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Quaternary Integrated Pest Management concept for powdery mildew in sugar beet. III. Economic damage threshold and loss prediction

Quaternäres Integriertes Pflanzenschutz-System für den Echten Mehltau der Zuckerrübe. III. Ökonomische Schadensschwelle und Verlustprognose

Abstract

The economic damage threshold and loss prediction are part of the Quaternary IPM (Integrated Pest Management) -concept developed for the control of powdery mildew in sugar beets. The evaluation of 73 field trials, conducted under the climatic conditions in central Europe (1993-2004), established that powdery mildew may cause 10-15% sugar yield losses and 0.5-0.7 % (absolute) reductions of sugar content at the maximum. The losses occur preferably under conditions of early disease initiation in July and high susceptibility of cultivar. Such situations also may increase the content of αAminoNitrogen and, therefore, the recovery of sugar may be reduced by 1-2%. The other non sucrose components are not affected through powdery mildew. Derived from disease loss relationships and after summarising all yield and quality factors, the value of AUDPC (Area Under Disease Progress Curve) 2, equal to a sugar yield loss of 1.8 %, is defined as the economic damage threshold.

In view of loss prediction, the exceeding of the economic damage threshold is likely if first symptoms appear before mid-August, the risk period is extended to the end of August in case of high susceptibility of cultivar. The risk periods are equal to action zones for fungicide treatments.

Key words: Beta vulgaris, epidemiology, economic damage threshold, *Erysiphe betae*, loss prediction, Quaternary IPM- (Integrated Pest Management) concept.

Zusammenfassung

Die ökonomische Schadensschwelle sowie die Verlustprognose sind Teil des Quaternären IPS (Integriertes Pflanzenschutz-System) –Konzeptes zur Bekämpfung des Echten Mehltaus in Zuckerrüben. Nach Auswertung von 73 Feldversuchen (1993-2004), durchgeführt unter den klimatischen Bedingungen Mitteleuropas, vermag der Echte Mehltau Verluste an bereinigtem Zuckerertrag von 10-15% auszulösen, der Zuckergehalt kann maximal um 0,5-0,7% (absolut) gemindert sein. Hohe Verluste sind wahrscheinlich unter der Bedingung eines frühen Epidemiebeginns im Juli sowie hoher Anfälligkeit der Zuckerrübensorte. Derartige Bedingungen führen ebenso zu einer Steigerung des αAmino-Stickstoff-Gehaltes, wodurch die Ausbeute an Zucker um 1-2% verringert wird. Die übrigen Nicht-Zuckerstoffe werden durch den Mehltau-Befall nicht signifikant beeinflusst. Unter Zusammenfassung aller Ertrags- und Qualitätsfaktoren wird mit Hilfe von Befalls-Verlust-Relationen unter Zugrundelegung des AUDPC (Area Under Disease Progress Curve) -Wertes eine wirtschaftliche Schadensschwelle von 2 definiert, gleichzusetzen mit einem Zuckerverlust von 1,8%.

Im Hinblick auf eine Prognose von Verlusten ist die Überschreitung der wirtschaftlichen Schadensschwelle wahrscheinlich, sofern Erstbefall vor Mitte August auftritt. Im Falle von hoch anfälligen Sorten ist die Risikoperiode bis Ende August auszudehnen. Die Risikoperioden entsprechen den Behandlungszeiträumen für Fungizidapplikationen gegen den Echten Mehltau der Zuckerrübe.

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1 Introduction

Powdery mildew in sugar beets is predominately a disease of the arid climatic zones (AHRENS and WELTZIEN, 1980; COOKE and SCOTT, 1993; DRANDAREVSKI, 1969; MUKHOPADHYAY, 1987). In Central Europe, however, occurrence is less frequent and mostly delayed into the late season (AHRENS, 1985; WOLF et al., 2006). Higher incidence is dependent on specific conditions of sugar beet growing such as susceptible cultivar, dry weather and a relatively missing of Cercospora leaf spots. *Cercospora beticola*, as a perthophyt, is destroying the green leaf mass and therefore induces an antagonistic effect to the biotrophic parasite (WOLF, 2002; WOLF et al., 2006). Overall, *Erysiphe betae* is a pathogen which may affect yield losses but the question is how to recognise situations which will lead to losses of yield and quality of sugar beets. The only mean of interfering with a current epidemic is the appliance of chemical fungicides. However, regarding the sporadic occurrence of powdery mildew, routine spray regimes oriented to the calendar are not adequate.

Despite the seemingly dependence on dry weather conditions, the chance of predicting the epidemic onset of powdery mildew precisely is quite poor (WOLF et al., 2006). Therefore, some other tools of Integrated Pest Management (IPM) are required to match the objectives of reducing fungicide treatments to an essential amount. These are acting thresholds as well as the damage threshold where the loss prediction is based on. The tools are linked with each other through our "Quaternary IPM-concept" (WOLF et al., 2004; WOLF and VERREET, 2003). The linking is compensating insufficiency of the single elements. As already mentioned, prediction of disease is not accurate enough in order to pinpoint fungicide sprays precisely. So far, only a so-called Negative-Prognosis is possible, which is determining the risk of first symptom occurrence. During the risk period observation of beet fields is advisable and as well to score the disease level in view of exceeding the acting threshold. The acting threshold is a quite early stage of the epidemic. It is determined by a plant infection of 50% or respectively a leaf infection prevalence of 5% (WOLF, 2002; WOLF et al., 2007). Mostly, it is coincident with the first symptom occurrence. Although the acting threshold is setting the efficiency of fungicide treatments to an optimum, this epidemic stage does not really damage the beet. Thus, if the exceeding of the acting threshold is indicated, a loss prediction is necessary. The loss prediction is focussed on to predict the likelihood of disease will exceed the damage threshold at harvest time. Only in this case, fungicide applications are justified according to the demands of IPM.

The principles of the Quaternary IPM-concept were already presented for the *Cercospora beticola* (WOLF et al., 2004; WOLF and VERREET, 2003; WOLF and VERREET, 2005a; WOLF and VERREET, 2005b). This paper depicts the specific implications of powdery mildew in sugar beets concerning the damage threshold and loss prediction in order to complete the Quaternary conception.

2 Material and methods

2.1 Field experiments design, disease scoring, yield and quality measurement

The trials were conducted from 1993 - 2004 and were located in Lower Saxonia and Bavaria, Germany. For the selective analysis of losses caused by *Erysiphe betae* only field studies of a relatively missing of *Cercospora beticola* were considered. The criterion here was a Cercospora specific AUDPC-value ≤1. Therefore the data set had been reduced to 73 field trials of differing environment. Used cultivars were assigned to different susceptibility, either highly (n=52) or low (n=21). The cultivars 'Ribella', 'Corinna' and 'Cyntia' were classified as highly susceptible, all the others as moderate to low susceptible (WOLF et al., 2006).

Each trial included at least a fungicide untreated control – below predicated as "Diseased" - and, besides different epidemic oriented IPM-applications, a three times treated variant to determine the disease free respectively site specific yield optimum – in the following predicated as "Healthy". Thus, every mark in the graphs (see results) is related to a single field study reflecting the difference between Diseased and Healthy.

Further descriptions, about field experiments and the scoring of disease incidence were already published (WOLF et al., 2006) as well as yield measurement had been remarked (WOLF et al., 1998; WOLF, 2002).

2.2 Data analysis

Electronic data processing was performed by using specific excel-data sheets. Curve fittings were applied to prepared data sets using the program "SlideWrite Plus" (Advanced Graphics Software, Inc. Encinitas, CA). For all chosen models, the probability level was 95%. The goodness of the respective relationships is assessed by the determination coefficient of regression (r^2, α=0.05).

2.2.1 Influence of incidence on yield and quality factors.

The damage potential was evaluated through one-dimensional regression analysis where the AUDPC (Area Under Disease Progress Curve)-value was the independent variable and yield and quality factors were the dependent variables. Due to the specific epidemiological behaviour of powdery mildew, i.e. the effect of decreasing visible incidence towards the end of the season, the AUDPC value (KRANZ and HOLZ, 1993) – this value (for this evaluation divided by 100) is related to the entire disease course - was preferred instead of disease severity (DS).

In the charts, the changes of non sucrose (Potassium, Sodium, αAminoN) contents and recoverable sugar are displayed as absolute differences of Diseased and Healthy. In terms of sugar content, beet yield and recoverable sugar yield, the respective differences are calculated as percentage in relation to Healthy.

2.2.2 Loss prediction. The AUDPC, loss of beet and recoverable sugar yield are estimated through a non-linear, one-dimensional regression model. The influence variable is here the time of first symptom appearance.

3 Results

3.1 Damage threshold: Influence of incidence on quality and yield of sugar beet

The most important quality factor of the beet is the sugar content. The latter is negative-linear correlated with the incidence. Thus, the sugar content is decreasing along the incidence is increasing (Fig. 1). Due to a relatively high variability of the correlated values, the relationship is not significant till AUDPC 5. If incidence is further rising, a clear trend of sugar content diminishing of 3-4% at the maximum is evident. The absolute decrease is corresponding to a sugar content reduction of 0.5-0.7%.

Higher non-sucrose contents of Potassium, Sodium and αAminoN may reduce the recoverable sugar. Nevertheless, powdery mildew has no significant effect on the contents of Potassium and Sodium in sugar beets (Fig. 2-A,B). The deviations vary in the range of ±4 mmol/kg beet and are assumed as randomly effects which are confirmed by low coefficients of regression.

In contrast, powdery mildew seems to increase the content of αAminoN (Fig. 2-C). The difference of Diseased and Healthy, however, is largely independent on the severity of disease. Apparently, there are already significant effects even in case of low incidence. This may be also interpreted as a synergistic effect of used fungicides. With other words, the fungicides are reducing the αAminoN contents in the variant Healthy, even if there is no incidence of powdery mildew.

This trend continues by the analysis of recoverable sugar (Fig. 3); not surprisingly, because this quality parameter comprises the effects of the non-sucrose components

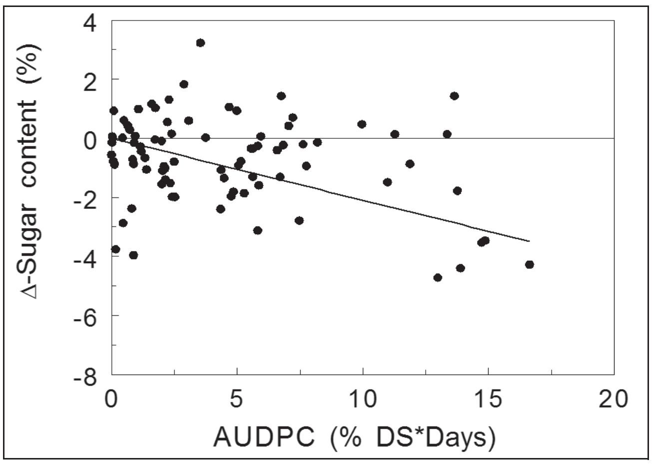

Fig. 1. Relationship[a] between powdery mildew incidence level (AUDPC[b]) and the relative difference of sugar content to "Healthy". [a] Δ-sugar content (%) = 0,21*AUDPC; r^2=0,27.[b] AUDPC=Area Under Disease Progress Curve = DS (%) x days / 100; DS= Disease severity (% infected leaf area).

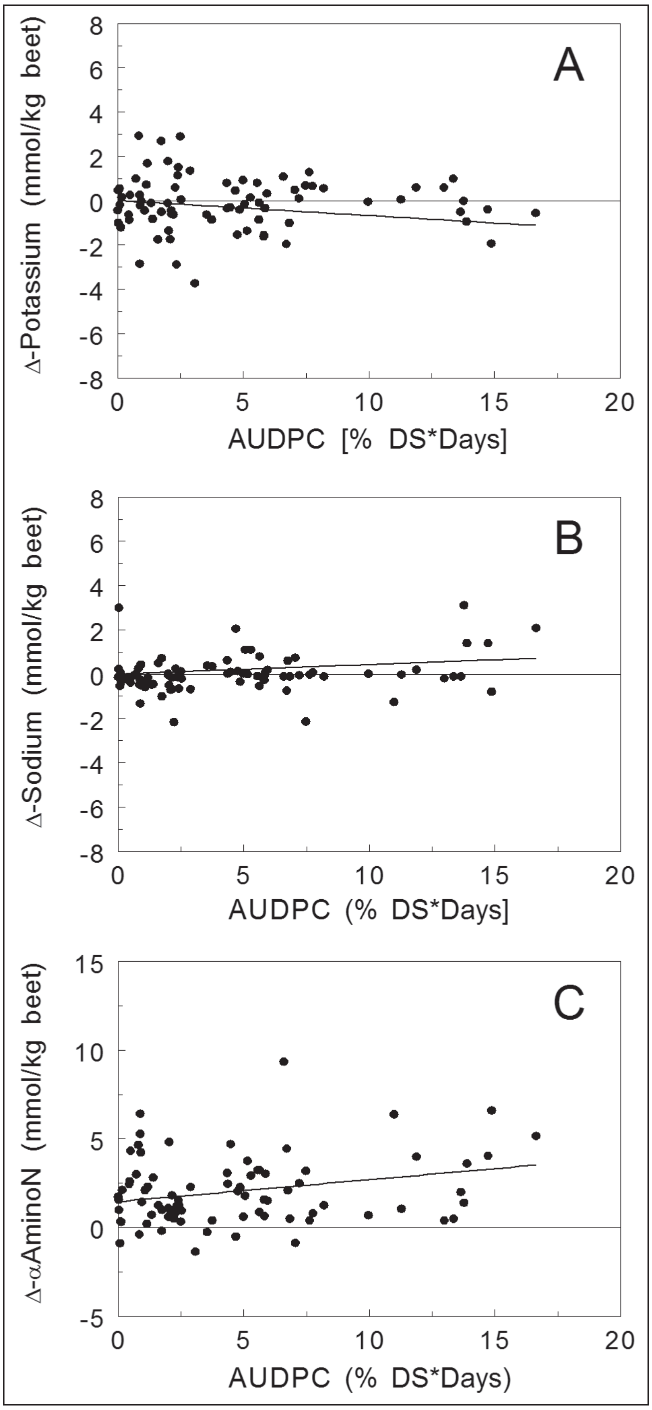

Fig. 2. Relationship between the level of powdery mildew incidence (AUDPC[d]) and non-sucrose components. In each case the absolute difference to "Healthy" is shown. A: Δ-Potassium[a], B: Δ-Sodium[b], C: Δ-αAminoNitrogen[c]. [a]Δ-Potassium = -0,067*AUDPC; r^2=0,02. [b]Δ-Sodium = 0,043*AUDPC; r^2=0,02. [c]Δ-αAminoN = 1,46 + 0,12*AUDPC; r^2=0,06. [d] Please see text figure 1.

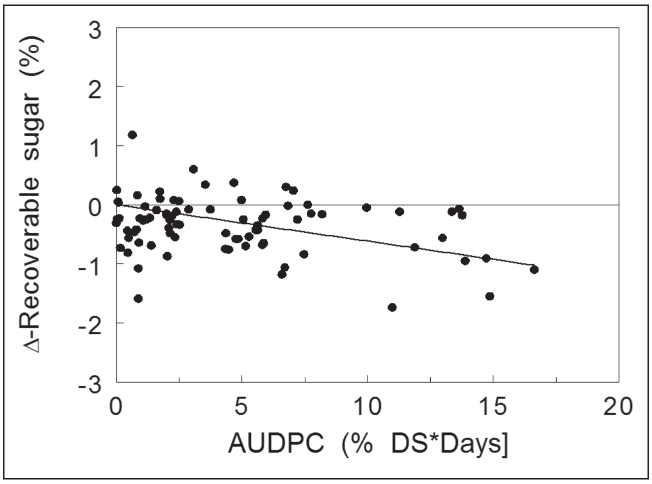

Fig. 3. Relationship[a] between powdery mildew incidence level (AUDPC[c]) and the difference of recoverable sugar[b] to "Healthy". [a] Δ-recoverable sugar = -0,06*AUDPC; r^2=0,23. [b] Calculated after the Braunschweiger Formel (GLATTKOWSKI and THIELECKE, 1995) [c] Please see text figure 1.

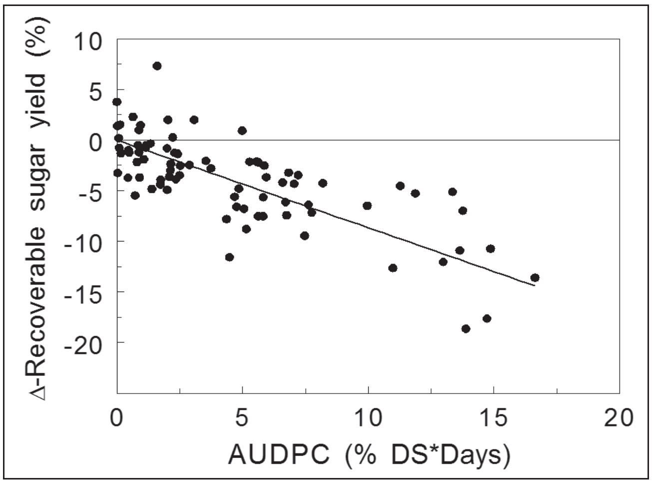

Fig. 5. Relationship[a] between powdery mildew incidence (AUDPC[b]) and relative difference of recoverable sugar yield to "Healthy". [a] Δ-recoverable sugar yield = -0,87*AUDPC; r^2=0,64. [b] Please see text figure 1.

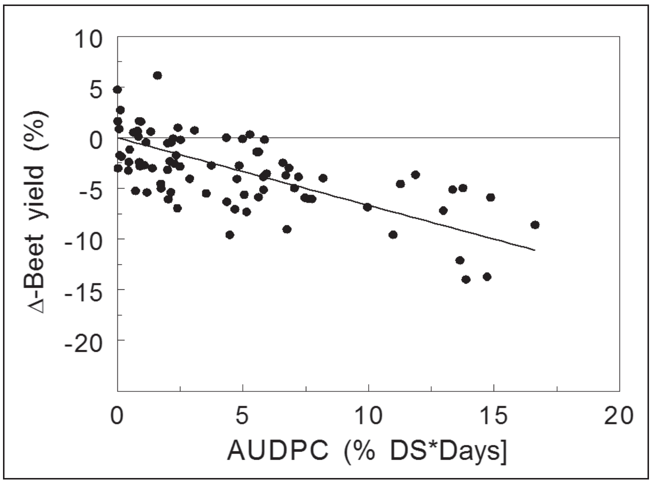

Fig. 4. Relationship[a] between powdery mildew incidence level (AUDPC[b]) and relative difference of beet yield to "Healthy". [a] Δ-beet yield = -0,67*AUDPC; r^2=0,52. [b] Please see text figure 1.

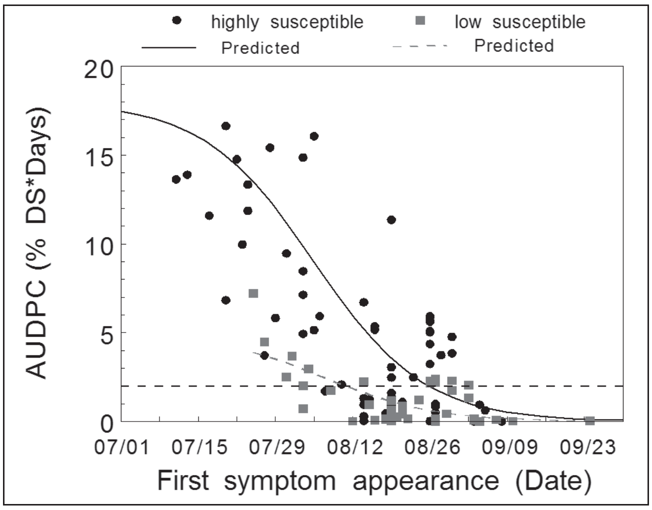

Fig. 6. Relationship of first symptom appearance and AUDPC[c]. Prediction of AUDPC is indicated through curves, full line representing highly susceptible[a] respectively dotted line low susceptible cultivars[b]. The dotted horizontal line at AUDPC=2 indicates the economic damage threshold. [a] Highly susceptible: AUDPC = 18/(1+exp (-(date-218)/-10)); r^2=0,64. [b] Low susceptible: AUDPC = 10/(1+exp (-(date-220)/-8)); r^2=0,55. [c] Please see text figure 1.

and powdery mildew had no impact on the contents of Potassium and Sodium. Thus, decrease of recoverable sugar is mainly dependent on αAminoN. Because the latter was correlated positive linear with the incidence, the regression to recoverable sugar must convert to negative-linear. Anyway, the reductions of 1 - 2% at the maximum are rather slight.

The beet yield is also negative-linear dependent on the height of incidence (Fig. 4). If the AUDPC increases by the value of 1, losses of about 0,7% will follow. In case of early epidemic onset, AUDPC-values may rise to 15 at the maximum, which is equal to a loss of 10%. In view of a proper definition of a damage threshold, the conclusion is that a mostly randomly affected variability of beet losses is evident till AUDPC 2.

In terms of economical affairs, the recoverable sugar yield may be assumed as the most important factor. This parameter comprises quality factors – non sucrose components and sugar content - as well as beet yield. The impact of AUDPC on recoverable sugar yield is not basically different to them of beet yield, although the extent of losses is increased. By analysing the negative-linear relationship, the value of AUDPC 1 causes a reduction of 0,9% of recoverable sugar yield (Fig. 5). Variation of the correlated values is also high and rather randomly affected within the range of AUDPC 0-2; if incidence is further increasing, losses must be expected with high probability. Under conditions of central Europe, *Erysiphe betae* may cause 15% losses of recoverable sugar yield at the maximum.

When overall summarising yield and quality factors, as a tolerance limit of incidence respectively a damage threshold the value of AUDPC=2 is defined. According to

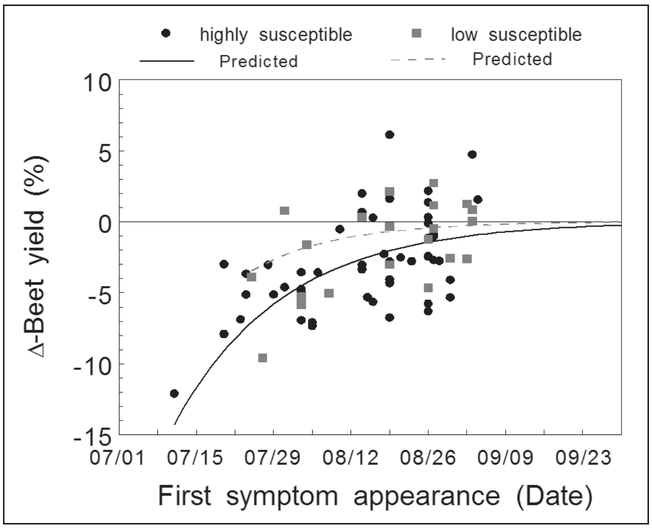

Fig. 7. Relationship of first symptom appearance and Δ-beet yield[b]. Loss prediction of beet yield is indicated through curves, full line representing highly susceptible[a] respectively dotted line low susceptible cultivars[b]. [a] Highly susceptible: Δ-beet yield (%) = -15*exp (-0,05*(date-192)); r^2=0,30. [b] Low susceptible: Δ-beet yield (%) = -8*exp (-0,065*(date-194)); r^2=0,08. [b] Difference of "Healthy" and "Diseased", expressed as percentage in relation to "Healthy".

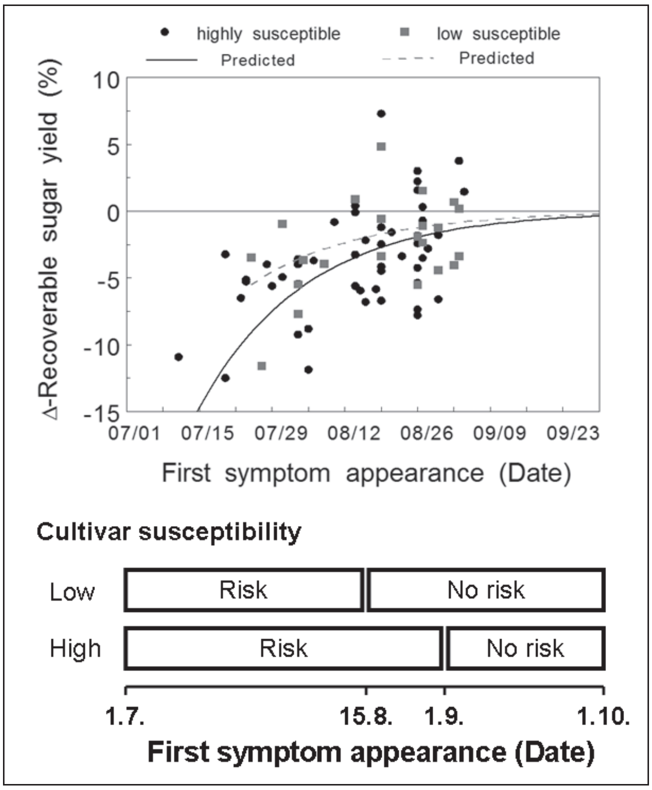

Fig. 8. Relationship of first symptom appearance and Δ-recoverable sugar yield[c]. Loss prediction of sugar yield is indicated through curves, full line representing highly susceptible[a] respectively dotted line low susceptible cultivars[b]. The scheme at the bottom indicates risk periods for economic losses dependent on first symptom appearance and cultivar susceptibility. [a] Highly susceptible: Δ-Recoverable sugar yield (%) = -17*exp (-0,048*(date-194)); r^2=0,25. [b] Low susceptible: Δ-Recoverable sugar yield (%) = -10*exp (-0,047*(date-194)); r^2=0,12. [c] Difference of "Healthy" and "Diseased", expressed as percentage in relation to "Healthy".

the regression equation of recoverable sugar yield, losses would account to 1,8%.

3.2 Loss prediction: Impact of epidemic onset on severity of epidemic

In order to assess the necessity of a fungicide treatment, loss prediction is required. The time of epidemic onset respectively first symptom appearance is a substantial factor concerning the duration and severity of incidence. As in a recent publication has been shown, fungicide applications are most effective during the onset of disease. Therefore, estimation of losses in dependency of disease initiation is crucial. Additionally, cultivar susceptibility is considered by building of two classifications, low-moderate and highly susceptible (Wolf et al., 2006).

The severity of epidemic, corresponding with the disease severity curve over the entire season, is expressed by the AUDPC-value. The latter is dependent on the time of disease initiation and cultivar susceptibility. The respective estimation of AUDPC may be performed by a negative-sigmoidal function (Fig. 6). If the epidemic onset takes place in July and cultivar susceptibility is high, severe epidemics are most likely, which exceed the damage threshold significantly by AUDPC-values in the range of 5 - 17. The extent of epidemic is declining strongly, if first symptom appearance is delayed in August. In case of high susceptibility, the sigmoidal curve fit indicates a drop of the curve beneath the tolerance limit at the end of August with further alignment to zero during September. If cultivar susceptibility is low, loss risk caused by *Erysiphe betae* is generally low (Fig. 6). There is just a marginal risk when first symptoms appear before mid-August.

The relationship of disease initiation and losses of beet yield respectively recoverable sugar yield is expressed by an exponential function of the type "$y=-y_{max}*\exp(-a*(x-t_0))$", where "$y_{max}$" indicates the maximum loss and "x" the calendar day of disease initiation; the term "$x-t_0=0$" determines the begin of the estimation respectively the time, where yield loss is the maximum. Deviations of correlated values from the curve fit are once again high and, therefore, the coefficients of determination rather low (Fig. 7). Overall, this may be a consequence of the slight damage potential of the biotrophic parasite. On the other hand, field experiments are naturally affected with randomly deviations which may explain part of the total variation. Maximum beet yield loss of 8% occurs if disease is initiated in the period of mid to end of July. The more the epidemic onset is delayed the smaller the differences between Diseased and Healthy. A conditional risk is evident until the end of August, particularly if cultivar susceptibility is high. Therefore, the incidence of powdery mildew can be neglected under conditions as follows: If cultivar susceptibility is low and first symptoms appear after mid-August respectively valid for high susceptible cultivars, if disease is initiated first during September.

The principles of the above reported relationship are the same if the recoverable sugar yield is the dependent variable (Fig. 8). Only the extent of losses is different. Under conditions of first symptoms appearance in the period of mid-end of July and high cultivar susceptibility, losses may achieve 10-15% at the maximum. The trend of decreasing losses continues during August; the average of sugar loss accounts to ≈2% at the middle of the month. In particular, if high susceptible cultivars are grown, economic losses cannot be excluded if first symptoms are found till the end of August. In terms of low susceptible reaction, however, the average losses tend to zero already from mid-August.

These findings may be summarised through a simple loss prediction scheme by distinguishing periods of risk and no risk (Fig. 8, bottom). The assessment of loss risk is dependent on the time of disease initiation and cultivar susceptibility. Hence, there is a loss risk if first symptoms appear till the end of August respectively mid-August in case of low susceptible cultivar. The periods are equal to action zones concerning fungicide applications.

4 Discussion

In central Europe, among fungal leaf diseases of sugar beets, *Erysiphe betae* may be assumed as an important damage factor, next to *Cercospora beticola*. Nevertheless, the loss potential is significantly lower, about one third of that the perthotrophic parasite may cause. At culmination of the epidemic, the mycel layer of powdery mildew may cover 40-60% of the total leaf area (WOLF, 2002; WOLF et al., 2006); despite high incidence, the losses are comparatively low, very seldom exceeding 10 % of the recoverable sugar yield. The inner quality of the sugar beet is only marginal affected; the sugar content may be reduced by 0.5-0.7% (absolute), as well as the αAminoNitrogen was slightly increased. Unlike other powdery mildews, *E. betae* has so far received relatively little attention from pathologists and the precise mechanisms by which it infects its host remain unclear (FRANCIS, 2007). In terms of loss potential, AHRENS and WELTZIEN (1985) performed evaluations during the early 80s of last century, which are widely confirmed by our conclusions. Thus, protective treatments may prevent 10-15% sugar yield losses.

Even though the damage potential is moderate, we have to conclude that there is a substantial loss risk worth to face with fungicide applications. Hence, the question is, to what situations it is opportune to spray. The strategy of handling fungicide treatments is in accordance to the principles of the Quaternary IPM-concept as already presented for *Cercospora beticola* (WOLF et al., 2004; WOLF and VERREET, 2002; WOLF and VERREET, 2005b). Nevertheless, some modifications had to be introduced to match the specific biology and epidemic behaviour of *Erysiphe betae*. The negative-prognosis may be summarised briefly, as in Germany disease initiation doesn't take place before mid-July, in low susceptible cultivars even later, from the beginning of August onwards (WOLF et al., 2006). A further important statement was that only fungicide sprays during the phase of disease initiation are most effective and provide best monetary profits (WOLF, 2002).

Therefore, in order to back decisions of fungicide treatments, this paper depicted the other two elements of the quaternary principle, the economic damage threshold and loss prediction. In view of a proper definition of the damage threshold, the AUDPC-value was preferred instead of the final disease severity. The object here was to prevent false correlations of yield factors with the incidence of powdery mildew. The epidemiology of powdery mildew involves a period of more or less steep increase followed by culmination, and, as a typical feature, sometimes disappearance of the mycel layer towards the end of the season (WOLF, 2002; WOLF et al., 2006). Hence, the calculation of AUDPC comprises all epidemic phases and may be assumed as suitable for disease loss relationships. In this way, if quality and yield parameters are summarised overall, a damage threshold of AUDPC 2 is derived. AHRENS (1985) stated economic yield losses under conditions of disease initiation before mid-August and incidence progressions exceeding 30%. This finding also is fairly according with our results. Exceptionally, the risk period should be extended till the end of August if a high susceptible cultivar is grown.

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References

AHRENS, W., 1985: Maßnahmen zur Schadensverhütung bei Befall mit dem Echten Rübenmehltau *Erysiphe betae* Van. Weltzien. IIRB, Brüssel, 289-205.

AHRENS, W., H.C. WELTZIEN, 1980: Investigations on the Distribution and Yield Losses Caused by the Sugar-Beet Powdery Mildew Erysiphe-Betae in Germany, Austria and Turkey. Zuckerindustrie **105** (10), 916-925.

COOKE, D.A., R.K. SCOTT, 1993: The Sugar Beet Crop - Science into Practice. London, Chapman & Hal.

DRANDAREVSKI, C.A., 1969: Untersuchungen über den Echten Rübenmehltau *Erysiphe betae* Vanha Weltzien. III: Geophytopathologische Untersuchung. Phytopathologische Zeitschrift **65**, 201-218.

FRANCIS, S., 2007: Sugar-beet powdery mildew *Erysiphe betae*. Molecular Plant Pathology **3** (3), 119-124.

GLATTKOWSKI, H., K. THIELECKE, 1995: Neue Formel zur Berechnung des technischen Wertes von Zuckerrüben. Zuckerrübe 1, 42-44.

KRANZ, J., F. HOLZ, 1993: Basics of Decision - Making and Planning for Integrated Pest Management IPM. Feldafing und Tschortau, Food and Agriculture Development Centre.

MUKHOPADHYAY, A.N., 1987: Handbook on Diseases of Sugar Beet Vol. I. Boca Raton, Florida. CRC Press.

WOLF, P.F.J., 2002: Über die Integration von Bekämpfungsmaßnahmen gegen pilzliche Blattkrankheiten der Zuckerrübe – IPS-Modell Zuckerrübe. Aachen, Shaker Verlag,.

WOLF, P.F.J., H. KLINK, J.A. VERREET, 2004: A concept in integrated pest management IPM of fungal leaf diseases of cereals and sugar beets. In: R. T. LARTEY, A. J. CEASAR (eds.): Emerging Concepts in Plant Health Management, 69-102. Research Signpost 37/661 2, Fort P.O., Trivandrum-695 023, Kerela, India.

WOLF, P.F.J., R. KRAFT, J.A. VERREET, 1998: Schadrelevanz von Cercospora beticola Sacc. in Zuckerrüben als Grundlage einer Verlustprognose. Z.Pflanzenkrankh.Pflanzenschutz **105** (5), 462-474.

WOLF, P.F.J., R. LENZ, K. BARON, J.A. VERREET, 2007: Quaternary integrated pest management concept for powdery mildew in sugar beet. I. Evaluation of epidemic oriented thresholds as indicators of fungicide treatments. Nachrichtenbl.Deut.Pflanzenschutzd. **59** (5), 107-112.

WOLF, P.F.J., R. LENZ, J.A. VERREET, 2006: Quaternary integrated pest management concept for powdery mildew in sugar beet. I. Analysis of epidemic determinants to predict disease onset. Journal of Plant Diseases and Protection **113** (2), 61-67.

WOLF, P.F.J., J.A. VERREET, 2002: Development and implementation of an integrated pest management system in Germany for the control of fungal leaf diseases in sugar beet: The IPM sugar beet model. Plant Disease **86** (4), 336-344.

WOLF, P.F.J., J.A. VERREET, 2003: Innovative combination of IPM-Integrated Pest Management tools - The IPM Sugar Beet Model. Comm.Appl.Biol.Sci., Ghent University **68** (4b), 491-498.

WOLF, P.F.J., J.A. VERREET, 2005a: Factors affecting the onset of Cercospora leaf spot epidemics in sugar beet and establishment of disease monitoring thresholds. Phytopathology **95** (3), 269-274.

WOLF, P.F.J., J.A. VERREET, 2005b: Modern Concepts of Integrated Pest Management IPM in Wheat and Sugar Beet. In: H.W. DEHNE, U. GISI, K.H. KUCK, P.E. RUSSEL, H. LYR (eds.): Modern Fungicides and Antifungal Compounds IV, 163-181. British Crop Protection Council, Hampshire, UK.