VII Control of late blight (*Phytophthora infestans*) and early blight (*Alternaria solani*) in potatoes

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Introduction

During the 2019 growing season, different experiments were carried out at AU Flakkebjerg, Dronninglund and Arnborg to improve late and early blight decision support systems (DSS) as part of our recent GUDP project. This report, however, presents some results from Flakkebjerg only. The late blight trials were carried out with Avarna (starch potato) and Folva (ware potato). The early blight trials were carried out with Avarna only.

Late blight trials

Materials and methods

Field experiments were carried out to validate the performance of late blight models at three locations in Denmark (Flakkebjerg, Arnborg and Dronninglund). The experimental design was a factorial randomised complete block design with four replicates. The factors were two potato cultivars (Folva and Avarna) which varied in their level of host resistance to late blight and eight fungicide treatments. Folva is a susceptible, ware and intermediate maturing cultivar. Avarna is a moderately susceptible, starch and late maturing cultivar. The plot size was 3.75 m × 8 m. The potatoes were planted on 17 April and emerged on 28 May. The late blight trials were artificially inoculated on 4 July by spraying a potato plant between the blocks with a sporangial suspension of *P. infestans* (1000 sporangia/ml). The severity of late blight was assessed at 7-day intervals as the percentage leaf area covered with late blight lesions per plot. All plots were harvested (15.75 m^2, 3 rows x 7 m from each plot) and starch content measured (weight under water of dry matter. % starch = dry weight – 5.75).

The late blight DSS (Skimmelstyring)

The late blight DSS can be found on https://www.skimmelstyring.dk/. It is beyond the scope of this report to present a detailed description of the late blight DSS, so only a brief description is given here. The Danish late blight DSS (**Skimmelstyring**) calculates the risk of infection of late blight based on local weather data (hourly air temperature and relative humidity). The risk of infection or infection pressure for late blight is calculated as the running sum of sporulation hours during a 5-day window including the current date, a 2-day weather forecast and two days of historic weather. Sporulation hours for late blight (HSPO) are defined as the number of hours with at least 10 or more consecutive hours with RH≥ 88% and the temperature between 10°C and 24°C. Depending on the infection pressure, the risk level in a day could be classified as low (< 20), moderate (20-40) or high (> 40) (Nielsen and Abuley, 2018). Fungicide application is done at 7-day intervals, but the actual dosage of fungicide recommended by the DSS is based on the infection pressure, proximity of late blight to the field and cultivar resistance. The late blight DSS uses two different dosage models (A and B). Model A recommends higher dosages than Model B (Table 1); thus, Model A is usually used for susceptible cultivars, while Model B is used for resistant cultivars. For example, when late blight has been found in the region (50-100 km from the field), Model A recommends 100% dosage compared to 75% dosage by Model B for infection pressure >20 (Table 1). Usually, a preventive fungicide such as Ranman Top or Revus is used. However, curative (e.g. Cymbal 45) or eradicative (e.g. Proxanil) fungicides are also recommended when spraying is done later than the forecasted date or actively sporulating lesions are found on the field, respectively.

Table 1. Recommended dosage (%) by Models A and B for different infection pressure and whether late blight has been found in Denmark or in the region (50-100 km from the field).

Infection pressure	Denmark		Region	
	Model A	Model B	Model A	Model B
>40 (high)	75	50	100	75
21-40 (moderate)	50	50	100	75
<20 (low)	50	50	75	50

The fungicide treatments are explained below.

- **Untreated**. No fungicide was applied to control late blight.
- **Routine**. Here 0.5 l/ha (full dose) Ranman Top (RT) (160 g/l cyazofamid) was applied at a 7-day interval from row closure.
- **Model A**. Fungicide application in this treatment was based on the infection pressure and dosage Model A from the blight management DSS.
- **Model B**. Fungicide application in this treatment was based on the infection pressure and dosage Model B from the blight management DSS.
- **Model A1, B1**. These follow the exact recommendation of either Model A (for A1) or Model B (for B1), except that spraying can be postponed or delayed for 3-4 days if the daily risk value (DRV) on the day of spraying is less than 10. Once spraying is postponed, there are four possibilities:
    - Spraying can be postponed again for additional days.
    - Spray 50% dose of RT if the forecasted DRV for one day (next day or two days) is at least 10.
    - Spray 75% dose of RT if the forecasted DRV is at least 10 for the next two days.
    - Spray 50% dose RT + 0.25 kg/ha Cymbal, if DRV for the present or previous day is at least 10.
- **Model A2, B2**. These follow the exact recommendation of either Model A (for A2) or Model B (for B2); however, spraying can be postponed or delayed for 1-2 days if the infection pressure on the day of spraying is less than 10. Once spraying is postponed there are four possibilities:
    - Spraying can be postponed again for additional days.
    - Spray 50% dose of RT if the forecasted infection pressure for one day (next day or two days) is at least 10.
    - Spray 75% dose of RT if the forecasted infection pressure is at least 10 for the next two days.
    - Spray 50% dose RT + 0.25 kg/ha Cymbal, if infection pressure for the present or previous day is at least 10.

Results

Fungicide application

Details of fungicide applications and the treatment frequency index (TFI) for the models and routine applications are shown in Figures 1a and b, respectively. All the models reduced the TFI compared to the routine treatment (Figure 1b). The most reduction in TFI was for Models B1 and B2 (Figure 1b). As expected, the introduction of the no-spray (i.e. Models A1, A2, B1 and B2) recommendations for each dosage model reduced the TFI compared to the original models (Models A and B). For example, following recommendations from Models A1 and A2 resulted in lower TFI than Model A (Figure 1).

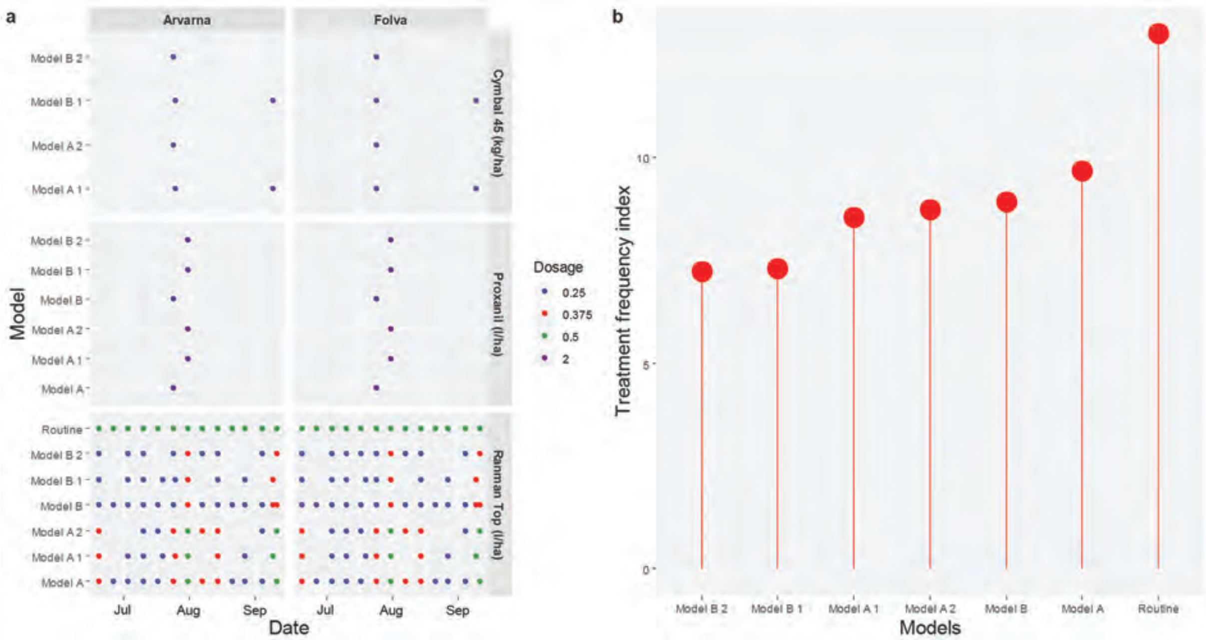

Figure 1. Details of fungicide application according to the models and the routine treatment (a) and the treatment frequency index (b).

Disease control

2019 was a year favourable to late blight compared to 2018 (see infection pressure in Figure 2) and thus it was more challenging keeping late blight under control. However, this was also a good year to test the effectiveness of the new models (A1/B1 and A2/B2) to control late blight under blight favourable weather. Indeed, in dry years like 2018, it becomes difficult to distinguish between good and bad models.

Figure 3 shows the development of late blight on both the untreated and treated plots for both Avarna and Folva. In using the disease progress curve (DPC) to compare the treatments, we do not include disease severity values after 28 August (for Folva) and 18 September (for Avarna). The reason for the exclusion of severity values after these dates is the onset of natural defoliation due to senescence. A look at the untreated for both cultivars reemphasises the importance of host resistance as a key component in controlling late blight (Figure 3). For example, on 1 August the untreated Folva plots had a mean late blight severity of more than 50% compared to less than 10% for Avarna.

For Avarna, all the fungicide treatments were effective in controlling late blight, with no apparent differences in their severity values at all assessment dates (Figure 3). Thus, new models (A1, A2, B1, B2) did not compromise control of late blight (Figure 3), even though these models had lower treatment frequency index (Figure 1).

Until 28 August, the disease severity on Folva was not different for all the fungicide treatments (Figure 3). On 28 August, which was the last date we included in our analysis of the disease data for Folva, the disease level on Folva treated according to Model B1 was much higher than the other fungicide treatments (Figure 3). However, all the treatments kept late blight below 25% (Figure 3).

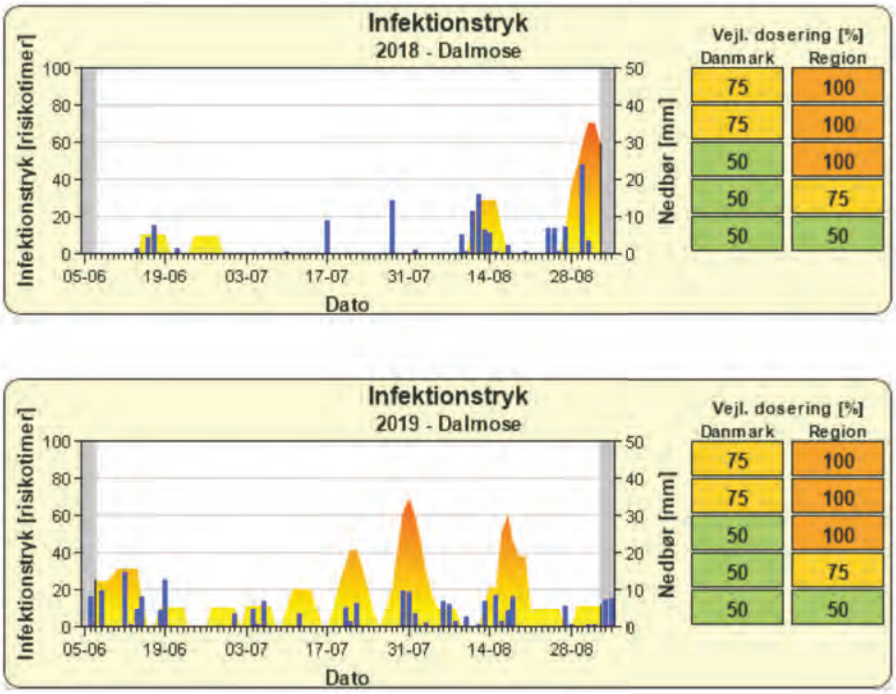

Figure 2. Infection pressure ((“Infektionstryk”) (yellowish coloured area) of late blight in 2018 (upper panel) and 2019 (lower panel) at Dalmose. The blue bars represent the amount of rainfall. The part of the figure with the caption “Vejl. dosering [%]“ shows the recommended dose as a percentage of the standard dose of Revus or Ranman Top for the given infection pressure when late blight is first seen in Denmark and in the region (https://www.skimmelstyring.dk/).

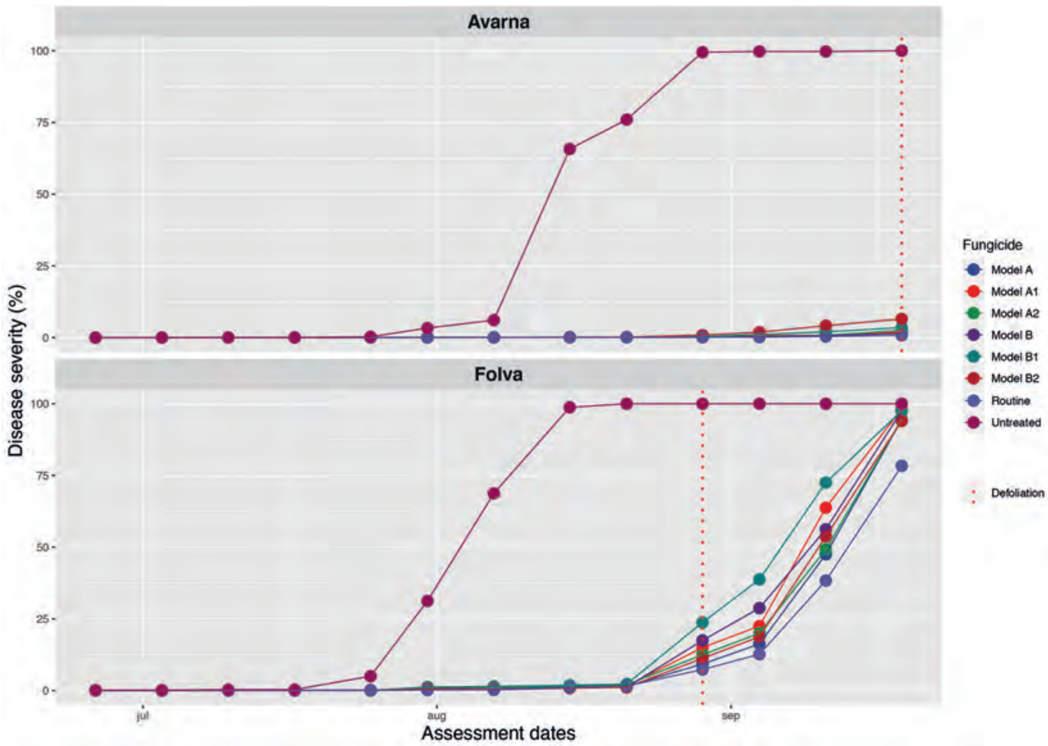

Figure 3. The development of late blight (caused by *Phytophthora infestans*) on Folva and Avarna. The broken red line shows the date defoliation due to senescence began on the cultivars. The disease severity values after this are not included in interpreting the results of the study.

Yield response

A substantial yield difference between the fungicide treatment and the untreated was observed for both Avarna and Folva (Figure 4). The difference in yield between the fungicide treatments and the untreated ranged from 47 to 58 tonnes/ha and 43-53 tonnes/ha for Avarna and Folva, respectively. This reemphasises the importance of disease control obtained by spraying. However, the yields from the fungicide treatments were substantial (Figure 4). The routine treatment was not associated with the highest yield. The highest starch yield was from Models B and A1 for Folva and Avarna, respectively (Figure 4). In most cases, the models were either higher or slightly lower than the routine treatment for starch yield in both Avarna and Folva. The results also show no marked yield difference between the models for yield in either Avarna or Folva. This suggests the applicability of Model B and its variants (B1 and B2) on both susceptible and resistant cultivars.

Except for Model B1 and the routine treatment, the variation (confidence interval) associated with mean yield of the treatments was narrower for Folva than for Avarna (Figure 4). This suggests the possibility of obtaining a more consistent yield from Folva than from Avarna. Even though the mean yield of the fungicide treatments was similar for Avarna, the variation associated with the yield from Model B2 was considerably larger compared to the other fungicide treatments (Figure 4) and could suggest higher uncertainty with Model B2. However, the fact that none of the yield values and confidence interval of Model B2 overlapped with the untreated is noteworthy (Figure 4).

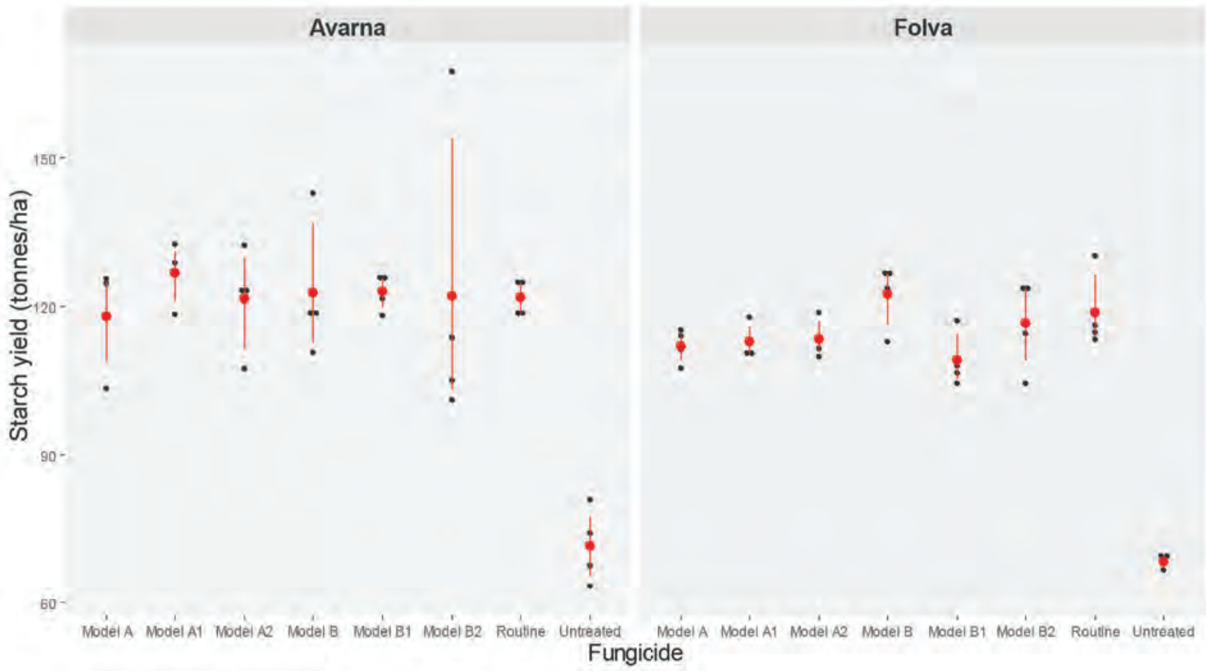

Figure 4. Mean starch yield (red dots) of Folva and Avarna treated according to the models, routine and untreated. The vertical red lines are the 95% bootstrapped confidence intervals and the black dots are the yield values for each replicate per treatment.

Conclusion

The current usage of the Danish late blight DSS recommends a weekly spraying of preventive fungicide (e.g. RT), but the actual dosage varies depending on the infection pressure and the proximity of late blight to the field. However, the experience from 2018 (a dry year) has shown that there is a need to include a no-spray recommendation when the infection risk is too low. This was achieved by testing Model A1/B1 and Model A2/B2. Generally, the present results support the inclusion of a no-spray recommendation. The experiments will be continued in 2020, with the focus of finding the best no-spray recommendation for the Danish late blight DSS. Moreover, the present results suggest that Model B and its variants (B1 and B2) could also be used for susceptible cultivars such as Folva.

Early blight trials

Materials and methods

Early blight (*Alternaria solani*) trials were carried out in Avarna only. The potatoes were planted on 17 April and emerged on 28 May. Inoculation was carried out with autoclaved barley grains infested with *A. solani* on 24 June. The inoculum was a mixture of isolates that have reduced sensitivity to strobilurins (with F129L mutations) and those that are sensitive (without the F129L mutation). Starch yield was assessed as described under the late blight trials. However, only two replicates were harvested for the early blight trials due to difficulty of harvesting the other two replicates.

The following models/treatments were investigated.

- **Untreated**. No fungicide application. This treatment served as a check for the overall disease level during the season.
- Standard treatment. 4-5x of 0.25 kg/ha Signum WG (67 g/kg pyraclostrobin + 267 g/kg boscalid) at 14-day intervals from 6 weeks after emergence.
- **TOMCAST**. Briefly, the TOMCAST model assigns disease severity value (DSV) to each day depending on the total leaf wetness and average temperature the leaf-wet hours (Abuley and Nielsen, 2017; Gleason et al., 1995). The DSVs range from zero (no risk) to four (high risk). The DSVs are summed until a predetermined threshold (e.g. 20) is reached for spray to be recommended (Abuley and Nielsen, 2017). A detailed description of this model can be found in Abuley and Nielsen (2017). The first fungicide application was done at 330 physiological days (Pdays) and when the total TOMCAST DSV was at least 25. Subsequent sprayings were done when 20 TOMCAST DSV accumulated. Physiological days are a measure of the thermal age of the potato plants, which is conceptually similar to growing degree-days. The calculation of Pdays is based on daily minimum and maximum temperatures from the emergence (50%) of the crop. The Pdays calculation is based on the equation by Sands et al. (1979).
- **Critical day model**. This model determines if there is sufficient leaf wetness in a day and favourable temperature for infection. The model characterises each day as a critical day (1) or a no-critical day (0). The first spraying is recommended when the plant is 330 Pdays and at least 3 days have been forecasted to be critical. Subsequent sprayings are based on three days forecasted of critical days.
- **Risk hour model**. The risk hour model calculates the number of risk hours required for infection by *A. solani*. Risk hours are the product of the probability of infection based on the average temperature during leaf-wet hours and the total leaf-wet hours in a given day. The first spraying is recommended when the plant is 330 Pdays and the risk hours since emergence are at least 72 hours. Subsequent sprayings are recommended when at least 72 risk hours are reached.

Age-dependent susceptibility of potatoes to early blight

The susceptibility of potatoes to early blight is age-dependent, with the result that older plants are more susceptible than younger plants. Thus, we adjust the fungicide dosage according to the age-dependent susceptibility (Abuley and Nielsen, 2017). For all the early blight models we investigated, the exact dose of fungicide (i.e. Signum WG) sprayed was adjusted according to the plant age (in Pdays). For late-maturing cultivars (e.g. Avarna) half dose was sprayed between 330 and 500 Pdays and full dose after 500 Pdays (Abuley and Nielsen, 2017).

Results
The fungicide application is shown in Figure 5. Fungicide application according to the standard treatment and TOMCAST model resulted in the highest and lowest TFI, respectively.

Unlike late blight, the development of early blight on the untreated was very slow for most part of the season. Rapid epidemic development on the untreated plots started towards the end of August (Figure 6). By the last assessment date, the untreated had reached 99%. The severity of early blight on all fungicide-treated plots remained low throughout the season (not more than 5%) (Figure 6).

The yield response of the treatments is shown in Figure 7. Except for the standard treatment, the yield values for the other treatments were associated with larger variation (broad confidence interval). Although, this could be interpreted as high uncertainty with the use of the models, the fact that only two replicates were harvested for the yield analysis could also account for this large variation.

The untreated had a lower yield than the fungicide treatments. The standard treatment resulted in the highest yield and this was markedly different (difference of approx. 7 tonnes/ha) from the untreated (Figure 7). The TOMCAST model had the highest yield amongst the models with a mean yield of 3 tonnes/ha more than the untreated (Figure 7). The critical days model had the lowest yield amongst the fungicide treatments (Figure 7). In all the difference in yield between the fungicide treatments and untreated ranged from approximately 1 to 7 tonnes/ha (Figure 7).

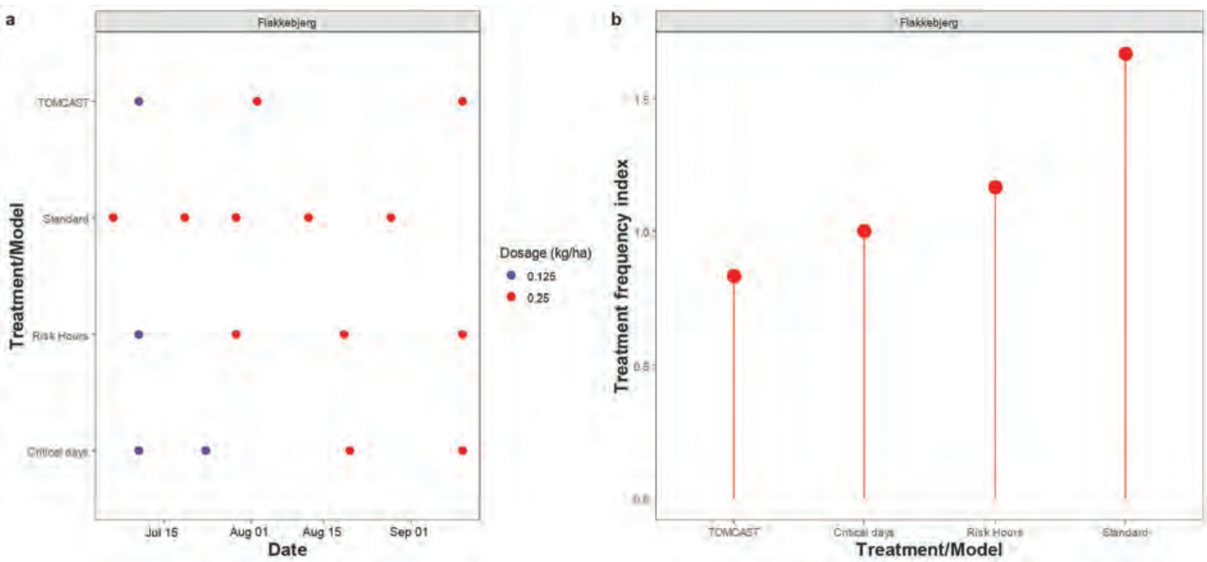

Figure 5. Details of fungicide application according to the models and the standard treatment (a) and the treatment frequency index (b).

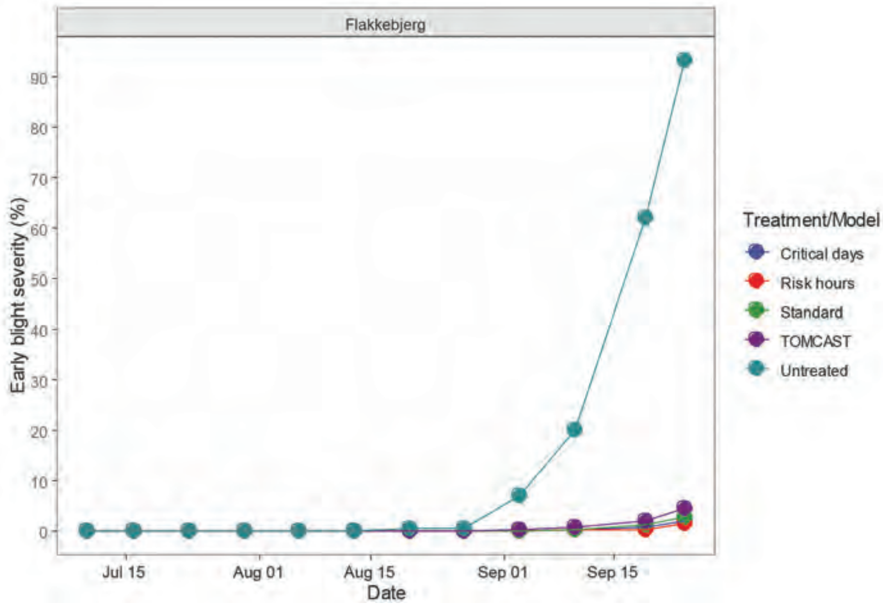

Figure 6. The development of early blight on Avarna treated according to TOMCAST, Risk hours, Critical days, standard application and untreated.

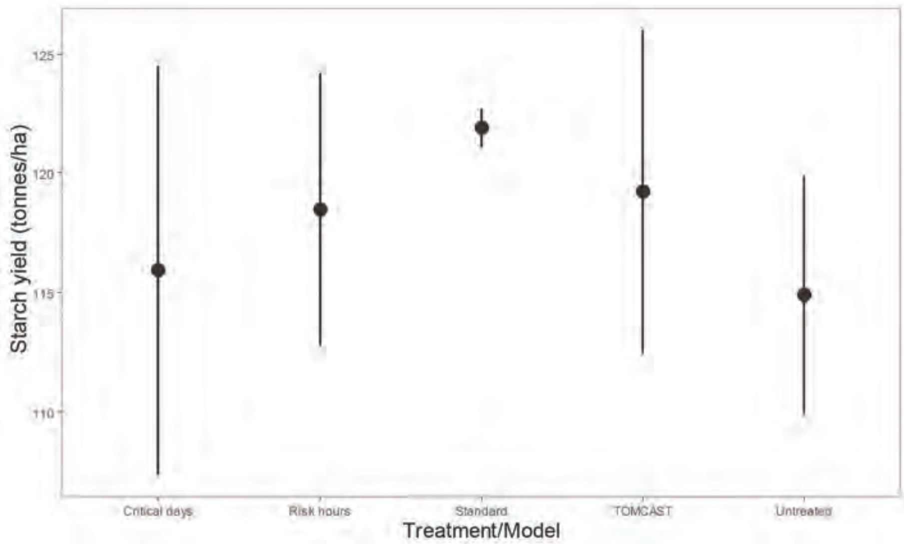

Figure 7. Mean starch yield (dots) of Avarna treated according to TOMCAST, Risk hours, Critical days, standard application and untreated. The vertical lines are the 95% bootstrapped confidence intervals.

Conclusion

In conclusion, the results show the possibility of reducing the TFI for controlling early blight by using the models. The TOMCAST model was the best model in terms of reducing the TFI without compromise on yield.

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