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An IPM2.0 Control strategy for Potato late blight based on cultivar resistance and monitoring of virulence in the local *P. infestans* population

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INTRODUCTION

In the Netherlands the total area under potato cultivation amounts to approximately 165.000 ha, annually yielding 7.9 million Mg of potato representing a value of about M€790. Potato late blight, caused by the oomycete *Phytophthora infestans*, is the major problem during potato cultivation in the Netherlands requiring an annual input of around 1400 tons of active ingredient. The number of fungicide applications for potato late blight control varies between 10 and 16 per season inferring a cost (chemicals, application and losses) of 125M€ per year, almost 16% of the total farm gate price (Haverkort *et al.* 2008).

From these figures it is clear that farmers, the potato industry, consumers and the environment could greatly benefit from more efficient and environmentally friendly ways to control late blight through e.g. the introduction and durable exploitation of host plant resistance. *P. infestans* however is renowned for its ability to adapt under the selection pressure exerted by e.g. the cultivation of resistant cultivars. In the past, newly introduced resistance was generally quickly overcome rendering the budget, time and effort spent to create it useless.

Traditionally, potato late blight control heavily relies on frequent (calendar based) applications of fungicides supported by preventive cultural measures such as the use of healthy seeds and the timely destruction of primary sources of inoculum. Cultivation of resistant cultivars is currently limited, mostly due to an overwhelming demand for a limited number of commercially very successful cultivars that are also very susceptible to late blight.

Integrated pest management (IPM) is a broad based ecological approach to structural agricultural pest and disease control that integrates pesticides into a management system incorporating a wide range of practices for economic control of a pest. In general, IPM builds on:

1. Acceptable pest levels with an emphasis on control.
2. Preventive cultural practices, including host plant resistance.
3. Monitoring: regular observation of the crop and the pathogen is the cornerstone of IPM.
4. Mechanical control.
5. Biological controls.
6. Responsible use of pesticides.

Additionally, basic epidemiology relates emergence of a disease to the disease tetrahedron (Figure 1, Zadoks and Schein 1979). Potato late blight (or any other plant disease) epidemics can only develop when a host is present, the pathogen is present and the environment ((micro) climate) is supportive for epidemic development. "Man" in turn is influenced by the pathogen, the host and the environment but also has the capacity to influence these three factors himself to (attempt to) prevent disease development.

When we compare currently applied potato late blight (PLB) control strategies with the theory comprised in IPM and the disease tetrahedron, inconsistencies become apparent. Calender based spray schedules only consider presence of the host. When the host is present (in a certain growth stage), sprays are applied according to schedule assuming the pathogen is also always present (in sufficient numbers) and the environment is suitable for epidemic development. By definition, this results in more sprays than strictly necessary and a sub-optimal spray schedule due to sub-optimal spray timing.

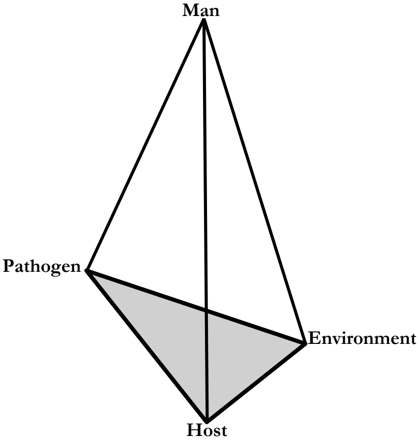

Figure 1. The disease tetrahedron. The base symbolizes the interaction of host, pathogen and environment. Man has various effects on each of these, important to the control and development of plant disease epidemics. (Zadoks and Schein, 1979).

Decision support systems (DSS's) (e.g. Dacom, Agrovision, NegFry, Phytopre, Simphyt etc.) introduced the concept of preventive fungicide applications directly preceding a predicted infection event. DSS's thus take into account the presence of the host and a conducive environment supporting epidemic development before spray advice is issued. This results in "spraying when necessary" and optimally timed spray applications although it is still assumed the pathogen is simply always present in sufficient numbers.

Here we set out to develop and test a more complete PLB IPM control strategy that uses host plant resistance as the backbone for PLB control, aims to deliver perfect PLB control AND prevent *P. infestans* from breaking the resistance while using as little chemical input as possible. This paper thus aims to introduce and evaluate 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.

MATERIALS AND METHODS

An IPM2.0 control strategy for potato late blight

The control strategy developed and tested uses host plant resistance as the back bone of the control strategy. Resistant cultivars are NOT sprayed as long as virulence to the R-gene(s) they contain is absent from the local *P. infestans* population. For this purpose, the local *P. infestans* population is continuously monitored for virulence against the R-gene(s) used during the entire growing season. If virulence against the R-gene(s) used is detected, the non-spray strategy is abandoned and replaced by a low input control strategy. Spray advice is then calculated on a daily basis using historic and forecasted weather to predict potential infection events. Preventive fungicide applications are recommended prior to predicted infection events if the residual protection from the previous spray application is insufficient. The dose rate of preventive fungicides depends on the resistance level of the cultivar: 25% dose rate on highly resistant (HR) cultivars, 50% dose rate on medium resistant cultivars (MR) and 100% dose rate on susceptible (S) cultivars. Furthermore, this resistance level based dose rate can be further reduced depending on the predicted fungicide degradation during the predicted critical period. If a critical period is predicted to last two days during which only half of the dose rate applied will be degraded, only half of the resistance level based dose rate will be applied. Last, when a spray advice is issued for the resistant cultivars the Distance Weighted Infection Pressure (DWIP) is calculated according to Skelsey *et al.* (2008). When the DWIP value is below the threshold, atmospheric conditions are unsuitable for viable aerial transport of sporangia and the spray advice is cancelled.

Host resistance thus truly is the backbone of the control strategy, only supplemented with (preventive) fungicide applications when necessary. Curative fungicides are applied when the calculations show that the crop is not sufficiently protected and the critical period has started 0.5 day or more ago.

Summarizing:

- A preventive fungicide application is necessary when:
  - infection event is predicted in the near future AND
  - the protection level from the previous spray is insufficient AND
  - virulence for the R-gene or R-gene combination used is present in the local *P. infestans* population.
- Reduced dose rates of protectant fungicides are used:
  - on crops with intermediate (50% reduction) or high levels (75% reduction) of resistance AND
  - prior to relatively short predicted infection events on all levels of resistance
- Scheduled sprays are delayed by 1 day on resistant cultivars when the Distance Weighted Infection Pressure (DWIP, Skelsey *et al.*, 2008) is below the threshold.

Field experiments

Field experiments were carried out in 2010 and 2011 in Lelystad and Valthermond, the Netherlands. Randomized block experiments with 6 cultivars and 4 replicates were established each year at both locations. Plots measured 8 * 12m. Cultivars included were: Bintje (S), Sante (MR), Bionica (HR), Chc containing clone (HR) and a Sto1 containing clone (HR) in Lelystad and Starga (S), Sante (MR), Bionica (HR), Chc containing clone (HR) and a Sto1 containing clone (HR) in Valthermond. Plots in this randomized block experiment were sprayed according to the advice calculated as described above.

Monitoring plots

Scattered across both farms, 20 – 45 unsprayed monitoring plots, each containing six plants of each genotype included in the spray experiment were planted. Monitoring plots were not sprayed at all during the entire growing season.

Monitoring of virulence

Monitoring plots were checked at weekly intervals during the growing season. *P. infestans* lesions were counted and sampled followed by removal and destruction of the remaining lesions. A maximum of two lesions per genotype, plot and date were sampled, collected in separate Petri dishes containing 15 ml 1.5% water agar and sent to the laboratory by courier.

In the lab, the lesion samples from the field experiments were analyzed for Sto1 virulence using a TaqMan PCR designed to amplify the Avrblb1/ipiO class I region Li *et al.* (2012). *P. infestans* isolates lacking class I ipiO were shown to be virulent on R*pi-blb*1 (Champouret *et al.*, 2009).

Lesion counts and PCR results were used as indicators for the presence or absence of specific virulences in the local *P. infestans* population.

RESULTS

First lesions on Bintje, Sante, Bionica, Chc1-clone and the Sto1-clone in Lelystad were found on respectively 18 July, 25 July, 1 August, 1 August and 8 August 2011. In Valthermond, first lesions on Starga, Sante, Bionica, Chc1-clone and the Sto1-clone were found respectively on 18 July, 25 July, 1 August, 8 August and 15 August 2011. The PCR assay for Sto1 virulence detected Sto1 virulence in a *P. infestans* sample originating from Bintje in Lelystad on 25 July and in a *P. infestans* sample originating from the Sto1–clone in Valthermond on 15 August. Both first findings of Sto-1 virulence triggered a change in the control strategy from non-spraying on the Sto1-clone to a low input spray strategy. Results regarding the fungicide input and infection levels in the 2011 spray experiment are given in Figure 2. The fungicide input in Figure 2 is expressed as "full dose rate equivalents". Infection is expressed as severity (% infected foliage). From Figure 2 we can see that in both locations the fungicide input dramatically decreases with increasing levels of resistance (left to right in the graphs). The level of control in Lelystad was excellent with *P. infestans* completely absent. In Valthermond, infection occurred in the susceptible and medium resistant cultivars, not in the HR cultivar Bionica and the HR Sto-1 clone. Chc1 plots in Valthermond were marginally infected. Apparently, the level of protection of a HR cultivar under a low input PLB control strategy is higher than the level of protection of an S or MR cultivar under a much higher fungicide input strategy.

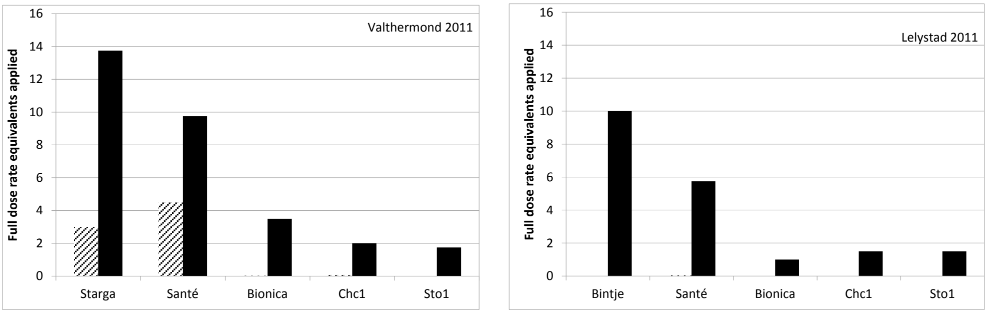

Figure 2. Results from the 2011 field experiments, fungicides input (■, full dose rate equivalents) and infection (% severity).

DISCUSSION

This study was initiated within the Dutch Umbrellaplan Phytophthora to help enhance the level of sustainability of potato cultivation. The fungicides used to control potato late blight pose a major burden on the environment. Reduction of this environmental burden would already greatly contribute to enhanced sustainability. As a result a more complete PLB IPM control strategy was designed and tested that uses host plant resistance as the backbone for PLB control, aims to deliver perfect PLB control AND prevent *P. infestans* from breaking the resistance while using as little chemical input as possible. The results are encouraging, demonstrating the possibilities high levels of host plant resistance have to offer with a reduction of the fungicide input of 80% or more. At the same time caution is necessary as *P. infestans* is well known for its ability to adapt under the selection pressure exerted by e.g. newly introduced resistance and fungicides.

Ideally, the R-gene content of cultivars grown under this IPM2.0 control strategy should be designed in such a way that it is very difficult to overcome in the first place, even for *P. infestans*. This means R-genes should be stacked in sufficient numbers and cultivars containing a single R-gene should be avoided since it can and will serve as a stepping stone for *P. infestans* to overcome stacks of R-genes. The switch from a non- spraying strategy to a low input strategy could then be made when e.g. all but one R-gene have been overcome. Monitoring the local *P. infestans* population thus remains of key importance to success.

Also, application of reduced dose rates hold a risk of exposing *P. infestans* to sub-lethal concentrations of active ingredients. This however only holds in a curative or eradicant application of a fungicide when active infections are exposed to sub-lethal concentrations of A.i.'s. In a preventive application, *P. infestans* is not actively growing in the crop and prevention of infection using a combination of host plant resistance (e.g. expressed as a very low infection efficiency) supplemented with reduced dose rates of fungicides is the goal. The overall resulting protection level of host plant resistance plus the fungicide application should at least be equal to the protection level resulting from a fungicide applied in the recommended dose rate on a susceptible crop. Results from the 2011 field experiment in Valthermond demonstrated that the protection level of a HR cultivar sprayed with reduced dose rates of preventive fungicides can even be higher than those on a susceptible cultivar sprayed with the recommended dose rate.

This paper thus demonstrates the viability of the next level of IPM2.0 control strategy for potato late blight allowing for a much more durable exploitation of host plant resistance, cheaper PLB control, a strongly reduced burden on the environment and a more durable growing system as a whole.

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