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Integration of pathogen and host resistance information in existing DSSs – introducing the IPMBlight2.0 approach

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INTRODUCTION

Potato Late Blight (PLB) caused by *Phytophthora infestans* is still a major problem for potato production in Europe (Schepers et al., 2018, this proceeding). Milder winters in Northern Europe are resulting in volunteer plants that may act as inoculum sources the forthcoming season. Sexual recombination is causing early infections from oospores in some regions. Intensive and widespread use of popular cultivars is causing pathogen adaptation to host resistance that might lead to higher fungicide use (Cooke et al., 2011). A stringent execution of the EU Legislation 1107/2009, reduces the access to a wide array of active ingredients with different mode of actions. This increases the risk of fungicide resistance as stated in the EuroBlight statement from the EuroBlight workshop in Aarhus 2017. These trends are causing a real threat to the EU goal of a sustainable control of potato late blight and reductions in the pesticide use in general (Directive 2009/128/EC on the sustainable use of pesticides). EuroBlight recommends best management practices in potato and it is clear that the use of resistant varieties is one of the most effective IPM measures (http://euroblight.net/control-strategies/best-practice/). Host resistance is often not stable across many years as pathogens may adapt and overcome resistances in specific varieties (Hansen et al., 2005; Cooke et al., 2011). The EuroBlight monitoring of the *P. infestans* population in Europe since 2013, mainly using SSR genotyping, highlighted how dynamic, regional and host specific these populations evolves and spreads in Europe. With the introduction of the IPMBlight2.0 project (Andrivon et al., 2018, this proceeding) more isolates will be phenotyped for fungicide resistance, virulence and aggressiveness enabling linkages between genotype and phenotype. EuroBlight also seeks collaboration with breeding companies and the official variety-testing network (VCU) to evaluate and document the type and level of resistance in commercial cultivars across Europe. This is the prerequisite for IPM2.0 in potato as defined and introduced by Kessel et al. (2011) and tested in the DuRPh project (Haverkort et al., 2016) and in the AMIGA project (Kesssel et al., 2017, in press). There is a need to introduce more complete PLB IPM strategies which use host plant resistance as the backbone for PLB control, aims to deliver total PLB control and to prevent *P. infestans* from breaking the host resistance whilst at the same time using as few chemical inputs as possible. This is the goal of the next level of IPM - IPM2.0 for potato late blight control allowing for a much more durable exploitation of host plant resistance, cheaper PLB control and a strongly reduced burden on the environment (Kessel et al., 2011).

In a statement from the EuroBlight workshop in Brasov, 2015, EuroBlight recommended i) to continue and expand the monitoring of *P. infestans*, ii) to intensify the phenotyping of important genotypes and iii) that EuroBlight offers to participate in the development of new and the adaptation of existing PLB Decision Support Systems (DSSs) to IPM2.0 as defined above (EuroBlight statement 2015, Brasov). These recommendations led to the C-IPM ERANET funded IPMBlight2.0 project 2016-2019 (Andrivon et al., this proceeding) covering all aspects mentioned in the statement. This paper will present results from the first step towards the implementation of the IPMBlight2.0 approach into a DSS modelling framework.

METHODS

Weather based blight risk sub-models from six existing European DSSs were programmed in the MATLAB modelling framework, and the blight risk was calculated using weather data from across Europe. In this paper we show results from simulations with data from a Danish weather station for two years, 2015 and 2016. Observations from the Danish late blight disease surveillance network were used to evaluate the model outputs, and results from one trap nursery were included in a simulation to demonstrate the potential of including the IPM2.0 approach on one of the DSSs calculation of a control strategy.

Sub-models

The weather based sub-models selected for this exercise were: Infection pressure (Blight Management, DK), Effective Blight Hours (EBH (Irish rules, IR)), Infection risk (Naerstad model, NO), Critical day (WUR Blight, NL), Produced spores (Mileos, FR) Risk 1-4 (Hutton Criteria, UK). The blight risk sub-models from each DSS were implemented using the MATLAB programming environment, enabling run of all sub-models with weather data from selected weather stations and years. All DSSs are described on the EuroBlight website (http://euroblight.net/control-strategies/dss-overview/). A reference humidity model was introduced as:

- Humid hours were calculated as occurring when Rh≥88% or leaf wetness ≥30 min/hh or precipitation ≥0,2 mm/hh.
- The cumulative total of humid hours was then calculated across three days (72 hours).

Weather data

Historical, hourly weather data were collated from DK, NO, UK, FR, IR and NL for the years 2014-2016. Weather data included were: Wind speed [m/s], Temp [°C], Rh [%], Leaf wetness [Min/hh], Precipitation [mm] and Solar radiation [MJ/m²].

Climate Data Interface - CDI

All the selected sub-models use Rh as an estimate of humid conditions for sporulation or as an estimator of leaf wetness for infection except the Naerstad model, which needs data on leaf wetness. Rh sensors are very sensitive for erosion of calibration. To quality control the weather data for the IPMBlight2.0 modelling exercises, we developed a “Climate Data Interface” (CDI) using the MATLAB programming environment. This component quality controls (QC) all data and writes the QC summary and elementary statistic in dedicated Excel files for further analysis. If consecutive missing values were fewer or equal to five hours values were estimated using a linear interpolation procedure.

Climate Data Interface operations and calculations:

- Number of missing values for each variable separately (when) (by station/ year / month)
- Interpolation of missing data if subsequent missing data <6 hours
- Min and max of weather variables (by station / year / month)
- Median, mean, min, max and std of the top 200 Rh hourly measurements. (by station /year / month)
- Mean Rh during hours with precipitation >0,5 mm, global radiation<0,5 MJ/m² and wind speed <5 m/s (by station / year / month)
- Estimated leaf wetness based on standard variables (several methods)

Calculation of blight risk for six weather based blight risk sub-models

The blight risk was calculated for the six sub-models using controlled weather data. This exercise enabled comparison of model outputs and analysis of blight risk in Europe across regions and years.

IPMBlight2.0 approach – assumptions and simulation with the Danish DSS, Blight Management

To demonstrate the implications of introducing the IPMBlight2.0 approach in one of the DSS we did a simulation exercise introducing an abstract “ghost” variety, but running the model with real weather data and results from the local trap nursery:

- Introduce a “ghost” variety carrying R8 and one effective but unknown R-gene in a simulation with actual 2017 weather data and real data from a trap nursery in the North Jutland region of Denmark.
- Monitor the regional *P. infestans* population for the presence or emergence of virulent strains against R-gene differentials and varieties in the trap nursery present at AKV Langholt, North Jutland region, 2017.
- Use the Blight Management DSS (DK) to simulate a control strategy according to the IPM2.0 approach for the “ghost”variety and compare results with a conventional control strategy.
- Calculate the fungicide use as the Treatment Frequency Index (TFI) as the number of normal dosages used in the simulated control strategy e.g. use of two time half dosage counts as one (1.0).
- Calculations were done for a susceptible starch cultivar and a resistant cultivar with original settings (Table 1) and, a resistant cultivar with use of the IPMBlight approach (Figure 6)

Trap Nursery

In 2017, ten trap nurseries were established in five EU countries in the frame of the IPMBlight2.0 project. The nurseries included all the Black’s differential set and some cultivars with known resistances: R1, R2, R3, R4, R5, R7, R8, R9, R10, R11, Bintje, Alouette, Carolus, Robijn, Sarpo Mira, Toluca, Coquine Irna, Kelly Irna, Makhaï Irna. Additional varieties were included at AKV Langholt, Dronninglund, Denmark e.g. Anouk (ware), Kuras (starch), Nofy (starch) and PL11-0111 (Starch). For this paper, results from this nursery were used for the IPMBlight2.0 modelling exercise. Disease severity [%] was scored ten times from 4 July to 13 September. A trap nursery data management system was developed to store and analyse the data. The goal for this system is to i) evaluate the level and type of host resistance in the differentials and additional cultivars tested using the EucaBlight approach (Hansen et al., 2007) and ii) use the data as input to the modelling work in the project.

RESULTS

Quality control of weather data

Several data sets tested with the CDI failed the quality control e.g. missing data for several days no leaf wetness or global radiation, only precipitation on daily basis or significant change in the offset of Rh measurements. In all the six sub-models analysed, Rh is a key variable for calculating the risk of sporulation and/or other parts of the life cycle. The Rh threshold used in the models varied from 85 to 90%. From one station, all Rh measurements were below 90%. Running the models with these data resulted in zero, or very low weather based blight risk. From the analysis of data from another weather station it was obvious that the sensor calibration was corrupted, (approximately 7% too low), but was then changed with a new sensor in July 2015 (Figure 1). For data from a third station the Rh measurements dropped suddenly and dramatically approximately 4% in July 2015, and this (too low) calibration stayed for the subsequent 2 years (Figure 2). Looking at data from many stations in North Europe across a number of years and several sensor types the level of Max Rh values should be in the range of 97-99%.

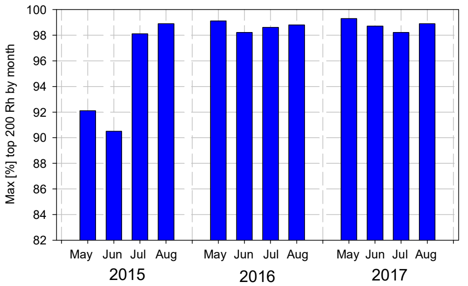

Figure 1. *Max Rh by month for hourly weather data at EU station A*

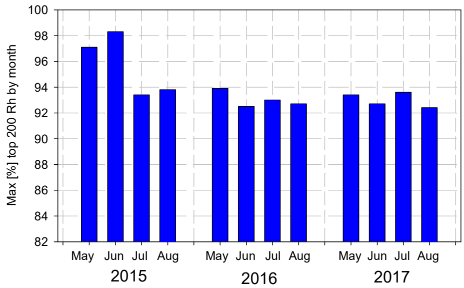

Figure 2. *Max Rh by month for hourly weather data at EU station B*

Comparison of blight risk sub-models and late blight development

Output from the six blight risk sub-models is visualised in the same graph together with the reference humidity model, including the date of first observed PLB attack in Denmark (red letter A) and date when PLB was recorded in the region for the first time (red letter B) (Figure 3 & Figure 4). The blight risk estimations are supplemented with biological data from Denmark, 2014-2017:

- Date when late blight was recorded in 5 or more conventional fields (marked A)
- Date when late blight was recorded for the first time in the region, less than 50 km distance from Dronninglund (marked B)
- Dates of first spray recommended in a susceptible and a resistant variety calculated with the Danish DSS.
- The number of sprays calculated for a susceptible and a resistant variety for the standard period 1 June to 30 September, using real data on late blight appearance from DK and from

the region as given in Table 1. Resistance level and the regional observation of late blight influences the calculations of the dose rates in the model.

Table 1. *Potato late blight appearance and DSS calculations for Denmark and Region Dronninglund, 2014-2017. See text for detailed explanations.*

Year	Denmark	Dronninglund, Region North Denmark			No of sprays, 1 June – 30 Sept.	
	Date of PLB in the Country (A)	Date of PLB in the region (B)	Recommended date for first spray, susc. variety	Recommended date for first spray, resis. variety	Susceptible variety	Resistant variety
2017	16 June*	16 June*	8 June	22 June	12,75	9,50
2016	10 June*	27 June	15 June	15 June	13,50	9,00
2015	22 June	6 July	22 June	29 June	12.00	8.00
2014	1 June*	17 June	6 June	6 June	14.00	9,75

** indications of oospores*

Under Danish conditions crop emergence is on average from 20 May to 1 June in the south and approximately one week later in the North of Denmark. Early infection from oospores is assumed to occur during crop emergence. Attacks originating from infected tubers normally take place around 15-30 June under normal conditions.

In 2015, blight was found in Denmark in five or more conventional fields on 22 June and in the Dronninglund region on the 6 July. All sub-models indicated a weather based blight risk in early May – before crop emergence and therefore not relevant for any early control actions. The month of May was relatively humid and mean temperatures were often below 10°C. Most models use a lower temperature threshold of 10°C and despite humid conditions the blight risk was therefore calculated as low until early to mid June – after a rise in temperature (Figure 3). There is a good correspondence between the blight risk sub-models for the indication of high blight risk e.g. the high infection pressure from the DK model is corresponding very well with several consecutive critical days as indicated by the WUR blight sub-model. Max risk is calculated during the same periods for more or less all sub-models (Figure 3). For Mileos, the risk is indicated as a build-up of produced spores, but again, the number of consecutive days with high spore loads corresponds well with high risk indicated by the other sub-models.

In 2016, temperatures in May were higher than the previous year and crop emergence was about a week earlier. Blight was found in Denmark in five or more conventional fields on 10 June in the Mid-South of Jutland (some of these fields with indications of infections from oospores) – and in the Dronninglund region on the 27 June. All sub-models indicated a weather based blight risk in late May, and in the Mid-South of Denmark (same infection peak) this coincided with more than 40 mm of rain during crop emergence. Early infections from oospores might be the reason for early observations of blight on young plants in this region. Due to later crop emergence on the North of Denmark this region most probably experienced an "escape" situation of the combination of crop emergence, high infection pressure and rain. All the sub-models predicted blight risk 5-10 days before blight was actually found in this region.

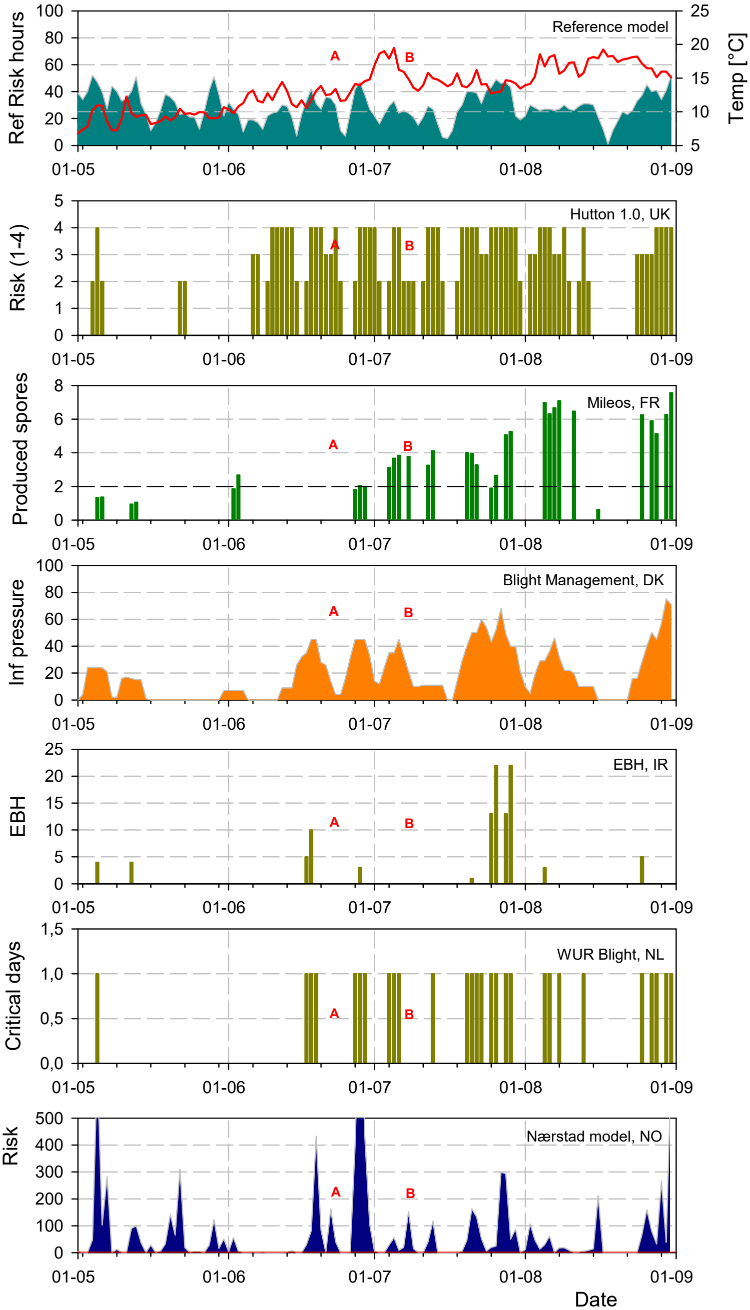

Figure 3. *Outputs of six blight risk sub-models and a reference model using weather data from Dronninglund, DK, 2015. The Letter A indicates the date when late blight was first recorded in Denmark. The letter B indicates when late blight was found in the Dronninglund region. For the Reference model the daily mean temperature is indicated on the right Y-axis.*

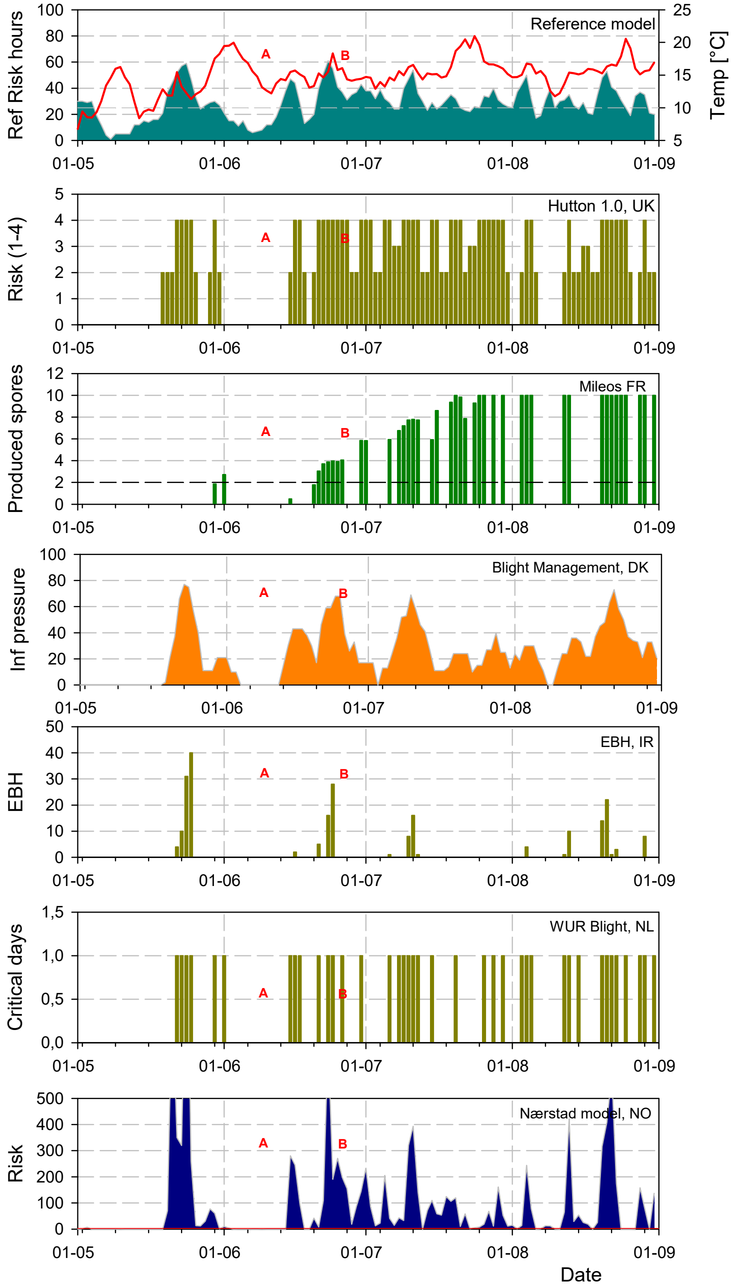

***Figure 4**. Outputs of six blight risk sub-models and a reference model using weather data from Dronninglund, DK, 2016. The Letter A indicates the date when late blight was found in Denmark. The letter B indicates when late blight was found in the Dronninglund region. For the Reference model the daily mean temperature is indicated on the right Y-axis.*

Trap Nursery data

In the trap nursery at Dronninglund, PLB was recorded for the first time on 4 July (Figure 5). First symptoms of late blight in Sarpo Mira was recorded on 21 August. The genetic basis of late blight resistance in 'Sarpo Mira' is highly complex, consisting of at least five different R genes that confer qualitative and quantitative resistance to late blight (Rietman et al., 2012). The rapid disease development in untreated Sarpo Mira in this trial is considered to be due to a general high stress load from not only blight but also a mix with *Alternaria* spp. and general senescence that was difficult to separate from each other. For all differentials and varieties tested, the rate of disease development (slope of the curves) was high indicating a less effective horizontal resistance. Kuras is the most popular starch potato variety in Denmark covering approximately 60% of 25-30.000 ha of starch potatoes. Fifteen years ago, late blight was often found in Kuras in August. In recent years, attacks in Kuras were recorded early in the surveillance network – indicating that the *P. infestans* population in Denmark has changed and now overcome resistances in Kuras. The variety Nofy is a new variety expected to replace Kuras and PLB was observed a month later than in Kuras. In a new clone, PL11-0111, late blight was not observed at all during the season, indicating the potential of exploiting effective resistance in late blight control.

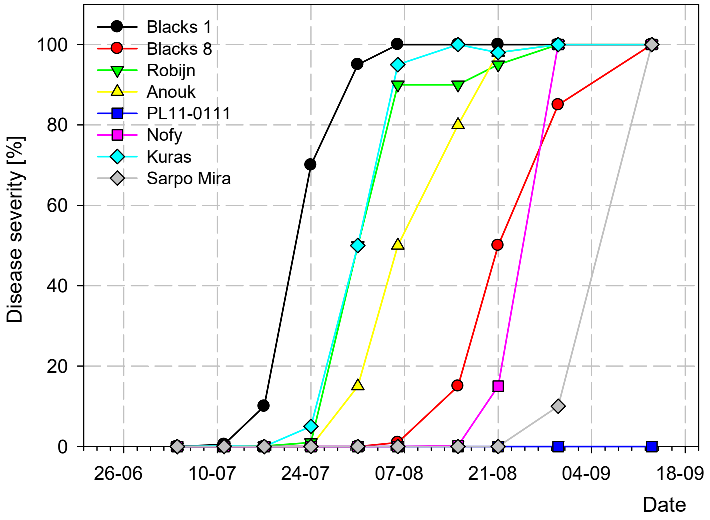

Figure 5. *Disease progress in selected differential clones and varieties tested at Dronninglund, Denmark, 2017. See text for detailed information.*

Simulation with a DSS based on the IPMBlight2.0 approach

Calculations with the Danish DSS were used to indicate how the implementation of the IPMBlight2.0 approach would influence the control in a "ghost variety" carrying R8 and an unknown but effective R gene (Fig 6). Infection pressure is given in yellow-orange gradient area, left y-axis (0-20 representing low, 20-40 medium and >40 units as high risk). Markers indicate the calculated recommended dosage of preventive fungicide i.e. Revus/Ranman. The red markers indicate time and dosage recommended for a strategy with weekly sprays. The light grey areas indicate when late blight appeared in the region and dark grey when late blight appeared in the field / trial. The red arrows indicate when a first spray is recommended in a resistant cultivar according to a current standard control strategy (top graph). This strategy results in a TFI of 9,5 (see also Table 1). Using the IPMBlight2.0 approach the preventive spray should be applied when R8 is eroded in the trap nursery (6 August). The assumption is that the R8 and the unknown R gene will protect the crop. When one of the R genes are broken, fungicides must be applied to protect durability of the remaining R gene. In the given example the resistant variety was treated from 10 August to 29 September in weekly intervals: 4 times 0,5 normal dosage, 2 times 0,75 dosage and one time 0,25 dosage totaling 3,75 normal dosage (TFI=3,75).

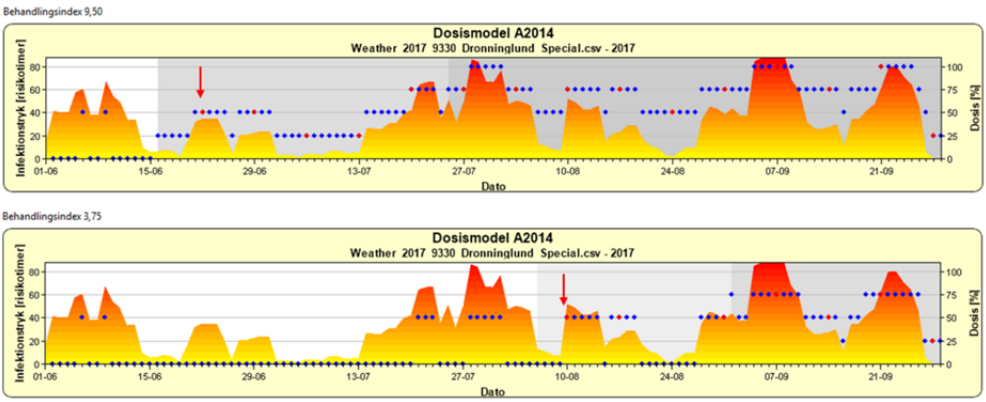

Figure 6. *Calculation of a control strategy using weather data from Dronninglund 2017. Top graph indicates a current control strategy in a resistant cultivar resulting in fungicide consumption of 9,5 normal dosages of a contact fungicide. Bottom graph indicates a control strategy in a resistant cultivar based on the IPMBlight2.0 approach resulting in fungicide consumption of 3,75 normal dosages of a contact fungicide. See text for further explanation.*

DISCUSSION

During the EU.NET.ICP concerted action (1996-2002) six different decision support systems for the control of late blight were tested in European validation trials in 2000 and 2001, Simphyt, Plant-Plus, NegFry, ProPhy, Guntz-Divoux/Milsol and PhytoPre+2000 (Hansen et al., 2002). It was concluded that all DSSs effectively controlled PLB at the same level as routine treatment, but with less fungicide input. It was also concluded that it was difficult to compare whole systems and it was recommended to analyse and compare systems on sub-model level. This was taken up by the ENDURE project (Hansen et al., 2010) and now again in this exercise. The goal in the IPMBlight2.0 project is to analyse, not only the six blight risk sub-models, but also how the different DSSs calculates a control strategy. Special focus will be on the DSS inclusion of host resistance and pathogen information. Innovative ideas on this were developed by Wageningen University and published in several publications based on the DuRPH, the AMIGA project and recently the GEOPOTATO project (Kessel et al., 2011; Haverkort et al., 2016; Kessel et al., 2017; Kesssel et al., this proceeding).

The first step in the analysis of the weather based blight risk sub-models was to check the quality of collated weather data. We noticed that the (lack of) quality of weather data used for running PLB sub-models is a problem. Input of low quality weather data might lead to wrong advice. If DSSs fail the growers may be reluctant to use the DSS again, or any DSS – even if bad weather data subsequently were identified as the cause of the wrong advice. When we then ran the models with quality controlled weather data, results indicate that more or less all DSSs indicate blight weather conditions accurately. The differences in the full DSSs include different steps and inclusion of other sub-models to go from weather based blight risk to a recommendation for control. Issues in this set of sub-models and/or "decision rules" can be: when to start chemical control, which fungicides to use (type and dosages), whether to use weekly intervals and variable dosages or variable intervals and full dosage, how to take resistance into account and how to present and visualise results.

The IPMBlight2.0 project will try to broaden out these very promising results on IPM2.0 to several existing DSSs in Europe as well as giving open access to test and evaluation of existing DSS sub-models in countries or regions where DSSs are not used today. The next step in the IPMBlight2.0 project will be to implement the six blight risk sub-models as well as supplementary sub-models as a series of interoperable web applications on the EuroBlight IT platform. On this platform, interfaces will be built to the trap nursery data management system, the EuroBlight pathogen monitoring data and the fungicide information that feeds into the EuroBlight Fungicide Table. In total, this will enable simulations of control strategies that analyse different innovative approaches and utilize excessive amounts of data on European level. Based on experience and results from this collaborative modelling framework, existing DSSs in partner countries will be adjusted. The improved DSSs will be tested in field experimental trials in the forthcoming years. The EU.NET.ICP project concluded that it was probably not possible to build one DSS for whole Europe. IPMBlight2.0 recognises this conclusion to be valid, but at the same time suggest to adapt its work to EU calls to the scientific community (and stakeholders) on sharing of data and software, adopt the open science ideas, implement and optimize e-infrastructures to support science and link up with the European Open Science Cloud Agenda (EOSC Declaration).

In October 2017, the Commission adopted a report addressed to the European Parliament and to the Council on the sustainable use of pesticides Directive (2009/128/EC) which takes stock of progress made by Member States on a range of topics. One key finding in the report is that Integrated Pest Management (IPM) remains underused by Member States. This is despite the fact that the number of EU-approved low risk/non-chemical pesticide substances has doubled since 2009. Compliance at individual grower level is not being systematically checked by Member States. When revising their National Action plans, Member States need to improve their quality, primarily by establishing specific and measurable targets and indicators for a long-term strategy for the reduction of risks and impacts from pesticide use (Report From The Commission To The European Parliament And The Council). In the recent EuroBlight statement from the Aarhus Meeting, EuroBlight offered to test innovative ideas and strategies through participatory actions. EuroBlight is also expressed its willingness to play an active role in the assessment of more complex and integrated blight control systems. All IPMBlight2.0 partners are also a part of EuroBlight and the EuroBlight network recognises that the value and visibility of its databases and web tools can be further enhanced to the benefit of a range of stakeholders. The integration of the IPMBlight2.0 activities and data with the EuroBlight existing data and tools is a step in this direction.

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