SkleroPro - a crop loss-related forecasting model for chemical control of *Sclerotinia* stem rot in winter oilseed rape in Germany

Simone Koch[1], Sarah Dunker[1], Benno Kleinhenz[2], Manfred Röhrig[3], Andreas von Tiedemann[1]

[1]*Institute of Plant Pathology and Plant Protection, Georg-August University Göttingen, Grisebachstraße 6, 37077 Göttingen, Germany; Email: atiedem@gwdg.de*

[2]*Center Institution for Decision Support Systems in Crop Protection (ZEPP), Rüdesheimer Straße 60-68, 55545 Bad Kreuznach, Germany;*

[3] *Information System for Integrated Plant Protection (ISIP), Rüdesheimer Straße 60-68, 55545 Bad Kreuznach, Germany*

Abstract

Sclerotinia stem rot (SSR) is an economically harmful disease in winter oilseed rape (OSR) in all regions with increased intensity of OSR cultivation. As resistant cultivars are not available, control of SSR relies on a routine fungicide spray at bloom in most areas. The economic evaluation of such sprays during the last fifteen years in Germany revealed 67% of fungicide treatments to be not cost-effective. Therefore, an economy-related forecasting model was developed based on disease/crop-loss relationships obtained from a three-year field experiment with a hybrid and a line cultivar. A further analysis demonstrated the significant impact of crop rotation, while crop density, nitrogen level and soil management did not have significant effects on disease incidence (DI). From a climate chamber study, 7 to 11°C and 80 to 86% relative humidity (RH) were established as minimum conditions for stem infection with ascospores and used in order to discriminate infection hours. DI significantly correlated with infection hours (Inh) occurring post growth stage (GS) 58 (late bud stage) ($r^2 = 0.42$; $P \leq 0.001$). In a parallel ontogenetic model, the developmental stages of OSR are simulated. The novel forecasting system, SkleroPro, consists of a two-tiered approach, the first providing a regional assessment of the disease risk, which is assumed when 23 Inh have accumulated post GS 58. The second tier provides a field-site specific, economy-based recommendation, including costs of spray, expected yield and rapeseed produce price. In field evaluations of SkleroPro the percentage of economically correct decisions varied from 70 to 81%, with potential savings of fungicides of 39 to 81% in individual years. This study demonstrates that in areas with abundant occurrence of *sclerotinia* the level of SSR in OSR can satisfactorily be determined by predicting stem infection during late bud and flowering and a simulation of apothecial development is not required. SkleroPro is the first crop-loss related forecasting model suitable for practical use in the control of a *Sclerotinia* disease and available to users in Germany via the internet since 2006. Its concept and components may be useful in developing forecasting systems for *sclerotinia* diseases in yet other crops.

Key words: economic damage thresholds, crop-loss assessment, decision support system

Introduction

Sclerotinia stem rot (SSR) caused by *Sclerotinia sclerotiorum* (Lib.) de Bary has growing importance in oilseed rape (OSR), *Brassica napus*, in Germany, as a consequence of the increased intensity in cultivation of this oil crop in the last two decades. Yield losses of up to 50% due to this disease may occur depending on regions and years (Pope et al., 1989). As resistant winter oilseed rape varieties are not available, prophylactic fungicide sprays at full bloom have become a widely applied control practice. However, earlier analyses have shown that only 27 and 33 % of fungicide sprays at bloom were cost-effective (Dunker & Tiedemann, 2004; Wahmhoff, 2000).

This unsatisfying situation has given rise to development of various approaches of decision support systems for this disease. Previous approaches of developing a prediction model for SSR in OSR were constricted to estimate the likelihood of an infection and were not able to predict the level of disease or crop loss. More importantly, earlier forecasting approaches are lacking an economic evaluation of the cost-effectiveness of a spray. Also, they had a low degree of computerization and required a relatively time-consuming input of field-specific data, e.g. on emergence of apothecia or ejected ascospores (Ahlers & Hindorf, 1987; Friesland, 2000, Nordin et al., 1992; Twengström et al., 1998). A petal test has been utilised in spring sown canola in Canada (Gugel & Morall, 1986). With multiple regressions based on petal infection and various canopy variables 55-98% of the disease incidence variability at harvest time was explainable (Turkington & Morall, 1993). More recently, attempts have been made to predict the carpogenic germination of sclerotia based on air temperature and the soil water potential as a component in a disease forecasting system for *sclerotinia* leaf drop in lettuce (Clarkson et al., 2004; Young et al., 2005). Apothecial development was found to be determined by a complex of factors which yet requires a closer analysis before its utilization in a reliable forecasting system.

The present work describes a crop-loss related forecasting model enabling a field-site specific recommendation for fungicide sprays at bloom against SSR. This novel forecasting model SkleroPro provides an accurate and easy-to-handle, fully computerized decision support system based on weather and field-site specific data and is made accessible to growers and advisors via the internet. This paper briefly outlines the model functionality and demonstrates its reliability under field conditions in diverse geographical situations.

Materials and Methods

Historical field data from 650 field trials were provided from the federal state extension services over a period of ten years (1994 to 2004). The data set was analysed for the strength of various agronomic determinants of SSR such as year, crop density, N fertilization, and frequency of OSR in the crop rotation. In addition, the historical field data were used for calculating correlations of disease incidence with weather variables.

Additionally, field experiments in ten federal states were conducted from 2002 to 2005. Data from these experiments were used to relate disease incidence to weather variables, in order to test the crop growth model for accuracy or to evaluate the economic efficiency of SkleroPro. Experiments comprised a fungicide-untreated control, one treatment according to the model recommendation, and a grower's variant with routine fungicide application at full bloom (GS 65). Plots were arranged in a randomized block design with four replications in each experiment. All fungicide treatments were performed with 0.5 L per hectare Cantus (a.i. Boscalid, registered trade mark of BASF).

Weather data were obtained online from the DWD (German Meteorological Service) in Offenbach through the ZEPP (Centre Institution for Decision Support Systems in Crop Protection) or directly from the federal extension service stations online. SkleroPro was validated by retrospective calculations using historical data from 76 field trials and by testing the model 32 field trials in 2005.

Experiments under controlled conditions were carried out in order to revisit the optimum requirements for ascospore infection of *sclerotinia* on stems of OSR given in the literature (Abawi & Grogan, 1979; Krüger, 1975) for temperature and rel. humidity. Controlled experiments were conducted with the spring-sown OSR cv. 'Heros'. Ascospores were produced by induction of carpogenic germination of sclerotia incubated in sand/soil mixture for 4 weeks at 15/10°C (day/night) temperature in the dark, followed by conditions of 18°C under near-UV light (12h per day).

(For more details in methodology see Koch et al., 2007.)

Results & Discussion

Identification of field-site specific determinants of disease incidence

The level of disease incidence varied strongly with the year of observation. The strongest field-site specific determinant of disease was the frequency of OSR cultivation in the crop rotation. In contrast, no significant relationship with disease incidence was found for crop density and soil management (ploughing *vs.* no-tillage). The level of nitrogen fertilization was split into three categories, low (< 175 kg per ha), medium (175-220 kg per ha) and high (>220 kg per ha), but also had no significant effect on disease incidence.

Functionality of SkleroPro

SkleroPro uses weather data from the closest weather station on relative humidity (RH) and temperature, precipitation (hourly reading) and sunshine duration (per day) for its initial computation step, in which these weather data are transformed into the plant canopy (CLIMA Cpy) of an OSR stand (Fig. 1). The computation starts when the late bud stage (GS 58) is reached. The date of mid bud stage (GS 55) and the kind of crop rotation (CropR) are to be provided by the user to start the model. A crop development model, ONTO, is run in parallel and based on T-Cpy. From field observations, the period of risk for SSR infection is assumed to start at GS 58 (late bud stage). Calculations end at GS 68 (late bloom) when sprays in the field are no more feasible. The forecasting follows a two-tiered procedure, starting with a regional disease risk assessment which is followed by a field-site specific forecast. Starting at late bud stage (GS 58) the model calculates and sums up the number of infection hours (Inh; see below). A regional risk of disease is assumed if the critical threshold of 23 infection hours is reached after the crop has passed GS 58. In such case, the number of Inh exceeding the threshold period is recorded and added up (InhSum). Technically, the crop rotation effect decreases or increases the threshold of Inh for stem infection. When the threshold of Inh is reached, a regional disease risk is assumed and a field-site specific calculation of the economic damage threshold starts (see below). The critical number of infection hours Inh_i in a specific field marking the threshold DI of the economic damage threshold is calculated from crop-loss regressions obtained from a previous study with a set of field trials (Dunker & Tiedemann, 2004). A recommendation to spray is put out when the number of Inh actually recorded from a weather station exceeds the critical level of Inh_i.

Determination of infection hours and of the economic damage threshold

Infection hours (Inh) are derived from hourly calculations of temperature and relative humidity in the plant canopy (T-Cpy, RH-Cpy; Fig. 1). According to the inoculation experiments in controlled conditions, the optimal temperature for stem rot infection was set at 18°C and the minimum temperature at 7°C. Based on these temperature points and on the requirements for relative humidity reported in the literature (Abawi & Grogan, 1979; Krüger, 1975) an index INFEST is calculated which discriminates hours suitable for infection. A suitable infection hour for stem infection is given at conditions of 7 to 11°C and 80 to 86% RH. The minimum number of Inh required for a successful infection in the field was determined by comparative regression analyses with a data set from 30 field trials conducted from 2000 to 2004. In a stepwise analysis the best correlations with DI were achieved with thresholds at 22 or 23 Inh. Accordingly, 23 Inh was used in SkleroPro as threshold for a successful stem infection.

When a continuous infection period of 23 Inh is recorded, the model starts a quantitative, field-site specific estimation of the expected level of disease and crop loss. Infection hours exceeding the threshold for stem infection are added up to the sum of Inh (InhSum; see Fig. 1). In order to calculate the economic damage threshold, the grower is asked to provide the actual rapeseed produce price, the spray costs and the expected yield. Economic calculations comprise several steps, in which spray costs are related to yield units and to the estimated crop loss derived from disease-crop loss functions developed in separate, three-year field inoculation trials (Dunker & Tiedemann, 2004). The recommendation of the model is based on the number of Inh recorded (InhSum) *vs.* Inh representing the economic threshold (Inh_i). When Inh_i is exceeded by InhSum, a recommendation to spray is put out on the same day.

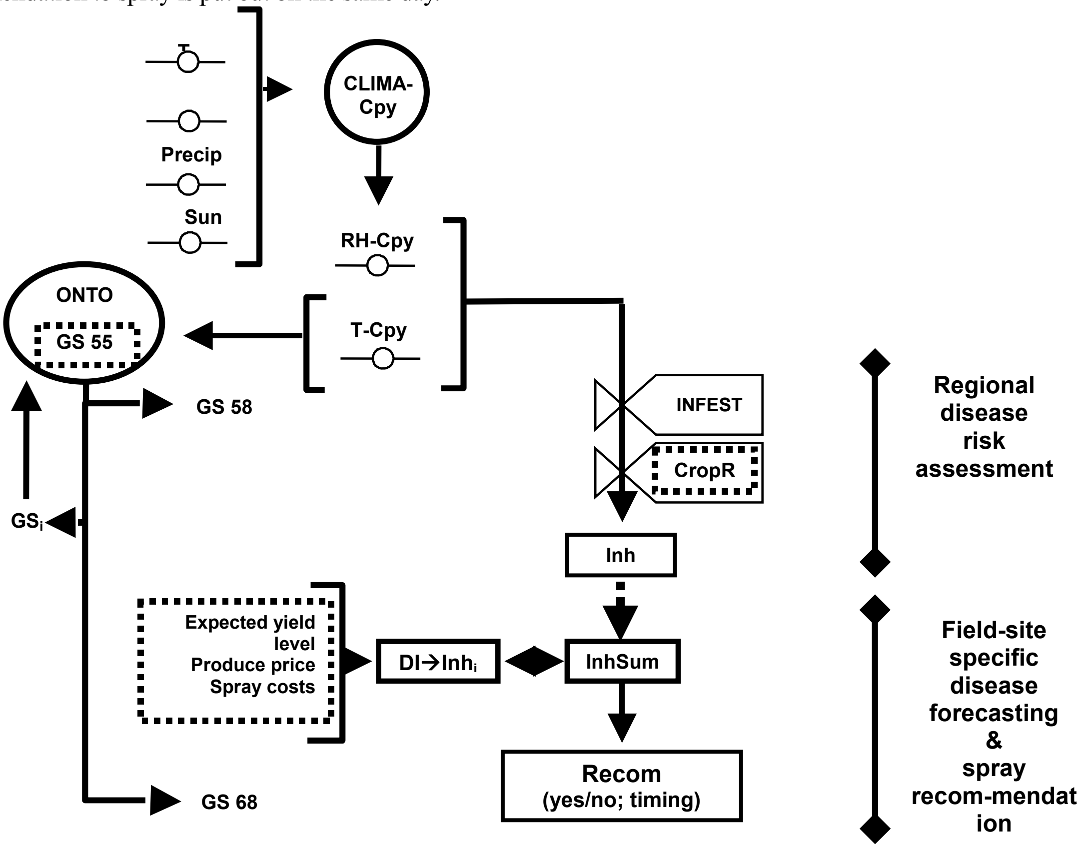

Fig. 1. Functional scheme of SkleroPro. T = temperature and RH = rel. air humidity; Precip = hourly rainfall [mm]; Sun = daily sunshine duration; GS = growth stage; CLIMA-Cpy = microclimate in the canopy; RH-Cpy = rel. humidity in the canopy; T-Cpy = temperature in the canopy; ONTO = simulation model of OSR development; GS = growth stages according to (20); CropR = frequency of OSR in crop rotation; DI = disease incidence; InhSum = sum of infection hours; Inh_i = number of infection hours corresponding to the level of DI at the economic damage threshold; Recom = recommendation of spray (yes/no and when). Data in dotted line boxes are to be provided by the user. Hourly readings from a weather station of T, RH, Precip and Sun are transformed into T-Cpy and RH-Cpy. Based on T-Cpy ONTO calculates the crop developmental stage and marks the period from GS 58 to 68 during which the model runs. Periods suitable for stem infection are discriminated by the INFEST function resulting in Inh. When the threshold of Inh for stem infection is exceeded, a regional risk of disease is assumed and a field-site specific forecast starts. Inh exceeding the threshold (modulated by the crop rotation factor, CropR) are added up to InhSum. The field-site specific economic damage threshold DI is derived from disease-crop loss functions (see text) and related to Inh_i. A recommendation to spray is put out (Recom) on the day when InhSum exceeds Inh_i.

Evaluation of SkleroPro in field trials

The prediction accuracy of SkleroPro was evaluated by retrospectively running the model with a historical data set of 76 field trials conducted from 1994 to 2004. The analysis revealed that 70% of the model recommendations were correct, while 24% overestimated the disease with a final disease level being below the economic damage threshold. Underestimation occurred in 6% of the cases resulting in sprays omitted although being cost-effective. Overall, only 53% of the routinely conducted sprays in these locations and years proved to be economically justified. Hence, SkleroPro recommendations would have saved 39% of unnecessary fungicide sprays compared to a routine application. An additional evaluation was undertaken in field trials conducted in 32 locations in Germany in 2005 and revealed an overall prediction accuracy of 81%. The rate of overestimation of disease was 19% while no case was recorded where the disease has been underestimated. In the 2005 field trials, only 9% of the sprays routinely conducted proved to be cost-effective and thus justified, as the temperature during the critical flowering stages in spring were abundantly too low. Hence, in 2005 SkleroPro would have been able to save 75% of unnecessary fungicide sprays compared to a routine application. The savings in fungicide applications due to the recommendations by SkleroPro calculated on the base of the historical data set or the 2005 field experiments are equal to gains in net return for the growers of 23 and 45 € per hectare, respectively.

This is the first crop-loss related forecasting model for a *sclerotinia* disease providing to the user a field-site and time-point specific recommendation of fungicide spray in an important field crop. Its practical value results from its high reliability combined with a minimum requirement of field-specific data to be manually provided by the user. SkleroPro has been made available to growers and advisors in the season 2006 via an established online infrastructure for agricultural extension through the internet portal 'ISIP' (Information System for Integrated Plant Production) at www.isip.de. The rationale, components and implementation of the model therefore could be useful in the development of *sclerotinia* forecasting systems in yet other crops and different climates.

References

Abawi GS, Grogan RG (1979) Epidemiology of diseases caused by *Sclerotinia* species. Phytopathology 69: 899-904.

Ahlers D, Hindorf H (1987) Epidemiologische Untersuchungen über den Schaderreger *Sclerotinia sclerotiorum* an Winterraps im Hinblick auf eine Prognose. Nachrichtenbl. Dt. Pflschutzd. 39: 113-119.

Clarkson JP, Phelps K, Whipps JM, Young CS, Smith JA, Watling M (2004) Forecasting *Sclerotinia* disease on lettuce: toward developing a prediction model for carpogenic germination of sclerotia. Phytopathology 94: 268-279.

Dunker S, Tiedemann A v (2004) Disease yield loss analysis for *Sclerotinia* stem rot in winter oilseed rape. IOBC Vol. 27 (19): 59-65.

Friesland H (2000). Agrarmeteorologisches Verfahren zur Prognose von Rapskrebs. Raps 18(1), 14-17.

Gugel RK, Morall RAA (1986) Inoculum-disease relationships in *Sclerotinia* stem rot of rapeseed in Saskatchewan. Can. J. Pl. Pathol. 8: 89-96.

Koch S, Dunker S, Kleinhenz B, Röhrig M, v. Tiedemann A (2007). A crop loss-related forecasting model for *sclerotinia* stem rot in winter oilseed rape. *Phytopathology* (accepted)

Krüger W (1975) Über die Wirkung der Witterung auf den Befall des Rapses durch *Sclerotinia sclerotiorum* (Lib.) de Bary. Nachrichtenblatt Dt. Pflanzenschutzd. 27: 1-6.

Nordin K, Sigvald R, Svensson C (1992) Forecasting the incidence of *Sclerotinia* stem rot on spring-sown rapeseed. J. Plant Dis. Prot. 99: 245-255.

Pope SJ, Varney PL, Sweet JB (1989) Susceptibility of cultivars of oilseed rape to *Sclerotinia sclerotiorum* and the effect of infection on yield. Aspects of Appl. Biol. 23: 451-456.

Turkington TK, Morall RAA (1993) Use of petal infestation to forecast *Sclerotinia* stem rot of canola: the influence of inoculum variation over the flowering period and canopy density. Phytopathology 83: 682-689.

Twengström E, Sigvald R, Svensson C, Yuen J (1998) Forecasting *Sclerotinia* stem rot in spring sown oilseed rape. Crop Prot. 17(5): 405-411.

Wahmhoff W (2000) Integrierter Rapsanbau: Untersuchungen zur Entwicklung integrierter Produktionsverfahren am Beispiel des Winterrapses (*Brassica napus* L.). Erich Schmidt Verlag, Berlin, Germany.

Young CS, Clarkson JP, Smith JA, Watling M, Phelps K, Whipps JM (2004). Environmental conditions influencing *Sclerotinia sclerotiorum* infection and disease development in lettuce. Plant Pathol. 53: 387-397.