms has to be contributed a key-function. Spraying thresholds pinpoint the exact time of a fungicide spray and they are defined as very early stages of the epidemic. Therefore ignoring or confusing symptoms leads easily to wrong decisions in timing of fungicide sprays.

The need of loss prediction appears from the fact, that there is no damage or loss at the time, when a spraying threshold is reached. There is a big difference between the spraying threshold (0,01% DS) on one hand and the economic damage threshold (5% DS) on the other hand. During an epidemic, the time period between ranges from 4-10 weeks, depending on weather, site and cropping conditions. Therefore a prediction of losses is needed, to realise the necessity of treatments. This prediction has to be done at the time, when the spraying threshold is exceeded. A fungicide spray is necessary, if the exceeding of the economic damage threshold is predicted before scheduled harvest time.

Nevertheless, modelling of IPM-systems is an ongoing process and will never be finished. It's just an approach to reality, which steadily needs improvements. That's not a new statement as well it's true.

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