Supplementary files

SIPPOM-WOSR: a Simulator for Integrated Pathogen POpulation Management of phoma stem canker on Winter OilSeed Rape. I. Description of the Model

Appendix 1: simulation of the attainable yield in SIPPOM-WOSR

E. Lô-Pelzer[1*], J.N. Aubertot[2], L. Bousset[3], M.H. Jeuffroy[1]

[1]INRA, UMR211 Agronomie, BP01, F-78850 THIVERVAL-GRIGNON, France
[2]INRA, UMR 1248 AGIR, BP 52627 Auzeville, F-31326 CASTANET TOLOSAN, France
[3]INRA, Agrocampus Rennes, UMR1099 BiO3P (Biology of Organisms and Populations applied to Plant Protection), F-35653 LE RHEU, France

Introduction

In SIPPOM, the crop growth sub-model has to simulate the crop growth during the infections, as well as the attainable yield, *i.e.,* the yield that could be obtained without losses due to the disease. Azodyn-rape (Jeuffroy *et al.,* 2003) simulates crop growth as well as yield. However, for simplification reasons in SIPPOM, we chose to use this existing model to simulate crop growth during infections (*i.e.,* when spores are released and plants are susceptible to infection, in autumn), and to propose a simple equation to estimate the attainable yield.

Attainable yield depends on the potential yield of the cultivar. Two major limiting factors were considered: growth status of the crop at the end of winter, characterized by the aerial biomass (as proposed in a tool to adjust nitrogen rate to apply, Reau and Wagner, 1998; Makowski *et al.*, 2005), and hydric status of the crop from end of winter to harvest (as proposed by Limaux, 1999), characterized by the hydric storage of the soil, and by the hydric deficit (balance between rain fall and soil and crop transpiration, Limaux, 1999). The mineral nitrogen rate applied was supposed optimal, and was not considered as a limiting factor.

The following relation has to be established:

$$YieldAtt = YieldPot_{cultivar} * relativeYieldLoss_{HS,HD} * relativeYieldLoss_{BMEW} \quad \text{Eq. 1}$$

With YieldAtt: attainable yield (seeds mass, [YieldAtt] = $M.L^{-2}$), $YieldPot_{cultivar}$: potential yield of the cultivar ([$YieldPot_{cultivar}$] = $M.L^{-2}$), HD: hydric deficit ([HD] = L), HS: maximum hydric storage in soil ([HS] = L), BMEW: crop dry aerial biomass per surface unit at the end of winter ([BMEW] = $M.L^{-2}$).

Material and methods

Potential yield

The potential yield of the crop has to be provided as an input variable in SIPPOM. If it is not known by the user, it can be deduced for instance from the website proposed by the French technical centre for oilseed crop (CETIOM, www.oleovar.cetiom.fr). Yields of several cultivars have been measured, resulting from experimental trials set up in several sites and years where the pest pressure was limited due to pesticides. Considering the most favourable site and year, the maximum yield can be considered as the potential yield of the cultivar.

Yield loss due to hydric status of the crop

According to Limaux (1999), the hydric deficit is calculated between the end of winter and the harvest as follows:

$$HD = \sum_{d} \left(ETPd - Rd \right) \quad \text{Eq. 2}$$

With ETPd: daily evapotranspiration of the plant-soil system ([ETP] = L); Rd: daily rainfall ([Rd] = L).

In order to establish the relationship between yield and hydric deficit, data from the "Observatoire des potentialités agro-climatiques de Lorraine" provided by E. Hance were used. This data has been collected during 12 years (1992-2004) in 10 sites in the French region Lorraine, presenting 19 different types of soil. Relationship between yield and hydric deficit depends on the type of soil, which has been characterized by its hydric storage. The relationship between yield, hydric deficit and hydric storage has been established by linear regression:

$$Yield_{HS,HD} = \alpha_1 HD + \alpha_2 HS + \alpha_3 HD * HS + \alpha_4 \quad \text{Eq. 3}$$

With HD: hydric deficit ([HD] = L), HS: maximum hydric storage in soil ([HS] = L

The predictive quality of this relation was cross validated. Reported to the maximum yield of the dataset, the relative yield loss due to hydric status of the crop was expressed**.**

Yield loss due to growth status of the crop

Data from CETIOM were provided: yields and dry aerial biomass at the end of winter were collected on 54 plots (35 sites) for 9 cultivars and during 7 years (1993-1999). Nitrogen was applied optimally on the plots. Given the distribution of values of yields related to biomass (Figure 1), a boundary line relationship was established between these two variables (Makowski *et al.,* 2007). The principle is to establish a line that links the maximum yield to the biomass. It represents the yield when the biomass is the only limiting factor, and points that are under this line take into account other unknown limiting factors. Two steps are necessary: the choice of the mathematical function, and the estimation of parameters by quantile regression (Makowski *et al.,* 2007). The following mathematical function was chosen (Cade *et al.,* 2000):

$$Yield_{BMEW} = \beta_0 \left(\frac{BMEW}{BMEW_0} \right)^{\beta_1} \exp(\beta_2 BMEW) \quad \text{Eq. 4}$$

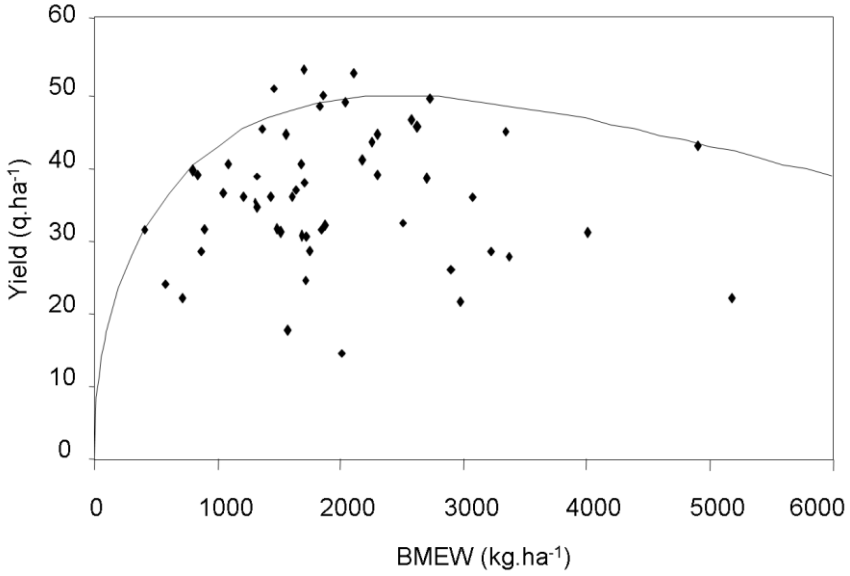
With $BMEW_0$: unit of crop biomass per surface unit at the end of winter ($[BMEW_0] = M.L^{-2}$). This equation can be linearized, which facilitates parameter estimation with the *rq* function of the R statistical software:

$$\ln\left(\frac{Yield_{BMEW}}{Yield_{BMEW}0} \right) = \ln\left(\frac{\beta_0}{BMEW_0} \right) + \beta_1 * \ln\left(\frac{BMEW}{BMEW_0} \right) + \beta_2 BMEW \quad \text{Eq. 5}$$

With $Yield_{BMEW}0$: unit of yield.

Parameters $\ln\left(\frac{\beta_0}{BMEW_0} \right)$, β_1 and β_2 were estimated for quantiles varying between 0,5 and 0,95 with a 0,05 step. The quantile corresponding to the more restrictive 95 % confidence interval for parameters estimation was selected. Reported to the maximum yield of the dataset, the relative yield loss due to growth status of the crop was expressed**.**

Figure 1. Relationship between yield and dry aerial biomass at the end of winter (BMEW). The boundary line has been established by quantile regression, for the quantile τ = 0,85



Results

Potential yield

Potential yields of 104 WOSR cultivars have been found in oleovar and are proposed to users.

Yield loss due to hydric status of the crop

The relationship between yield, hydric deficit and hydric storage (Equation 3) has been established by linear regression (R^2 = 90 %) and parameters were estimated: α_1 = -0.0855 q. $ha^{-1}.mm^{-1}$, α_2 = 0.1057 q. $ha^{-1}.mm^{-1}$, $\alpha_3 = 2.98.10^{-4}$ q. $ha^{-1}.mm^{-2}$, α_4 = 31.554 $q.ha^{-1}$

The predictive quality of the relation was evaluated by cross validation (without considering correlation between sites and years of collection). The RMSEP was 2.18 $q.ha^{-1}$ for an average observed yield of 32.9 $q.ha^{-1}$.

The relative yield loss due to hydric status was therefore:

$$relativeYieldLoss_{HS,HD} = a_1 HD + a_2 HS + a_3 HD * HS + a_4 \quad \text{Eq. 6}$$

With $a_1 = -1.7.10^{-3}$ mm^{-1}, $a_2 = 2.2.10^{-3}$ mm^{-1}, $a_3 = 6.1.10^{-6}$ mm^{-2} and a_4 = 0.644.

Yield loss due to growth status of the crop

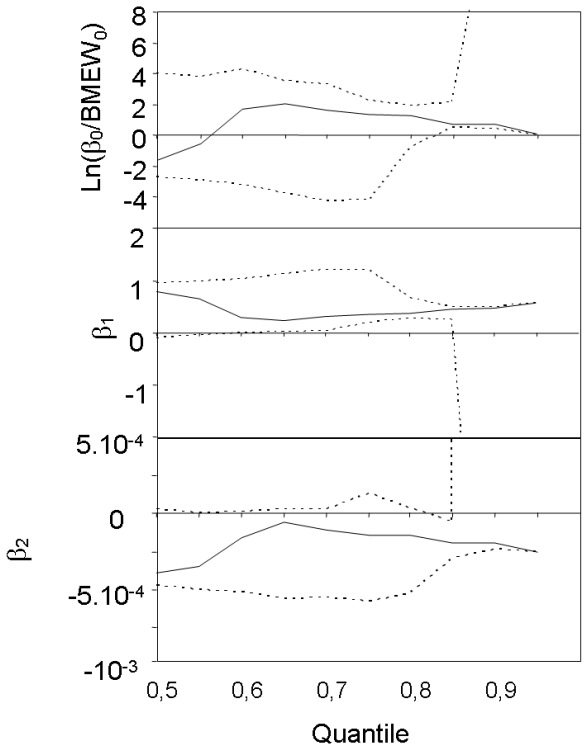
The more restrictive confidence interval correspond to the quantile τ = 0,85 (Figure 2). Corresponding values of parameters of Equation 4 are: β_0 = 2.07 $q.ha^{-1}$; β_1 = 0.467; $\beta_2 = -1.9.10^{-4}$ $kg^{-1}.ha$.

The obtained boundary line is represented in Figure 1. Relative yield loss due to crop status is therefore:

$$relativeYieldLoss_{BMEW} = b_0 (BMEW / BMEW_0)^{b_1} \exp(b_2 BMEW) \quad \text{Eq. 7}$$

With $b_0 = 3.84.10^{-2}$, b_1 = 0.467, $b_2 = -1.9.10^{-4}$ $kg^{-1}.ha$.

Figure 2. Parameters estimations (full line) and 95 % confidence intervals (dotted line) depending on the value of the quantile. [β_0] = [$BMEW_0$] = $M.L^{-2}$, [β_1] = 1, [β_2] = $M^{-1}.L^2$.



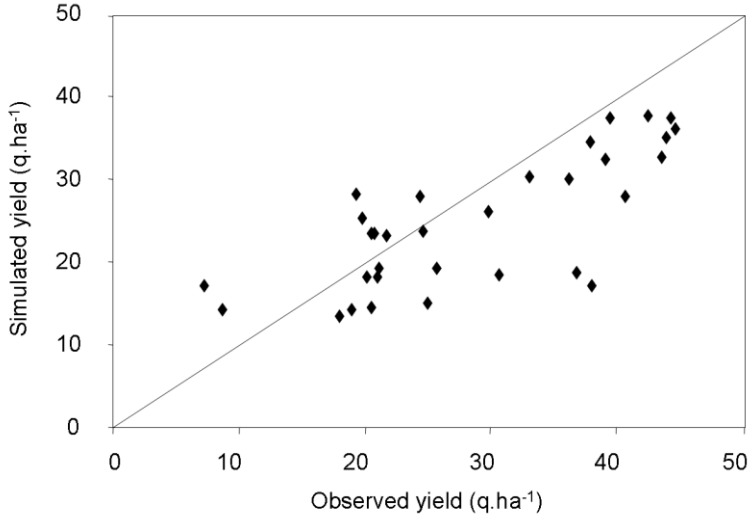
Discussion

Finally, the attainable yield is simulated in SIPPOM as follows:

$$YieldAtt = YieldPot_{cultivar} * (a_1 HD + a_2 HS + a_3 HD * HS + a_4) * b_0 (BMEW / BMEW_0)^{b_1} \exp(b_2 BMEW)$$

This relation has been evaluated, using independent data provided by M. Morison, collected in 3 French sites and during two years (2004-2005 and 2005-2006). Comparison between observed and simulated data shows that the attainable yield is under-estimated (Figure 3), with a RMSE of 8.0 $q.ha^{-1}$, and a bias of 4 $q.ha^{-1}$. The proposed relationship gives proper order of magnitude of attainable yield, but could be improved for specific use of SIPPOM, such as the ranking of strategies according to agronomical or economical output variables.

Figure 3. Comparison between observed and simulated yields for 32 plots from French trials



Appendix 2: simulation of the effect of quantitative resistance on G2 severity disease index in SIPPOM-WOSR

E. Lô-Pelzer[1*], J.N. Aubertot[2], L. Bousset[3], X. Pinochet[4], M.H. Jeuffroy[1]

[1]INRA, UMR211 Agronomie, BP01, F-78850 THIVERVAL-GRIGNON, France
[2]INRA, UMR 1248 AGIR, BP 52627 Auzeville, F-31326 CASTANET TOLOSAN, France
[3]INRA, Agrocampus Rennes, UMR1099 BiO3P (Biology of Organisms and Populations applied to Plant Protection), F-35653 LE RHEU, France
[4]CETIOM, BP04, F-78850 THIVERVAL-GRIGNON, France

Introduction

Few data are available to describe the mechanisms of action of quantitative resistances. Nevertheless, field observations show that WOSR quantitative resistant cultivars present a less severe canker, even if the number of observed leaf-spots is similar (Delourme *et al.*, 2006). These resistances are more and more used in fields, alone or in association with specific resistance, and it seemed necessary to represent their effect in SIPPOM-WOSR. Due to the lack of data, this effect was simply represented in the model: cultivars are either with a quantitative resistance, or without. Based on the calculation of the G2 severity disease index (DI) proposed by Aubertot *et al.* (2004b), the DI is decreased for cultivars with a quantitative resistance:

$$DI = \alpha_{RQ} \frac{DI_{\max} \exp\left(a_0 + a_1 N_{\max} + a_2 TT + a_3 BMBW\right)}{1 + \exp\left(a_0 + a_1 N_{\max} + a_2 TT + a_3 BBMBW\right)} \quad \text{Eq. 1}$$

With DI: G_2 disease index (Aubertot *et al.*, 2004c; [DI] = 1), α_{RQ}: decrease coefficient of DI due to quantitative resistance ($\alpha_{RQ}<1$), DI_{max}: maximum value of DI ($[DI_{max}] = 1$), N_{max}: maximum number of leaf spots per plant ($[N_{max}] = 1$) during the infection season (from emergence to December 31st), TT: thermal time for the last trimester ($[TT] = \theta.T$, with 0°C base temperature), BMBW: fresh aerial biomass per surface unit at the beginning of winter ($[BMBW] = M.L^{-2}$). $[\alpha_{RQ}] = [a_0] = [a_1] = [a] = [b] = 1$, $[a_2] = \theta^{-1}$, $[a_3] = M^{-1}.L^2$.

Material and methods

An experiment was conducted in Grignon (48.9°N, 1.9°E, 130 m elevation, Ile-de-France, 40 km west from Paris) two successive years (2004-2005 and 2005-2006), to analyse

the effect of cultivar, crop density and nitrogen rate on the yield. In this context, data were collected on 63 (2004-2005) and 71 (2005-2006) individual plants from two cultivars, Aviso (with a quantitative resistance) and Bristol (susceptible). Data were a number of leaf-spots collected at 4 dates (5/11, 2/12, 17/02 and 12/04 in 2004-2005, and 24/11, 9/02, 16/03 and 6/04 in 2005-2006), and a canker severity. An observed G2 disease index (Aubertot *et al.*, 2004c) can be calculated as follows:

$$DI_{obs} = \frac{\sum_{i=2}^{6}[2(i-2)+1]n_i}{\sum_{i=1}^{6} n_i} \qquad \text{Eq. 2}$$

Where n_i is the number of plants noted with the canker severity i.

Thermal time during the last trimester (TT) was also measured. The biomass at the beginning of winter was set at 570 g.m $^{-2}$, and a simulated G2 disease index (Aubertot *et al.*, 2004b) was calculated as follows:

$$DI_{sim} = \frac{DI_{\max} \exp(a_0 + a_1 N_{\max} + a_2 TT + a_3 BMBW)}{1 + \exp(a_0 + a_1 N_{\max} + a_2 TT + a_3 BBMBW)} \qquad \text{Eq. 3}$$

With DI_{max}: maximum value of DI ($[DI_{max}] = 1$), N_{max}: maximum number of leaf spots per plant ($[N_{max}] = 1$), TT: thermal time for the last trimester ($[TT] = \theta.T$, with 0°C base temperature), BMBW: fresh aerial biomass per surface unit at the beginning of winter ($[BMBW] = M.L^{-2}$).

The quantitative resistance is supposed to not alter the number of leaf spots (the effectiveness of infection by a spore is only due to the specific resistance and we suppose that there is no effect on aggressiveness as no data were available; Delourme *et al.*, 2006). The simulated DI (Equation 3) does not take into account the quantitative resistance, but assess the difference in DI due to differences in the number of leaf-spots for both cultivars:

$$DI_{Sim}Aviso = \alpha_{LS} * DI_{Sim}Bristol \qquad \text{Eq. 4.}$$

With α_{LS}: coefficient representing the effect of the difference of leaf-spots number on DI.

On the contrary, the quantitative resistance impact on observed DI values:

$$DI_{Obs}Aviso = \alpha_{LS} * \alpha_{RQ} * DI_{Obs}Bristol \qquad \text{Eq. 5}$$

From equations 4 and 5, it is possible to deduce the value of the parameter α_{RQ}:

$$\alpha_{RQ} = \frac{DI_{obs}Aviso}{DI_{obs}Bristol} * \frac{DI_{sim}Bristol}{DI_{sim}Aviso}$$

Results

Depending on the date of observation, α_{RQ} varies from 0.57 to 0.85 (Table 1), with an average of 0.65. In SimCanker (Aubertot *et al.*, 2004b), the considered number of leaf-spots N_{max} is a maximum number observed during the infection season (from emergence to December 31st). This correspond to $\alpha_{RQ} = 0.61$ in 2004 (dates to consider for N_{max} are 5/11 et le 2/12), and $\alpha_{RQ} = 0.66$ in 2005 (date to consider for N_{max} is 24/11). Finally, α_{RQ} was fixed at 0.65 in SIPPOM.

Table 1. Estimation of the coefficient representing the effect of the quantitative resistance in the severity disease index calculation in SIPPOM (α_{RQ}), depending on the date of observation of the number of leaf-spot. N_{LS} represents the maximum number of leaf-spots observed among the 63 (2004-2005) and 71 (2005-2006) plants, at the different dates (with the corresponding DI_{sim} calculated at each date), whereas N_{max} represents the maximum number of leaf spots observed during the infection season (from emergence to December 31st, maximum N_{LS} for concerned dates: 5/11 and 2/12 in 2004, 24/11 in 2005), used in the expression of the DI in SIPPOM (Aubertot *et al.*, 2004b), DI_{sim} being the associated value of DI.

2004-2005	Aviso	Bristol	α_{RQ}	2005-2006	Aviso	Bristol	α_{RQ}
TT (°C.d)	705	705		TT (°C.d)	755.5	755.5	
BMBW ($g.m^{-2}$)	570	570		BMBW ($g.m^{-2}$)	570	570	
N_{LS} 5/11	17	44		N_{LS} 24/11	3	6	
N_{LS} 2/12	26	29		N_{LS} 9/02	6	17	
N_{LS} 17/02	3	5		N_{LS} 16/03	15	19	
N_{LS} 12/04	19	20		N_{LS} 6/04	34	108	
N_{max}	26	44		N_{max}	3	6	
DI_{sim} 5/11	7.44	8.86	**0.68**	DI_{sim} 24/11	3.63	4.26	**0.66**
DI_{sim} 2/12	8.26	8.43	**0.58**	DI_{sim} 9/02	4.26	6.46	**0.85**
DI_{sim} 17/02	5.02	5.44	**0.61**	DI_{sim} 16/03	6.10	6.79	**0.63**
DI_{sim} 12/04	7.67	7.77	**0.57**	DI_{sim} 6/04	8.34	9.00	**0.61**
DI_{sim}	8.26	8.86	**0.61**	DI_{sim}	3.63	4.26	**0.61**
DI_{obs}	2.71	4.78		DI_{obs}	3.09	5.50	

Discussion

Simulated DI_{sim} are always above observed DI_{obs}, even for the susceptible cultivar. It can be due to the fact that thermal time values in the experiment are at the boundary of the validity domain of SimCanker (between 742 and 836 °C.d).

Despite the fact that experiment was not set to estimate the parameter α_{RQ}, estimated values are quite stable when dates of observation of leaf-spots vary. According to expert opinion (Pinochet, Pers Com..), cultivars cumulating a specific and a quantitative resistance present in average a DI value of 2.5, cultivars with a quantitative resistance alone an average DI value of 3-4, whereas susceptible cultivars present an average DI value of 6. In these conditions, α_{RQ} would vary from 0.42 (= 2.5/6, value that include the effect of the specific resistance) to 0.67 (= 4/6). The chosen value seems therefore reasonable.

Appendix 3: simulation of the number of leaf-spots in SIPPOM-WOSR

E. Lô-Pelzer[1*], J.N. Aubertot[2], L. Bousset[3], M.H. Jeuffroy[1]

[1]INRA, UMR211 Agronomie, BP01, F-78850 THIVERVAL-GRIGNON, France
[2]INRA, UMR 1248 AGIR, BP 52627 Auzeville, F-31326 CASTANET TOLOSAN, France
[3]INRA, Agrocampus Rennes, UMR1099 BiO3P (Biology of Organisms and Populations applied to Plant Protection), F-35653 LE RHEU, France

In analogy with Monteith's equation (Monteith, 1977), three efficiencies were defined to express the increase of the mean number of phoma leaf spots per plant (ΔN, [N] = 1) during Δt (thermal time, [t] = θ.T), taking into account the latent period L (derived from Aubertot *et al.*, 2004b):

$$\frac{\Delta N(t+L)}{\Delta t} = \varepsilon_{\text{int}} \varepsilon_{gen} \varepsilon_{\text{inf}} \frac{NbSpores}{Density} \qquad \text{Eq. 1}$$

The daily increase of leaf spots per plant depends on the latency of apparition of a leaf spot ([L] = θ.T), the genetic efficiency ([ε_{gen}] = 1), the interception efficiency of spores by plant in a pixel ([ε_{int}] = 1), on the infection efficiency ([ε_{inf}] = 1), the number of ascospores landing per thermal time unit and per surface unit ([NbSpores] = $L^{-2}.\theta^{-1}.T^{-1}$) as well as on crop density ([Density] = L^{-2}). The latency of apparition of a leaf spot was taken as L = 250°C.day (0°C basis; Brunin and Lacoste, 1970). The secondary infections by conidia are not represented, as their effect on high canker severity leading to yield loss is supposed negligible (Hall, 1992). The daily number of leaf spots is the difference between the number of appearing leaf spots (Equation 1) and the number of dying leaf spots: leaf spot life duration has been set at the half of the life duration of a leaf (fixed at 550°C.d, 0°C basis, Dejoux, 1999). The interception efficiency of ascospores by plants determines the quantity of ascospores deposited on leaves. It depends on the leaf area index ([LAI] = 1) of the crop intercepting spores, calculated in the crop-growth sub-model:

$$\varepsilon_{\text{int}} = 1 - \exp^{[-kLAI]} \qquad \text{Eq. 2}$$

with k: extinction coefficient ([k] = 1). A value of 0.73 was attributed to the parameter k, according to Gabrielle *et al.* (1998).

In the genetic sub-model, the genetic efficiency, representing the frequency of virulent pathotypes, is calculated as:

$$\varepsilon_{gen} = 1 - \sum_{i=1}^{i=n_p} f_i I_i \qquad \text{Eq. 3}$$

where n_p is the number of pathotypes ($n_p = 2^{nvir}$), f_i is the frequency of pathotype i within the incoming ascospores, and I_i is the incompatibility for pathotype i (I_i = 1 if pathotype i has an avirulence gene corresponding to a specific resistance present in the considered cultivar, else I_i = 0).

Finally, the infection efficiency takes into account the phenology of the crop and fungicide applications. It is calculated as follows:

$$\varepsilon_{\text{inf}} = \varepsilon_j \left(1 - \varepsilon_{fung}\right) \qquad \text{Eq. 4}$$

where ε_j is the probability that a spore creates a leaf spot at the j-leaf stage ([ε_j] = 1), and ε_{fung} is the efficiency of the fungicide ([ε_{fung}] = 1). Brunin and Lacoste (1970) performed an experiment during which the infection efficiency was measured at different phenological stages. These results were used to develop a relationship between infection efficiency and the phenological stage at inoculation. Three sets of observations allow hypothesising a relationship between the observed disease incidence I_j and the phenological stage (inoculation at the j-leaf stage ([I_j] = 1):

$$I_j = I_{\min} + \left(I_{\max} - I_{\min}\right) e^{-\alpha_1 j^{\alpha_2}} \qquad \text{Eq. 5}$$

with I_{max} and I_{min}: maximum and minimum incidence of the disease ([I_{min}] = [I_{max}] = 1), j: number of leaves ([j] = 1) and α_1 and α_2: phenological parameters ([α_1] = [α_2] = 1). In order to develop a relationship between the infection efficiency and the phenological stage during inoculation, the number of phoma leaf spots observed in Brunin and Lacoste's experiment was supposed to follow a Poisson distribution. Under these assumptions, it can be shown that the phenological infection efficiency can be written as:

$$\varepsilon_j(t) = -\alpha_3 Ln\left[1 - \left(I_{\min} - (I_{\max} - I_{\min}) \exp(-\alpha_1 j(t)^{\alpha_2})\right)\right] \qquad \text{Eq. 6}$$

where α_3 is a dimensionless coefficient.

Parameters of equation 5 were estimated based on Brunin and Lacoste (1970): I_{max} = 0.9996, I_{min} = 0.1000, α_1 = 5.773.10^{-2}, α_2 = 3.220. Using equation 6 with these parameters, data from Biddulph *et al.* (1999) were used to estimate α_3 = 0.13. The equation representing the fungicide efficiency is based on Wermelinger *et al.* (1992): if the fungicide is applied at t_{fung} ([t_{fung}] = T), ε_{fung} = 0 for t < t_{fung} and t > t_{fung}+r_{fung}, r_{fung} being the fungicide remanence ([r_{fung}] = T). Otherwise, $\varepsilon_{fung}(t) = 1 - \left(\frac{t}{r_{fung}} \right)^2$. The remanence of the fungicide was set to 2 weeks (Penaud, Pers. Com.).

References

Aubertot, J.N., Pinochet, X., Reau, R., Doré, T., 2004b. SimCanker: a simulation model for containing phoma stem canker of oilseed rape through cultural practices. Proceedings of the 4th international crop science congress. Brisbane, Australia.

Aubertot, J.N., Schott, J.J., Penaud, A., Brun, H., Doré, T., 2004c. Methods for sampling and assessment in relation to the spatial pattern of phoma stem canker (*Leptosphaeria maculans*) in oilseed rape. European Journal of Plant Pathology 110, 183-192.

Biddulph, J.E., Fitt, B.D.L., Leech, P.K., Welham, S.J., Gladders, P., 1999. Effects of temperature and wetness duration on infection of oilseed rape leaves by ascospores of *Leptosphaeria maculans* (stem canker). European Journal of Plant Pathology 105, 769-781.

Brunin, B., Lacoste, L., 1970. Recherches sur la maladie du colza due à *Leptosphaeria maculans* (Desm.) Ces. et de Not., II: pouvoir pathogène des ascospores. Annals of Phytopathology 2, 477-488.

Cade, B.S., Guo, Q., 2000. Estimating effects of constraints on plant performance with regression quantiles. OIKOS 91, 245-254.

Dejoux, J.F., 1999. Evaluation d'itinéraires techniques du colza d'hiver en semis très précoces. Analyse agronomique, conséquences environnementales et économiques. Ph.D. INA P-G, Paris, France.

Delourme, R., Chèvre, A.M., Brun, H., Rouxel, T., Balesdent, M.H., Dias, J.S., Salisbury, P.A., Renard, M., Rimmer, S.R., 2006. Major gene and polygenic resistance to *Leptosphaeria maculans* in oilseed rape (*Brassica napus*). European Journal of Plant Pathology 114, 41-52.

Gabrielle, B., Denoroy, P., Gosse, G., Justes, E., Andersen, M.N., 1998. Development and evaluation of a CERES-type model for winter oilseed rape. Field Crops Research 57, 95-111.

Hall, R., 1992. Epidemiology of blackleg of oilseed rape. Canadian Journal of Plant Pathology 14, 46-55.

Jeuffroy, M.H., Valantin-Morison, M., Saulas, L., Champolivier, L., 2003. Azodyn-Rape: a simple model for decision support in rapeseed nitrogen fertilisation. Proceeding of the 11th international rapeseed congress, Copenhagen, Denmark.

Limaux, F., 1999. Modélisation des besoins du blé en azote, de la fourniture du sol et de l'utilisation de l'engrais. Application au raisonnement de la fertilisation en Lorraine. Ph.D. Institut National Polytechnique de Lorraine, France.

Makowski, D., Maltas, A., Morison, M., Reau, R., 2005. Calculating N fertilizer doses for oil-seed rape using plant and soil data. Agronomy for Sustainable Development 25, 159-161.

Makowski, D., Doré, T., Monod, H., 2007. A new method to analyse relationships between yield components with boundary lines. Agronomy for Sustainable Development 27, 119-128.

Monteith J. 1977. Climate and the efficiency of crop production in Britain. Philisophical Transactions of the Royal Society of London, Series B, (281). pp: 277-294.

Reau, R., Wagner, D., 1998. Les préconisations du CETIOM. Oléoscope 48, 10-13.

Wermelinger, B., Candolfi, M. P., Baumgartner, J., 1992. A model of the European red mite (*Acari, Tetranychidae*) population dynamics and its linkage to grapevine growth and development. Journal of Applied Entomology 114, 155-166.