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SCAN BEAN: *SCLEROTINIA SCLEROTIORUM* FLOWER CONTAMINATION FORECAST MODEL ON BEANS

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ABSTRACT
Sclerotinia (*Sclerotinia sclerotiorum*) has been on the rise in recent years, especially on growing beans. This disease infects the crop at the flowering stage and causes rot to appear on bean pods. The result is lost yield for the producer.
In this context, Syngenta in collaboration with professionals (UNILET and the vegetable industry sector), measured the contamination of the petals over three years using a biological test (petal kit, developed by CETIOM). A unique knowledge base was built, compiling 770 analyses from 443 fields collecting historical agronomic practices and meteorological events for over ten years.
Multivariate analysis of this information can be used to offer the first decision support system (DSS) to help growers in spraying fungicide applications (Scan Bean). This means managing the damage to the bean harvest.

Keywords: Decision Support System (DSS), sclerotinia, beans, flowering, petal kit.

RÉSUMÉ
SCAN BEAN : MODELE DE PREVISION DE LA CONTAMINATION DES FLEURS DE HARICOTS PAR *SCLEROTINIA SCLEROTIORUM*
Depuis quelques années, le sclérotinia (*Sclerotinia sclerotiorum*) est en recrudescence notamment sur les légumes d'industrie comme les haricots et pois de conserve. Cette maladie contamine la culture au moment de la floraison et provoque l'apparition de pourritures sur les gousses de haricot et les tiges. Ces dégâts peuvent conduire jusqu'au refus de la récolte du producteur par le transformateur.
Dans ce cadre, Syngenta, en collaboration avec l'UNILET et la filière des légumes destinés à l'industrie proposent le premier modèle agro-climatique d'aide au positionnement des applications anti-sclérotinia sur haricot (Scan Bean).
Ce nouvel outil repose solidement sur une base inédite de connaissances, rassemblant 443 parcelles pour lesquelles l'historique agronomique et météorologique sur 10 ans a été collecté. Afin de mesurer la contamination des fleurs durant 3 années, les partenaires ont réalisé 770 kits pétales sur ces parcelles (kit pétale, mis au point par le CETIOM).
L'analyse multi-variée de ces informations nous permet aujourd'hui de proposer le premier modèle agro-climatique d'aide au positionnement raisonné des applications fongicides pour gérer le risque et éviter les dégâts à la récolte.

Mots-clés : Outil d'Aide à la Décision (OAD), sclérotinia, haricots, floraison, kit pétale.

INTRODUCTION

Sclerotinia sclerotiorum is a pathogenic fungus causing Sclerotinia Stem Rot (SSR) which remains in the soil for eight to ten years and attacks numerous crops (Saharan *et al.*, 2008). Rotations involving frequent susceptible crops help to add sclerotia to the soil and thus increase the pressure from the disease (Twengstrom *et al.*, 1998). Climatic conditions in France result in major infestations on common beans (*Phaseolus vulgaris)*. A French survey by UNILET of producer organizations established yield losses due to the disease at €4.8 million on beans in 2009 when the pathogen pressure was high (Le Delliou, oral communication, 2015).

The bean crop is sensitive during the flowering period. The petals play an essential role in the onset of the disease. When the apothecia reach maturity and the ascospores are released into the atmosphere, any bean flowers present are infected. The risk of infected petals sticking to the pods and of the disease advancing towards the stems is therefore an important factor in the decision to spray with a fungicide. It is especially important to assess the state of petal infection as speciality plant protection products currently on the market only have a preventive activity (fludioxonil, boscalid and iprodione) against this disease. CETIOM has developed a diagnostic test to assess this risk - the "Kit pétale" (KP) – or Petal Kit - on oilseed rape. This method involves plating the flowers in Petri dishes containing a medium that turns yellow and indicates the presence of the fungus on the flowers. This kit represents a method for product application timing (Penaud *et al.*, 2009).
However, this test is limited as it only gives a snapshot of the situation when the flower samples are taken to detect their infection. Nor does it incorporate forthcoming climatic conditions. In addition, the four days required for the test to reveal itself means a delay in rationalizing the timing of chemical applications.
With this in mind, Syngenta and UNILET have together developed the Scan Bean DSS. It improves monitoring of the infection state of the petal population by giving an indication on a daily basis with three days of weather forecasts.

MATERIALS AND METHODS:

SCAN BEAN DSS DESCRIPTION:

Scan Bean is an Internet application (http://www.sclero-haricot.syngenta.fr) running on web browsers that can accessed with a login and password. Its development with responsive design technologies can be adapted for different computer screen sizes and all hand-held devices (touch pad, smartphones, etc.). This DSS is connected to the Syngenta weather network, allowing farmers and advisors to anticipate spikes in bean contamination within five days of the forecast.

A simulation consists of locating a field on a map, entering the bean variety, sowing date, soil type (12 USDA triangle soil texture) and the ten previous crops. All user fields are symbolized with an icon on a map. Fields can be filtered by the number of the sowing or flowering weeks. The field symbol changes color according to the daily sclerotinia risk status (grey: out of flowering period, green: no treatment required, orange: warning and red: treatment recommended) (Fig. 1a).

Users are advised by e-mail or text message seven days before the estimated flowering date. Farmers must then confirm the flowering date, give the bean height and the percentage of leaf coverage between two rows. Until this information is completed, meteorological data are collected and calculations are computed immediately. The result is a daily graph (Fig. 1b), plotting estimations: flowering intensity (FAI: purple line), percentage of contaminated flowers (PFIest: orange lines) and the treatment threshold (PFITT: red line).

Users can also add irrigation and treatment dates (past or planned) to help manage their spray plan decision.

Figure 1: Scan Bean web contamination management interface

Figure 1: Interface web de pilotage de la contamination de Scan Bean

Treatment simulation:

The treatment profile proposed as standard is a simple decreasing efficacy function that considers twelve days of persistence. This protection is proportional to the treatment efficacy profile. A preventive mode of action is simulated, preventing ascospore germination after the spray date. In this study, the profile close to SWITCH® treatment to 1 kg/ha (300 g/ha cyprodinil + 200 g/ha fludioxonil) was simulated.

Flower contamination (PFIest):

The Scan Bean flower contamination routine is an improvement on the Raiso-Sclero® model developed on oilseed rape by Syngenta in collaboration with CETIOM (Varraillon *et al.*, 2011). It estimates quantitatively the likely Sclerotinia spore release by accounting for a variety of important contributory factors. Firstly, soil microclimate is modelled based on its microstructure and meteorological data and with soil temperatures estimated by the STICS method (Brisson, 1998) and soil water potential by the Green–Ampt infiltration and redistribution method (Gowdish, 2009). Secondly, a model of the sclerotia germination based on the Clarkson (2004) criteria for soil temperature and water potential is applied. This assumes that apothecia ripen at a depth of 5 centimeters and live for 8 to 20 days depending on the exact climatic conditions. Spores are released when the local humidity drops suddenly (Clarkson, 2003). Once released, the spores will migrate to crop flowers where they can attack the body of the crop if the environmental conditions are right. The Scan Bean model is also capable of estimating what proportion of released spores will migrate to flowers.

Treatment threshold (PFITT):

The PFITT is calculated by Scan Bean. Set at 30% of flower contaminated as default, Scan Bean take into account significant agronomical practices to adapt the threshold according to IP in an untreated situation.

A high disease intensity estimation reduces the PFITT to 10% and a low disease intensity increases the decision threshold to 40%.

FLOWERING INTENSITY (FAI) TRIALS:

Flowering define the sensitive contamination period for beans. The model starts by calculating the beginning of flowering using a variety knowledge database of flowering earliness indices (UNILET team sources). Scan Bean then simulates the FAI.

UNILET and Syngenta conducted seven trials on two types of bean in 2009 to establish the curve. These trials involved counting the number of flowers on twenty plants every five days from the appearance of the first white buds (beginning of flowering) to the end of flowering. The counts were standardized in each trial by adjusting the maximum flowers to 100%. Each counting date was rescaled in thermal time (Growing Degree Day base 0°C, GDD) from the beginning of flowering. The trials were superposed and a shoulder regression function was applied (Fig. 2). No distinction could be made between beans and French beans.

Figure 2: Bean flowering intensity model
Figure 2: Modélisation de la floraison

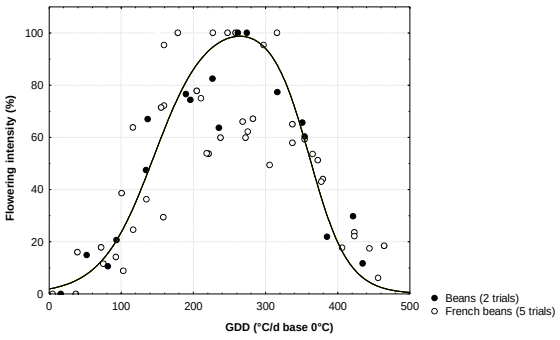
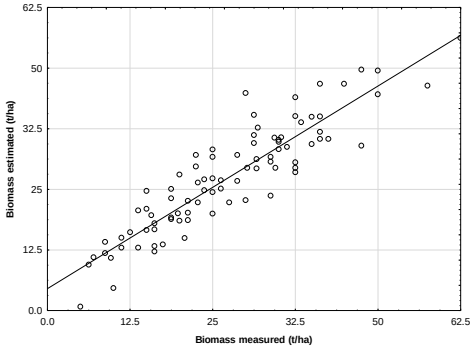


Figure 3: Bean biomass model
Figure 3 : Modélisation de la biomasse



"PETAL KIT" TRIALS:

Between 2012 and 2014, 443 trials (195 in 2012, 189 in 2013 and 59 in 2014) were conducted in two of France's main bean production areas: Brittany and the Loire Valley (BZH) and Picardy and North Calais (NPC). Trials consisted of field beans (beans or French beans) conducted by farmers. During these three years of experiments, the flowering beans were sprayed between mid-June to mid-September for the last sowing dates.
An untreated fungicide plot (control) was delineated inside the field (half boom width to 10-12 meters length ≈ 100 m²). Flowering contamination was measured in all situations using KP in the control and disease severity were measured in both areas. Treatment schedule information was also collected (number of treatments, type of product, dose rates, etc.).

Agronomic and weather history:

Ten years of agronomic practices and daily weather data (temperature, precipitation and humidity) were collected in each trial. For more than forty agronomic parameters (bean type, previous crops, soil and treatment maintenance, etc.), best variables were selected in the model using Statistica® datamining procedures. Several combinations of score based on the ability of the ten previous crops to multiply the SSR (Tab. 1) were investigated.

Table I : Crop potential SSR multiplication (Nivet, unpublished data)
Tableau I: Potentiel multiplicateur des cultures.

High	Low	*None*
oilseed rape, beans, peas, celery, celeriac, carrot, cabbage, courgette, chicory, lettuce, melon, sunflower, tobacco, soybean	Onion, potato, salsify, broccoli, field bean, lupine, lucerne, clover, vetch, phacelia, radishes, mustard, turnip, cauliflower	*Other crops*

Flowering infection (PFIobs) assessments:

KP detection was used to estimate the proportion of flowers infected with *Sclerotinia* ascospores. To use the kit, forty flowers are removed from the field and deposited directly in Petri dishes on a semi-selective growing medium (Taverne *et al.*, 2003). After four days of incubation in the dark at 20-23°C, the presence of *S. Sclerotiorum* is revealed by the presence of a pH indicator in the medium that turns from blue to yellow, as the fungus produces sufficient oxalic acid to acidify the medium (Steadman *et al.,* 1994). The percentage of infected flowers (PFIobs) is then determined.

Previous work on beans (Olivier *et al.*, 2008) showed that petal age and flower colour did not have a substantial effect on the germination and development of *S. Sclerotiorum.* However, because time exposure varies according to flower age, we standardized samples by collecting twenty young flowers (white) and twenty old flowers (yellow) to estimate the percentage of infected flowers.

In each of the 443 controls, we performed a KP at both the beginning of flowering (first white bud, BBCH 59) and seven days later (at the maximum of flowering intensity) (giving PFIobs1 and PFIobs2). The mean value of two KP was used to compare flowering infection (PFIobs = [PFIobs1 + PFIobs2] /2) as an estimation of contamination intensity history during the flowering period.

Biomass estimations:

At the beginning of flowering in the control, row cover (%) and bean height (cm) were measured. Biomass (t/ha) was weighed in 89 plots in 2012 (UNILET data, 2012) to establish a biomass model using bean cover and height (r^2 =0.83). This model (Fig. 3) was used as a routine estimation function in 2013 and 2014.

Disease severity (IP) measurements:

Sclerotinia attacks were recorded in each trial field. At harvesting, 200 plants were assessed in the control and 200 in farmer-treated fields and scored in four damage severity classes (A: healthy plants, B: 1 to 2 spots, C: more than two spots and D: more than 40% total plants destroyed).

IP ("Indice Pathologique"), the disease severity index used by UNILET, was calculated balancing the severity level of attacked classes as seen below :

$$Disease\ severity\ index\ (IP) = \frac{[\%B]}{4} + \frac{[\%C]}{2} + [\%D] \qquad \text{Equ. 1}$$

UNILET (Le Delliou, oral communication, 2015) therefore considers an IP of less than 40% associated with low impact on bean pod quality yields. On the other hand, an IP higher than 60% reflects a major impact on bean pod production for industrial processing. Between 40-60, it is essential to consider the yield date in order to harvest before the onset of disease symptoms on pods.

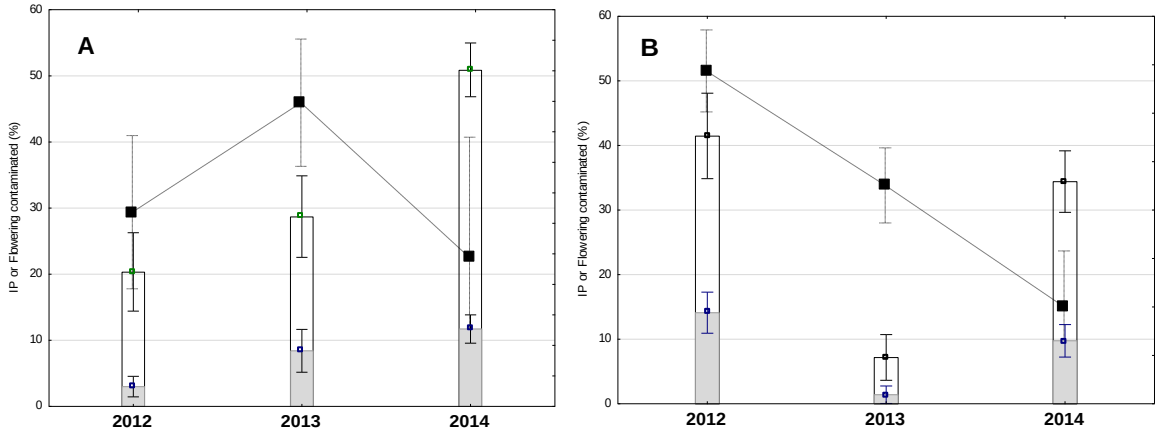
RESULTS & DISCUSSION

THREE YEARS OF FLOWERING CONTAMINATION AND DISEASE SEVERITY MONITORING:

The pressures of disease noted from our data set show the differences following the three years and the two production regions that we have studied (Fig. 4). In the most northern region of France (NPC), the IP in the fields protected with fungicide applications by the farmer have increased on average from 2.9 to 11.7% from 2012 to 2014. In the Brittany region (BZH), the most damage was noted in 2012 with an IP of 14.1%. The least damage of the study was noted in 2013 with an IP of 1.4%.

Looking at the difference in infestation level between the untreated sample plot and the farmer's field, it can be noted that the fungicides have reduced the disease pressure ca. twenty IP points (IP control plot - IP in treated field), all treatments and soil and climatic conditions taken together. The higher the pressure level the greater the benefit noted for the treatments (examples: NPC in 2014 IP gain: 53.8 - 15.3 = 38.5%; BZH in 2013: IP gain: 7.2 - 1.4 = 5.8%).

Figure 4: Disease severity and flower contamination measured from 2012 to 2014 in two French areas.
Figure 4: Intensité de la maladie et contamination des fleurs de 2012 à 2014 dans 2 régions Françaises.



A: In the North of France (NPC). B: in Brittany (BZH). Grey box : disease severity (IP) in the treated field, White box : IP in the untreated plot, Dash line : petal kit (KP) in the untreated plot.

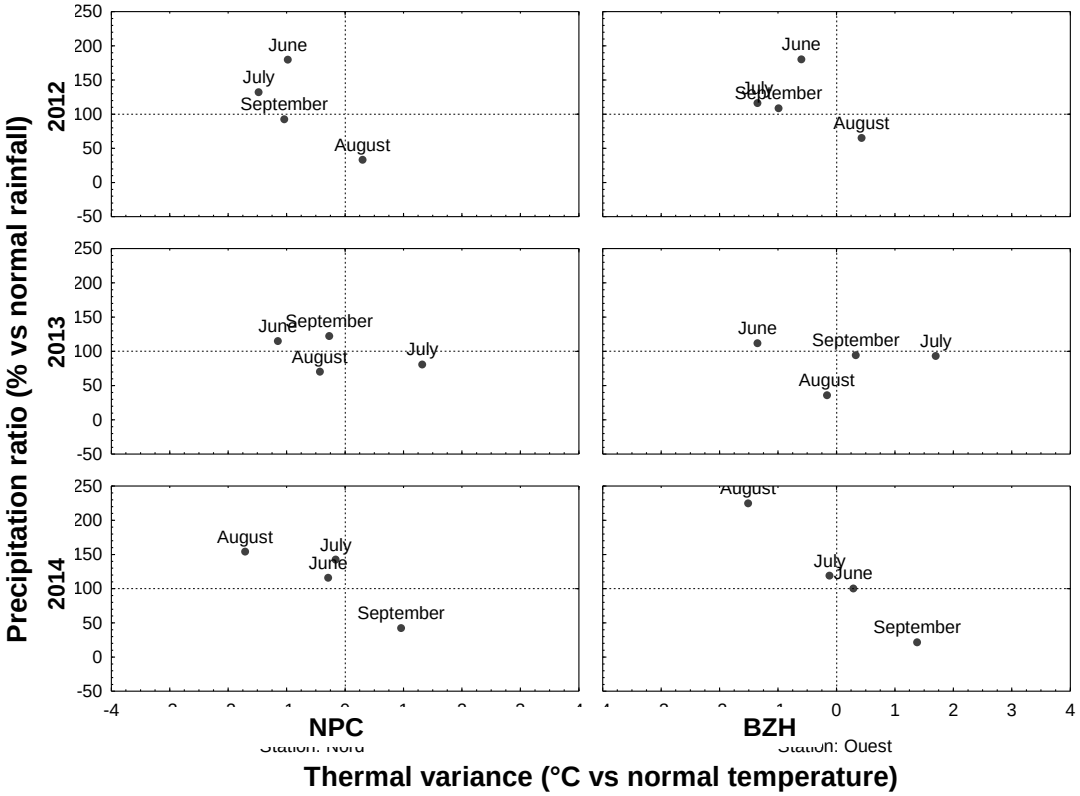
Looking at the correlation between percentage of infected flowers, PFIobs1 at the beginning and PFIobs2 in the middle of flowering, it can be seen that they are not correlated with the IP (r^2=0.03, r^2=0.01). The average percentage of two KP (PFIobs) is better correlated but still very insufficient (r^2=0.30). These annual estimations of PFIobs and IP for each region in the control and farmer plot are summarized in figures 4A and 4B. It is clear that the annual PFIobs follows the same trend as the IP in 2012 and 2013 in the two regions studied. However, in 2014 the PFIobs no longer follows the level of damage noted, as the PFIobs should be greater than the values noted in 2012 and 2013 in NPC and between 2012 and 2013 in BHZ.

WEATHER CONDITIONS:

The weather conditions used by the model during the bean flowering period (mid-June to mid-September) are summarized below (Fig. 5) as monthly temperature and rainfall charts.
The difference in monthly temperatures is expressed as the difference between the average temperature of any month of the year and the normal (temperature noted over the last ten years). The positive anomalies are therefore interpreted as hot climates compared with normal and the negative differences as cold trends.
The rainfall anomalies are expressed as the ratio between the monthly accumulated rainfall in the year and the normal accumulation for the month. A rainfall ratio greater than 100% indicates a humid context and a value lower than 100% a dry anomaly.

In 2012, the climate conditions were marked by a fairly cool climate (differences < 1°C) with a rainy June (75% of excess precipitation). August showed a water shortage of some 50% compared with a normal year. The excessive rain and cool temperatures do not favor plant growth. The cycles are extended in both regions. Sclerotinia appeared early in the season and remained, especially on the common beans. The yield was often impacted by loss of pods and harvest expectations.
The weather context at the start of the 2013 season featured a rather cool June (-1°C) followed by a hot July. August was particularly dry, especially in Brittany. Thanks to the dry summer conditions, the disease only became established in September. Overall, 2013 has been the most healthy of the last ten years with a slight flat, nevertheless, in NPC.
The 2014 climate was noticeable for huge thermal and hydric ranges at season end. This turnaround was very marked in BZH by rain (125%) and cold (-1.5°C) anomalies in August and very dry (20%) and hot (+1.5°C) in September. The September climate in both regions allowed a (slight) alleviation in emergency measures: bringing harvests forward and intensifying the sorting and cleaning in the processing plant.

Figure 5: Monthly weather conditions during bean flowering in three years of testing
Figure 5: Conditions climatiques mensuelles durant la floraison des haricots entre 2012 et 2014.



VALIDATION OF DAILY FLOWER CONTAMINATION PERCENTAGE IN SCAN BEAN:

We have compared the results of 770 KP (PFIobs1 and PFIobs2) with the estimated PFIest to validate the model. Table II summarizes the means observed per region and per year.
The PFIest trends for the NPC region between 2012 and 2014 increased from 23.1 to 55.1%, thus following the annual IP trend (20.3 to 53.8%). Remember that this was not the case with the PFIobs obtained with the KP as the lowest annual value of 27.7% was noted in 2014 in this region.

Table II: Flowering infection and disease severity in untreated plot in two French regions.
Tableau II: Infection à floraison et intensité de la maladie dans les témoins dans 2 régions Françaises.

Year	Area	# samples	IP	PFI			
				mean ± std		Prediction Est. vs Obs. with 30% threshold	
				Obs. (KP)	Est.	% True	% False -
2012	NPC	188	20.3 ± 28.3	30.7 ± 28.3	23.1 ± 21.9	64.6	18.8
	BZH	197	41.7 ± 31.6	44.1 ± 24.8	51.6 ± 24.2	62.9	10.7
2013	NPC	194	28.7 ± 29.7	37.8 ± 25.2	44.6 ± 31.0	65.3	15.3
	BZH	182	7.2 ± 16.9	32.4 ± 21.2	33.0 ± 27.2	57.1	18.1
2014	NPC	64	53.8 ± 36.5	27.7 ± 29.4	55.1 ± 20.8	30.3	15.2
	BZH	50	32.4 ± 25.9	24.2 ± 23.2	60.3 ± 22.7	34.0	2.0

The simulated means for the BZH region varied by 51, 33 and 60% from 2012 to 2014. Here again the PFIest followed the annual IP variations whilst the average PFIobs in 2013 widened. Note the very

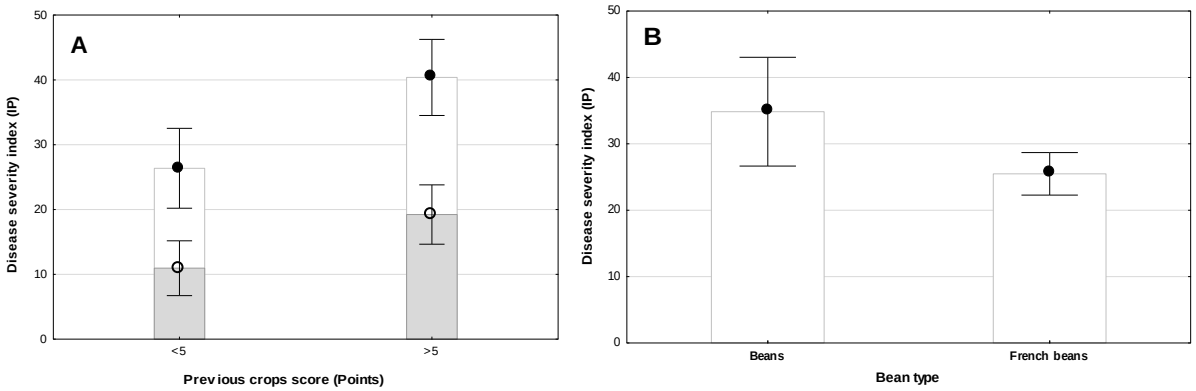
high PFIest value in 2014 (60.3%) for the BZH region, which is explained by the abnormally high rainfall noted in August of that year (Fig. 5F).

Previous studies (Hascoët, 2012) carried out on the BZH 2012 data set have shown that by using the ROC method, the treatment threshold (PFITT) is 30% of infected flowers (AUC=0.83). Note that this result is the same as the one obtained by CETIOM (Penaud *et al.*, 2009), with a KP at F1 (early flowering, 50 plants with at least one flower).
To compare the Scan Bean PFIest and the KP PFIobs forecasts, we have expressed the percentage of "true forecasts" in Table II (True: PFIest and PFIobs higher or lower than 30%) and "false negative forecasts" (False: PFIest lower than 30% and PFIobs higher than 30%). The False - should be avoided as they represent for a farmer a risk of not treating despite the disease being detected and risk of dispute in advising him.
Thus, it can be noted that the model would have produced between 57.1 and 64.6% of "good forecasts" in 2012 and 2013. On the other hand, in 2014 the True rate is far less good (30 to 34%). Scan Bean overestimated the risk as the rate of false negatives does not exceed 15%. The reason, as previously : the very humid conditions in August. These conditions are shown by the model as an unfavorable period for the maturing of sclerotia and the forming of apothecia. In 2014, we noted a disproportion of kits with no infected flowers (10% in BZH to 28% in NPC of kits carried out whereas this proportion had never exceeded 2% the previous years, regardless of the region). Two possible KP anomalies can be mentioned: many nil kits could have been affected by extremely hot storage conditions (high temperatures inside cars > 23°C) which rendered the kits inactive and changes of the manufacturing recipe was the reason for variations in sensitivity.

VALIDATION OF DISEASE SEVERITY IN SCAN BEAN AND TREATMENT THRESHOLD VARIATION:

To take the history of the plot into account in the Scan Bean advice, we have extracted from our surveys the main questionable variables in the losses of quality (IP) noted at harvesting in our 443 reference trials.
Using the multivariate linear analysis (GLM) of different parameters, we were able to isolate three main criteria in our dataset, including some already quoted in the UNILET studies and the decision plot grid of our colleagues (Hasclérix®, BASF, 2014). These criteria were also used on oilseed rape (Twengstrom et al., 1998) to build a forecast model of the sclerotinia risk.

Figure 6: Influence of biomass, crop rotation and bean type on IP
Figure 6: Influence de la biomasse, des cultures dans la rotation et du type de haricot sur l'IP.



A: IP vs highly significant effects: biomass (< 20 t/ha in grey boxes, > 20 t/ha in white boxes) and crop score of multiplicative SSR previous crops; both have a p value threshold < 1% B: IP vs Significant effect: bean types, p value threshold between [1-5]%.

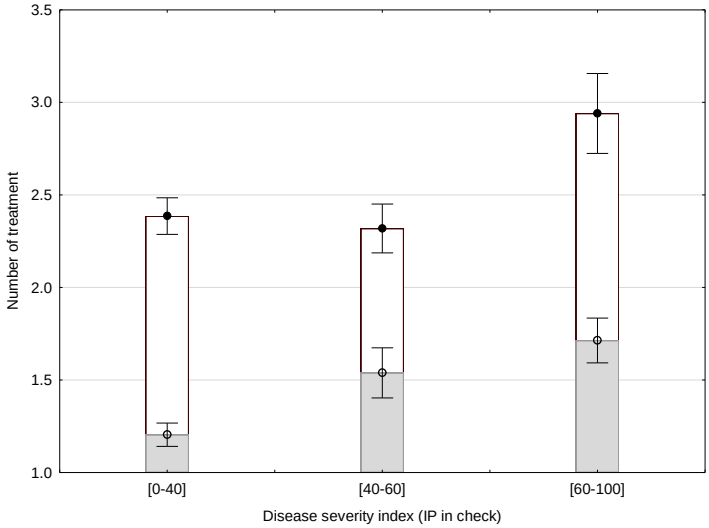
The main highly significant criterion (p<0.01, Hs) impacting the IP is the biomass measured at the start of flowering. This plant volume has a very positive influence on the onset of the disease,

probably by maintaining climate conditions in the soil that are very favorable to the development of apothecia. The crop cover between rows influences the maintaining of the humidity under the cover and protection from the sun's rays could play a part (Sun et al., 2000).
The second Hs criterion is the number of susceptible crops in the rotation. To assess this criterion, we have accumulated a number of points based on the propagation potential of the crop SSR (Tab. 1); the more propagating crops in the rotation the higher the IP (0-100%).
If these two Hs criteria are crossed (Fig. 6A), an IP in the order of 10% can be expected for plots with a biomass lower than 20 t/ha and few propagating crops in the rotation (score < 5). Conversely, an IP of 40% can be expected for plots greater than 20 t/ha and with a score >5.
The third significant parameter emerging from the GLM analysis (0.05>p>0.01, S) is the type of bean (common or French bean). A common bean brings up higher IP values than the French beans (Fig. 6B). This last factor is correlated with the biomass as common beans normally have a more extensive plant volume that the other types of bean. Secondly, the exposure time of common beans is longer: an additional two to three weeks is needed to harvest a common bean. This difference is mainly due to the longer time between start of flowering and end of pod maturation (48 days for a common bean against 28 days for a French bean) (Kouassi, unpublished data, 2011). Also, the germination of spores into mycelium has more time and is more likely to encounter favorable climatic conditions for developing symptoms.
It has been possible to define a linear combination from these three variables to estimate the IP in the controls of different plots (IPest). This information has been incorporated into the model so that the trigger threshold (PFITT) can be modulated based on the IP estimation. Thus, if the IPest level is nil, the PFITT will be fixed at 40% and when the IP is 100%, the PFITT is lowered to 10% of the PFIest.

NUMBER OF RECOMMENDED FUNGICIDE APPLICATIONS AND DISEASE SEVERITY:

In the final results section, we have compared the number of applications by the farmer with the number of treatments potentially triggered by Scan Bean in the 443 plots. When the PFITT is exceeded, we simulate the same day a fungicide protection of twelve days of decreasing persistence over time set on a mode of action closed to a SWITCH at full dose rate.

Figure 7: Number of fungicides treatments recommended by Scan Bean and realized by farmers against disease severity (IP)
Figure 7: Nombre d'applications fongicides préconisé avec Scan Bean et réalisé par les producteurs par rapport à l'intensité d'attaque finale (IP).



Treatments from 443 trials performed in 2012-2014 in France. Grey box; number of treatments recommended with Scan Bean, white box: number of treatments by farmers. Classes concern the quality of pods of interest to industry: < 40: Disease occurrence without affecting pods, [40-60]: Disease likely to impact pods following harvest date, > 60: Disease on pods certain, especially on immature crops.

The values are summarized in the graph (Fig. 7) and ranked following three IP levels noted in the untreated controls according to the IP terminals defined by UNILET (40 to 60% IP).

When grouping the 443 trials, we note that the number of treatments by farmers is 2.4 ± 0.7 (TRTobs). In simulation, the Scan Bean treatments would have led to 1.3 ± 0.8 treatments on average using this same dataset.
The number of TRTobs varied between one and five treatments (1: 1%; 2: 58%; 3: 32%; >4: 9%). Note that one treatment is applied systematically and that cases of more than four treatments applied involve particular areas and strategies for plots with the use of reduced product rates. A look at the distribution following the IP classes shows that the TRTobs for low to medium IP classes (< 60) varied little (2 to 3 treatments) and is high (3 treatments) for an IP > 60 (with a certain risk of pods being attacked). The number of treatments has been adapted to the risk to the plot in case of major infestations but with difficulty for infestation levels below 60% IP.
The number of TRTest treatments simulated with Scan Bean was between zero and five treatments (0: 15%; 1: 38%; 2: 43%; 3: 3%; > 4: 1%). The number of treatments estimated with Scan Bean is significantly proportional at the infestation level in the controls.

CONCLUSION AND FUTURE WORK

Scan Bean is now in use to alert technicians and growers in main northern bean-growing areas throughout France (more than 30 000 hectares of beans were planted in 2014). It is the first DSS on the web employed by users to manage their fungicide applications for SSR control. This DSS allows for a daily estimation of petals infected with *S. sclerotiorum* ascospores from the first white bud to the end of bean flowering.
On that basis, the model recommends a treatment threshold which adapts to the estimated damage level. This estimation is based on a statistical analysis of previous flowering agronomic events. Thanks to this information and a three-day weather forecast, industries and farmers are able to anticipate and manage the SSR risk rationally. They can find their bean production areas on a map and query it with the flowering status given by the model.
The Scan Bean® performance was evaluated with UNILET and Syngenta's partners between 2012 and 2014, using a large number of KP biological tests. It is the first time such monitoring took place in France on beans. This database showed a good correlation between the spray decision advice with KP in 2012 and 2013 ([57-65]%).
However, in 2014 the model tended to over-estimate the PFI compared with the KP. This year, in the NPC area, we observed the highest IP ever > 50% (remember that 60% is considered to have a critical impact on the industrial process). This study revealed that the IP was not correlated with KP (r^2=0.3) on beans as previously shown by CETIOM in oilseed rape. However, the PFI with Scan Bean compared with the KP seems to correlate better with the annual IP variation. A high level of PFI with Scan Bean in 2014 was due to the extremely wet conditions observed during August. This weather period was interpreted through models as potentially suitable soil water conditions for sclerotia germination.
Water transfer in the soil is a key point of the model. We often noticed poor estimations in fields with a sandy soil texture. These types of soil are very common in the Cote d'Opale region in the NPC area.
On-going studies using soil probes will provide new information to improve soil simulation, especially concerning organic matter content. We also found this kind of soil in the South Atlantic coastal area (SO), which accounts for one third of bean cultivation in France. The SO area data was not integrated in Scan Bean training, as we noted a far lower SSR pressure.
Concerning treatment advice performance, results showed the number of treatments recommended by Scan Bean was correlated with disease severity in fields. This DSS could be helpful in improving the adaptation of the number of fungicide applications with IP < 60%. Following the current trend of sustainable agricultural practices, Scan Bean is an additional tool to apply the product at the right time.

Other studies with UNILET consisted of many different treatment schedules with application dates (UNILET, Windows trials 2012-2014, not published) focusing on the importance of the early flowering application. These sorts of trials confirmed the correct Scan Bean timing and could be used later to adapt the different treatment profile products according to efficacy and dosage. This chemical knowledge combined with genetic tolerance factors will lead to extensive field improvement in the Scan Bean risk forecast.

Scan Bean was built on petal kit surveys. Unfortunately, this biological test is sensitive to other plant pathogens and could produce false ''positive'' Sclerotinia detection. Nor can we exclude no detection due to poor KP storage conditions.

Recently, we tested a new tool to measure *S. sclerotiorum* occurrence. This technique consisted of daily counting of spores in the atmosphere using air traps. In British OSR fields, three years of daily DNA analysis (Rogers *et al.*, 2009) was performed which was insensitive to other plant pathogens (*S. minor, S. trifoliorum* and *Botrytis cinerea*). This study comparing air trapped spores with Scan Bean spore releases strongly endorsed the model as being reliable (Jackman *et al.*, 2013). Substantial spore release was correctly predicted ± 1 day. However, probably because petals and weather conditions interacted in ascospore capture, the quantity of *S. sclerotiorum* ascospores in the air was not correlated with KP in OSR (Penaud *et al.*, 2011).

Finally, Warwick and ADAS researchers in a recent paper (Clarkson *et al.*, 2014) used lettuce to model the effect of the quantity of ascospores on the disease development rate. Combining their works with Scan Bean quantification and timing of inoculum could develop new functionality in scheduling harvest dates according to estimated symptom dates, thereby ensuring that growers and industries bring together the best potential for bean quality.

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