APPLIED CROP PROTECTION 2019

LISE NISTRUP JØRGENSEN, THIES MARTEN HEICK, ISAAC KWESI ABULEY, SOLVEJG K. MATHIASSEN, PETER KRYGER JENSEN, HELENE SALTOFT KRISTJANSEN & PETER HARTVIG

DCA REPORT NO. 167 · MAY 2020

AARHUS UNIVERSITY
DCA - DANISH CENTRE FOR FOOD AND AGRICULTURE

APPLIED CROP PROTECTION 2019

DCA REPORT NO. 167 · MAY 2020

AARHUS
UNIVERSITY
DCA - DANISH CENTRE FOR FOOD AND AGRICULTURE

Lise Nistrup Jørgensen, Thies Marten Heick, Isaac Kwesi Abuley, Solvejg K. Mathiassen, Peter Kryger Jensen, Helene Saltoft Kristjansen & Peter Hartvig

Aarhus University
Department of Agroecology
Forsøgsvej 1
DK-4200 Slagelse

APPLIED CROP PROTECTION 2019

Series and number:	DCA report No. 167
Report type:	Dissemination
Year of issue:	May 2020, 1st PDF edition, 1st printing
Authors:	Senior Scientist Lise Nistrup Jørgensen, Postdoc Thies Marten Heick, Postdoc Isaac Kwesi Abuley, Senior Scientist Solvejg K. Mathiassen, Senior Scientist Peter Kryger Jensen, Technician Helene Saltoft Kristjansen, Trial leader Peter Hartvig. All from Department of Agroecology, Flakkebjerg, Aarhus University
Financial support:	The report is finance by many different sources. The specific funding is given for each chapter in the preface.
Review:	Professor Per Kudsk, Senior Scientist Peter Kryger Jensen, Academic employee Mette Sønderskov all from Department of Agroecology, Aarhus University
Publisher:	DCA - Danish Centre for Food and Agriculture, Blichers Allé 20, PO box 50, DK-8830 Tjele. Tel. 8715 1248, e-mail: dca@au.dk, web: dca.au.dk
Please cite as:	Each chapter should be sited specifically. The overall report cited as In: Lise Nistrup Jørgensen, Thies Marten Heick, Isaac Kwesi Abuley, Solvejg K. Mathiassena, Peter Kryger Jensen, Helene Saltoft Kristjansen, Peter Hartvig. Applied Crop Protection, Aarhus University, DCA - Danish Centre for Food and Agriculture. 126 p. - DCA report No. 167.
Layout:	Charlotte Hamann Knudsen, Department of Agroecology, Aarhus Universitet
Cover photos:	Uffe Pilegaard, Department of Agroecology, Aarhus University.
Print:	Digisource.dk
ISBN:	Printed version 978-87-93998-02-5
	Electronic version 978-87-3998-03-2
ISSN:	2245-1684
Pages:	126
Internet version:	https://dcapub.au.dk/djfpublikation/djfpdf/DCArapport167.pdf
Keywords:	Crop Protection, pesticides, efficacy testing, control strategies, Decision support systems, fungicide resistance.
	Reports can be freely downloaded from dca.au.dk

Contents

Preface

The publication "Applied Crop Protection" is a yearly report providing results and advice to farmers, advisors, industry and researchers on crop protection. The publication summarises data which are regarded to be of relevance for practical farming and advice. It covers information on the efficacy profiles of new pesticides, effects of implementation of IPM (integrated pest management) aiming at reducing the use of pesticides and illustrates the use of Decision Support Systems (DSS) in combination with resistant cultivars. It also includes an update on pesticides resistance to ensure that only effective strategies are used by the farmers to minimise build-up of resistance.

The series of reports was initiated in 1991, when the Danish Research Service for Plant and Soil Science (Statens Planteavlsforsøg) as part of the Ministry of Agriculture was responsible for biological testing of pesticides and provided a certificate for biological efficacy based on the level of efficacy in field trials. Later this system was replaced by the EU's legislation for efficacy data. Efficacy testing of pesticides was opened up to all trial units, which had obtained a GEP certification (Good Experimental Practice) and fulfilled the requirements based on annual inspections. Since 2007 the report has been published by Aarhus University (AU) and since 2015 it has been published in English to ensure a greater outreach.

The choice of topics, the writing and publishing of the report are entirely done by staff from Aarhus University and the report content is not shared with the industry before publication. All authors and co-authors are from AU. The data on which the writing is based are coming from many sources depending on the individual chapter. Below is a list with information on funding sources for each chapter in this report.

Chemical companies supplied pesticides and advice on their use for the trials and plant breeders provided the cultivars included in specific trials. Trials were located either at AU's research stations or in fields owned by private trial hosts. AU collaborated with local advisory centres and SEGES on several of the projects, e.g. when assistance was needed regarding sampling for resistance or when looking for specific localities with specific targets. Several of the results were also published in shared newsletters with SEGES to ensure a fast and direct communication to farmers.

Internal scientific review of specific chapters was carried out by Per Kudsk, Mette Sønderskov, Lise Nistrup Jørgensen, and Peter Kryger Jensen.

Chapter 1: Climate data for the growing season 2018/2019 and specific information on disease attack in 2019. The information was collected by AU.

Chapter 2: Disease control in cereals. Trials in this chapter were financed by ADAMA, Corteva, Bayer Crop Science, BASF, Syngenta, Nordic seed, KWS and Sejet Plantbreeding, but certain elements were also based on AU's own funding.

Chapter 3: Control strategies in different cultivars. Trials in this chapter were financed by income from selling the DSS system Crop Protection Online as well as input from Bayer Crop Science and BASF. Certain elements were based on AU's own funding as part of a PhD project (Rose Kristoffersen).

Chapter 4: Diseases in red fescue. The project was financed by ”Frøafgiftsfonden”.

Chapter 5: Fungicide resistance-related investigations. Testing for fungicide resistance is carried out based on a shared cost covered by projects and the industry. In 2019 ADAMA, Corteva, Bayer, BASF and Syngenta were involved from the industry. The Swedish part is financed by the Swedish Board of Agriculture, and AU-AGRO was involved.

Chapter 6: Fungicide strategies against powdery mildew resistance in sugar beet. The project was financed by ”Sukkerroe-afgiftsfonden”.

Chapter 7: Control of late blight (*Phytophthora infestans*) and early blight (*Alternaria solani*) in potatoes. Trials in this chapter were financed by Nordisk Alkali, Bayer, BASF, Syngenta. Major elements were based on AU's own funding as part of a PhD project (Isaac Abuley). Several of the trial plans were carried out in collaboration with SEGES; these included the testing of DSS.

Chapter 8: Screening of herbicide efficacy on different *Bromus* species. The project was financed by agricultural tax funds (promilleafgiftsmidler) via SEGES.

Chapter 9: Drift from different application techniques in potatoes and the influence of a filter crop in the buffer zone. The investigation was financed by “Kartoffelafgiftsfonden” as a part of the project: “Mekaniske, termiske og kemiske metoder til nedvisning af kartofler”.

Chapter 10: Spray drift from application techniques when desiccating offshoots in strawberry. The study was financed by “Danish Horticulture”.

Chapter 11: Spray drift and deposition uniformity with conventional technique and Hardi Twin air assistance at two wind speeds. The study was financed by Hardi International A/S.

Chapter 12: Results of crop protection trials in minor crops in 2019. The projects were financed by various agricultural tax funds, GUDP, chemical companies and Swedish minor use funding.

I Climate data for the growing season 2018/2019

Helene Saltoft Kristjansen

This chapter describes the overall weather conditions in Denmark during the growing season (September 2018–August 2019) and, in particular, in Flakkebjerg where the majority of the Aarhus University (AU) trials were located.

General weather conditions in Denmark

In September, the rainfall was unevenly distributed across the country. Central and Western Jutland received a significant amount of rain and experienced several cloudbursts. The eastern parts of the country had far less rain. The average precipitation in September exceeded the normal precipitation by 11%. Both October and November had less precipitation than normal, 47 and 34 mm respectively, which was 48% below normal. Autumn temperatures reached an average of 10.1°C, which was 1.3°C above normal (1961-90).

The winter was warm and dry. The average temperature during the winter was 3.5°C, which was 2.9°C above normal. In general, precipitation exceeded the normal precipitation (1961-90) but compared with a 10-year average (2006-15) precipitation was below normal during the winter. The number of days with temperatures below zero in December-February was limited to only 31 days, which was 22 days fewer than normal. The snow cover during the winter was very low with 1.3 days recorded on average for December-February, which was 7.5 days below normal.

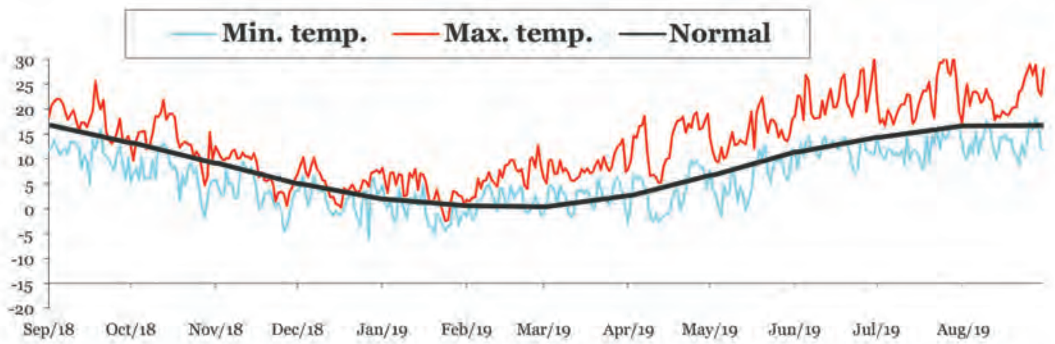
Spring 2019 began wet; precipitation was extremely high and set a new record with an average in March of 106 mm, which was 130% above normal (1961-90). However, precipitation was unevenly distributed across the country with 124 mm recorded in Central and Western Jutland and only 84 mm recorded in Western and Southern Zealand. It should be noted that almost all precipitation in March occurred during the first 15 days of the month. Temperatures in March and April exceeded the normal temperatures and reached an average of 5.5 and 8.1°C, which was 3.3 and 2.4°C respectively above normal. April was very dry, with only 15 mm precipitation recorded in the last days of the month. April 2019 saw a record of sunny hours with 274 hours of sunshine recorded, which exceeded the normal average by 69%. In contrast, May 2019 was quite cold compared to the previous year. The temperature average of 9.8°C and precipitation average of 54 mm were both considered normal (1961-90).

The average temperatures in June, July and August reached 16.2,16.7 and 17.4°C respectively, which was slightly above normal (1961-90). Cloudbursts (> 15 mm in 30 min.) were recorded several times during the summer. Rainfall was unevenly distributed across the country. Particularly Central and Western Jutland had significant precipitation due to cloudbursts. Across the country, June and July had average precipitation of 58 and 67 mm respectively, which was close to normal. The average precipitation in August increased to 91 mm, which was 36% above normal. Rainfall and cloudbursts were unevenly distributed and especially Jutland was exposed. Farmers in Jutland experienced massive difficulties harvesting crops. Despite heavy rainfall, the number of sunny hours exceeded the normal in June, July and August. With recorded sunshine of 252, 222 and 202 hours, all summer months exceeded the normal by 21%, 13% and 9% respectively.

Weather conditions at Flakkebjerg

At Flakkebjerg, normal autumn temperatures were recorded but precipitation was low with 21.3, 24.6 and 23.9 mm, respectively, recorded during the autumn, which was far below normal. Winter cereals were sown and established without any problems.

The first frost did not occur until January, and only very few days had temperatures below zero degrees. In general, the winter was warm and dry. All winter, the temperatures were far above normal with an average of 3.2°C, which was 2.2°C above normal. Snowfall only occurred on a few days in January. High temperatures continued during March and precipitation increased heavily. During the first 17 days of March 91 mm of rain was recorded, which was 55 mm above normal. This surplus of precipitation was much needed due to the dry autumn and winter. The considerable amount of precipitation in March and high temperatures in both March and April ensured establishment of spring crops. May turned out to be cold (10°C) and windy (Figure 1). Precipitation in May was close to normal, but because of lack of precipitation in April most fields suffered from drought in spring 2019 and crops slowed down growth for a while (Figure 2). Temperatures increased during June, July and August. Average temperatures during the summer together with evenly distributed average precipitation ensured good infestation of leaf diseases in cereals (Figure 2). In Figure 3, the drought situation during the season can be seen for each of the important growing months. Most fungicide trials at Flakkebjerg were irrigated 2 times during the summer. In general, the harvest of crops was easy and most crops were harvested under dry conditions by the end of August. Cereal yields were high due to good cropping conditions and high fungicide responses were also measured in crops with severe disease infestations.



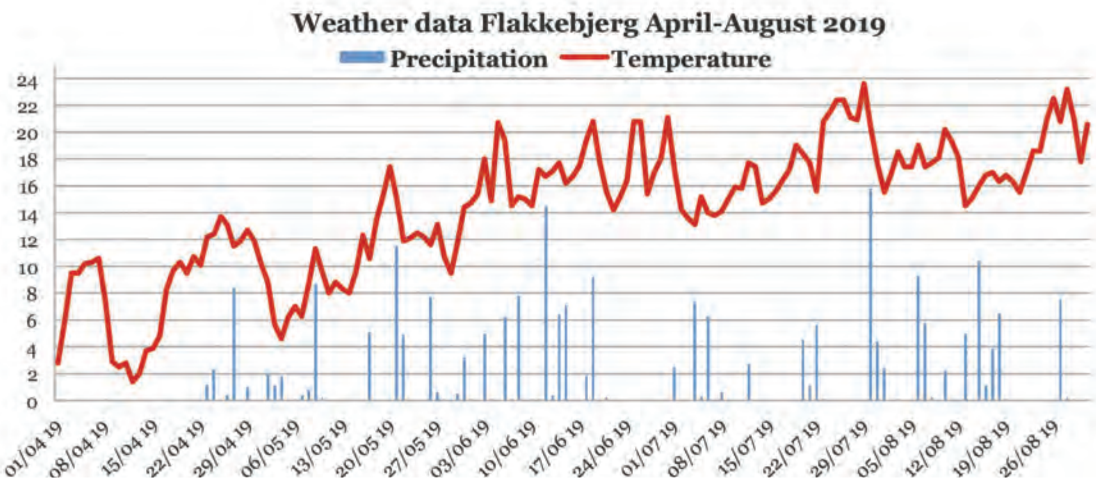


Figure 1. The automatic weather station at Flakkebjerg is located 12 km from the West Zealand coast. The climate at Flakkebjerg is representative of the area in which most of our trials are situated. The normal climate is given as an average of thirty years (1973-2013).

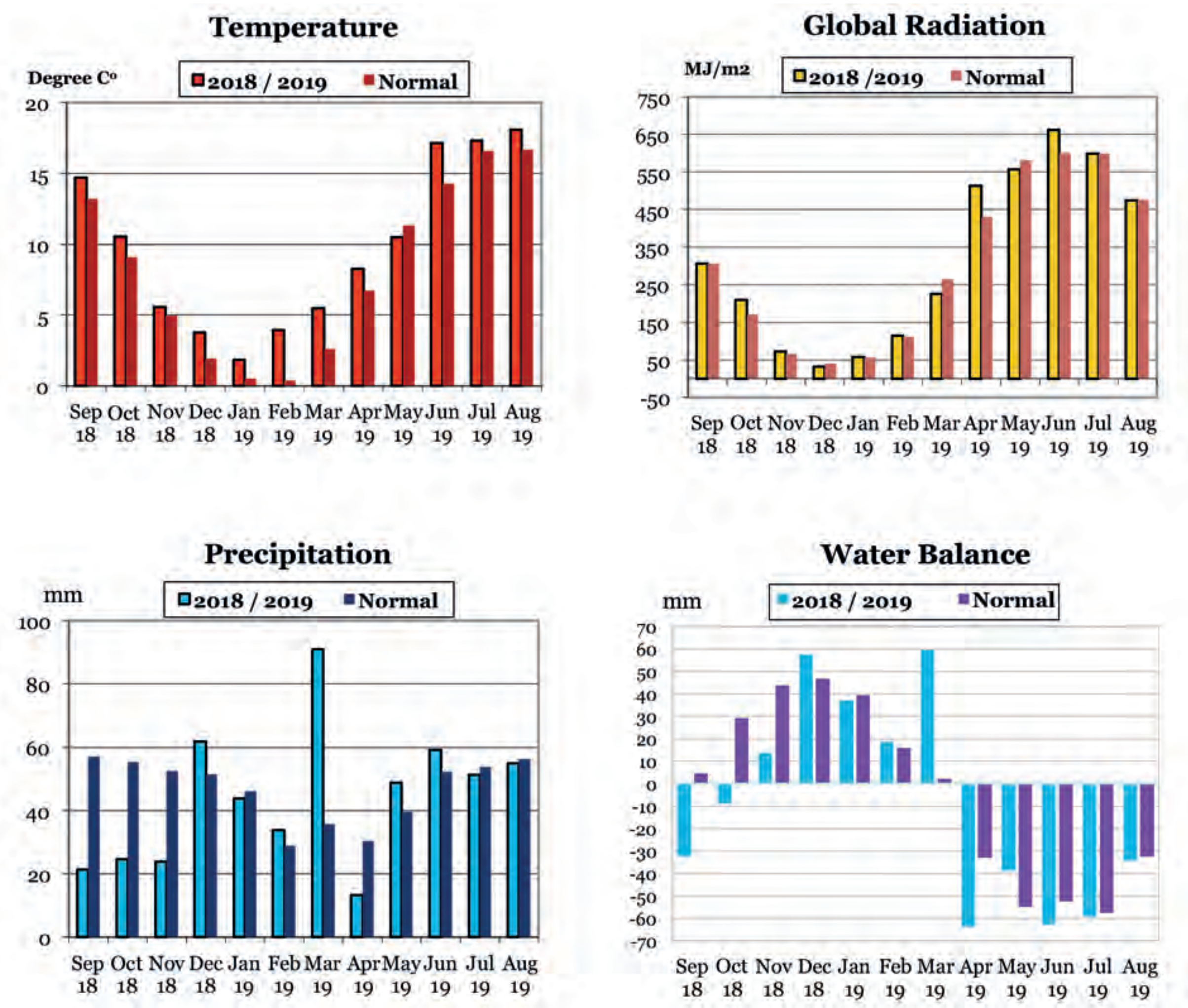


Figure 2. Climate data from AU Flakkebjerg for the growing season September 2018–August 2019. The temperature is in °C, the global radiation measured in MJ/m^2, the precipitation in mm, and the water balance is the difference between precipitation and potential evaporation.

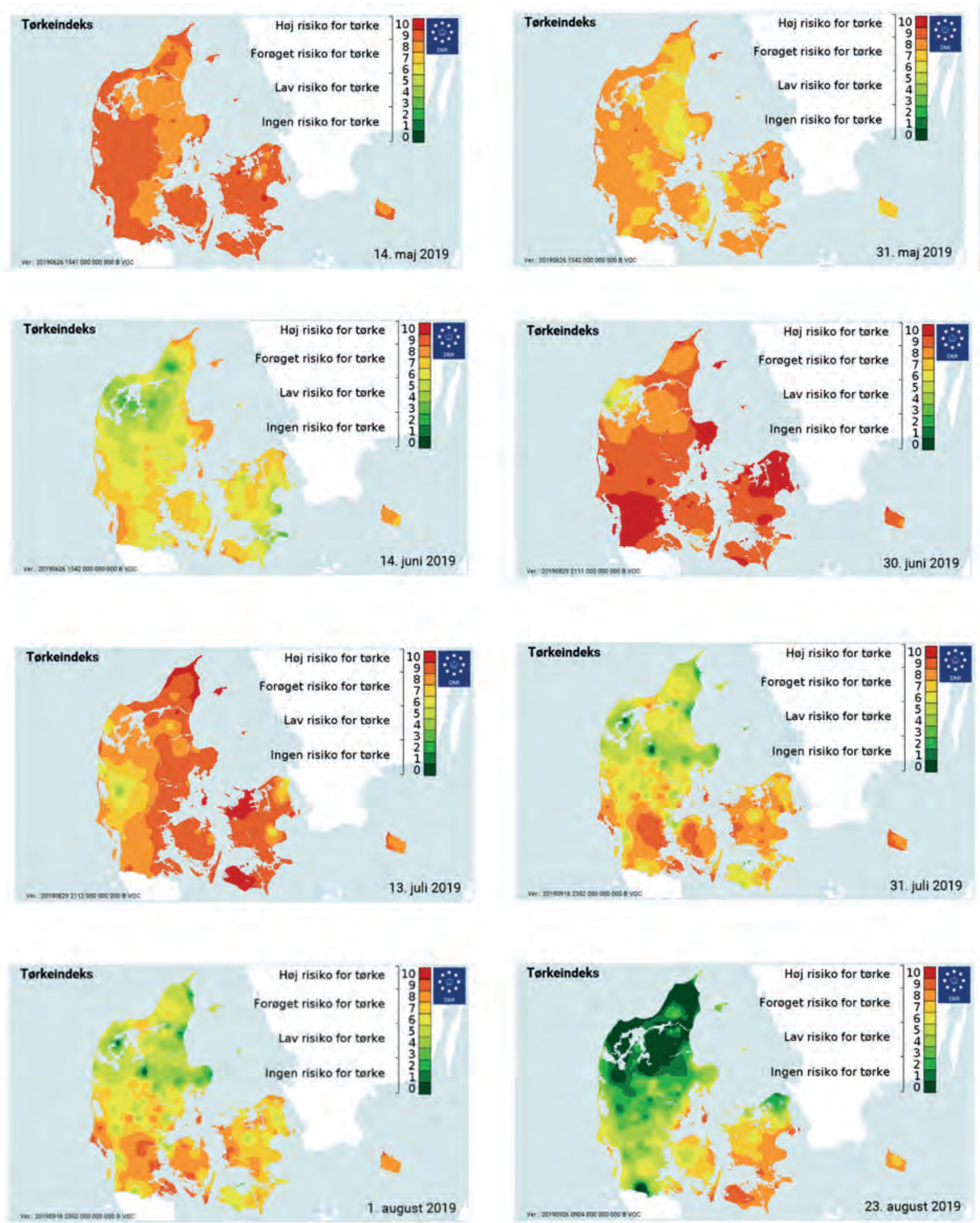


Figure 3. Drought index for May-August 2019. Danish Meteorological Institute (DMI).

Drought Index 2019 (DMI)
Scale:

- 0-2 No risk of drought (green)
- 3-5 Low risk of drought
- 6-8 Increased risk of drought
- 9-10 High risk of drought (red)

1. Disease attacks in 2019

Lise Nistrup Jørgensen, Thies Marten Heick, Niels Matzen, Helene Saltoft Kristjansen & Hans-Peter Madsen

The occurrence of diseases in the fungicide trials in 2019 is described in this chapter. Knowledge of disease occurrence is important for an evaluation of whether the target diseases were present at significant levels. Efficacy assessment trials depend on the level of disease infestation and significant attacks are often required to obtain representative results. Yield levels in cereal trials are ranked and compared with the previous years.

Wheat

Powdery mildew (*Blumeria graminis*). The sandy soil in Southern Denmark (Jyndevad) is well known for its high levels of powdery mildew infestation and, as expected, severe attacks were also observed in 2019. For the country in general, the level of mildew attacks was low to moderate. Attacks were recorded in the cultivars Torp, Kalmar, Cleveland and Ambition. Observations carried out by the advisors in the national monitoring system organised by SEGES also showed moderate attacks this year.

Septoria leaf blotch (*Zymoseptoria tritici*). The level of *Septoria tritici* attacks varied between sites and cultivars, but in general the attacks were moderate to severe. The mild winter gave good conditions for inoculum to develop an attack, but the attacks of *Septoria tritici* were delayed due to a lack of precipitation in April and cold weather in May. Precipitation increased during May, which provided better conditions for *Septoria tritici* to develop. Most cultivars showed measurable symptoms of *Septoria tritici* on the upper leaves from GS 51 in late May. Attacks on the second leaf and the flag leaf increased rapidly during June, and the significant attacks provided good opportunities for late flag leaf assessments in cultivars such as Hereford, Cleveland and Kalmar. The level of *Septoria tritici* attack assessed at GS 75 was relatively high, reaching 56% on leaf 2 and 34% on leaf 1 at GS 75.

Yellow rust (*Puccinia striiformis*). Fields with the susceptible cultivars Substance and Ambition were inoculated with yellow rust in the second week of April. The weather was windy and the cold weather in May delayed the development of yellow rust. Substance is well known for its high susceptibility and despite the cold weather in May, the attacks were moderate to severe. Ambition is in general less susceptible and this year only moderate attacks of yellow rust developed on this cultivar. In trials inoculated with yellow rust, the attacks increased to a level of 15% on the flag leaf at GS 73. An attack of yellow rust is known to reduce yields, and attacks in 2019 showed significant yield responses to fungicide treatments. Fields with Benchmark, in particular, were severely infected.

Brown rust (*Puccinia triticina*). The mild winter 2018/2019 provided good conditions for inoculum to survive the winter. Due to cold weather conditions during May, no attack of brown rust was seen in spring and early summer. In late June, a minor attack was observed in a few trials but without significant consequences for crop yields. The attack of brown rust in the cultivar Hereford (natural infection) was assessed to be low to moderate, reaching a level of 3% on leaf 1 at GS 75.

Tan spot (*Drechslera tritici repentis*). Attacks of tan spot developed in April in fields with winter wheat as the preceding crop and minimal tillage. Due to the cold weather and slow development of tan spot, no T1 treatments against tan spot were needed. During May, the infection rapidly spread to the upper leaves. Trials at Flakkebjerg, where pre-infected straw was spread in the autumn, showed severe attacks, providing optimum conditions for efficacy evaluations. Field trials at Flakkebjerg were established in the cultivar Graham, which is susceptible to tan spot. During May and June, the attacks of tan spot increased and severe attacks were assessed at all leaves during the growing season. At GS 73, the disease level increased to 53% on the flag leaf and 93% on leaf 2.

Fusarium head blight (*Fusarium* spp.). To ensure that *Fusarium* was established at an assessable level, all *Fusarium* trials were inoculated. Inoculation combined with irrigation during flowering almost always lead to visible attacks. Daily irrigation was installed in small plots where cultivars were tested for susceptibility. The moist conditions in these trials ensured a severe attack of *Fusarium*, allowing for an assessment of the level of susceptibility of the cultivars. In the large plots, the winter wheat crop were inoculated during flowering and irrigated 1-2 times during the same period. Due to the optimal weather conditions during flowering, the attacks in inoculated field trials were severe and gave good opportunities for detecting differences in fungicide performance.

Triticale and rye

Yellow rust (*Puccinia striiformis*). A severe attack of yellow rust developed in the triticale trials in 2019. The triticale trials were naturally infected and the infestation levels on the flag leaf increased to 61% at GS 71. The disease level gave good opportunities for ranking the performances of the fungicide products.

Brown rust (*Puccinia recondita*) appeared in winter rye with a severe attack late in the season. Despite the late incidence of attack, good opportunities for ranking the performances of the products were present. At GS 77, the attack increased to 75% on leaf 2 and 34% on the flag leaf.

***Rhynchosporium* (*Rhynchosporium commune*).** A moderate attack of *Rhynchosporium* developed early in the winter rye trials in 2019. The disease level provided relatively good opportunities for ranking the performances of the products. The attack of *Rhynchosporium* in rye increased to 10% on the upper leaves at GS 77.

Winter barley

Powdery mildew (*Blumeria graminis*). A minor attack of mildew developed in the cultivar Matros during the growing season; due to the low level of attack, the opportunities for ranking the performances of the products were limited.

Brown rust (*Puccinia hordei*). Brown rust was the prevalent disease in winter barley in 2019. From early spring, this disease was present at most sites and in most cultivars. In the field trial, Kosmos, Memento and Celtic developed severe attacks, which gave good opportunities for ranking the efficacy of the different fungicides in 2019. The average attack of brown rust in this year's trial at AU reached a level of 32% on leaf 2 at GS 71-75.

***Rhynchosporium* (*Rhynchosporium commune*).** In general, the level of *Rhynchosporium* attack in winter barley was low in 2019. A minor attack of *Rhynchosporium* developed in the cultivar Frigg but the year provided only limited opportunities for ranking the performance of products. The average attack of *Rhynchosporium* reached a level of 3% at GS 71-75.

Net blotch (*Drechslera teres*). A minor to moderate attack of net blotch developed during the season in winter barley trials in the cultivar Celtic. Opportunities for ranking fungicide performances were limited. In trials with net blotch, the average attack in the susceptible cultivars reached a level of 5% on leaf 2 at GS 71-75.

Ramularia leaf spot (*Ramularia collo-cygni*). In general, attacks of *Ramularia* developed late in the season and few cultivars showed assessable symptoms of *Ramularia*. Trials in the cultivars Kosmos, Memento and Celtic developed moderate to severe attacks. In specific *Ramularia* trials, the average attack reached a level of 30% on the flag leaf and 50% on leaf 2 at GS 73-77. The severe attack of *Ramularia* gave good opportunities for ranking fungicide performances.

Spring barley

Powdery mildew (*Blumeria graminis*). The attacks in 2019 were limited to the cultivar Milford, which does not carry mlo resistance. Attacks in trials with attack of mildew provided possibilities for ranking the performances of fungicide products. Attacks of powdery mildew reached a level of 10% at GS 57-65 on leaves 2-3.

Net blotch (*Drechslera teres*) was common in fields in 2019. In general, attacks were moderate to high and in some susceptible cultivars, the attacks of net blotch were assessed as severe. In 2019, both Chapeau and Laurikka developed moderate to severe attacks. In the trials, both cultivars provided good possibilities for ranking the performances of the fungicides. Attacks of net blotch in Chapeau and Laurikka reached an average level of 27% on leaf 2 at GS 73-75.

Brown rust (*Puccinia hordei*). In all trials, severe attacks developed in 2019 and in particular in the cultivars Chapeau, Milford, KWS Irina and Laurikka. This provided a good opportunity for ranking fungicide performances. The attack at Flakkebjerg reached an average level of 30% on leaf 2 at GS 73-77.

Ramularia leaf spot (*Ramularia collo-cygni*). *Ramularia* was present in the cultivars Chapeau, Milford and KWS Irina in 2019. *Ramularia* developed late in the season. In the trials, all cultivars provided good opportunities for ranking the performances of the products. The attack of *Ramularia* reached an average level of 24% on leaf 2 at GS 73-77.

Yield increases in fungicide trials in cereals

Harvest conditions were good in 2019. In general, the harvest of winter barley was carried out without problems and high quality harvest products were sampled during July. Winter barley trials were irrigated once in May and showed fine performances due to sufficient precipitation during the growing season. The winter barley wilted a bit early due to high infection of brown rust. Yields reached 60-85 dt/ha. The general yield response was high for winter barley. The severe attack of especially brown rust was the reason for the yield increases. Standard treatments yielded an average increase of 11.6 dt/ha.

The weather in August was more inconsistent as regards precipitation but most trial samples were of good quality. The winter wheat trials generally yielded well due to a good response to the fungicide treatments and sufficient precipitation. Winter wheat trials yielded in the range of 70-120 dt/ha with an average yield of 90 dt/ha. Yield increases following fungicide treatments in winter wheat were significant and most trials and fungicide treatments were profitable (Table 1). Even for Informer, which was the most resistant cultivar, a yield increase of more than 10 dt/ha was recorded.

Spring barley developed well during the season and no irrigation was required. A short period with very high temperatures did, however, stop crop growth earlier than expected due to fast senescence. This had an impact on the yield levels, which stayed moderate around 60-70 dt/ha. The yield response to fungicides in spring barley was also significant. The early severe attack of particularly net blotch and brown rust in spring barley gave significant yield responses in the trials. Standard treatments in spring barley resulted in an yield increase of 14.3 dt/ha.

Table 1. Yield increases (dt/ha) for disease control in fungicide trials. The results are from the reference treatments which typically are two treatments per season. Numbers in brackets indicate the number of trials. Data originate from SEGES and AU Flakkebjerg trials.

Year	Winter wheat	Spring barley	Winter barley
2005	6.4 (126)	5.4 (43)	4.6 (60)
2006	8.0 (106)	3.3 (63)	5.1 (58)
2007	8.5 (78)	7.2 (26)	8.9 (13)
2008	2.5 (172)	3.1 (29)	3.2 (36)
2009	6.3 (125)	5.1 (54)	6.3 (44)
2010	6.6 (149)	5.6 (32)	5.9 (34)
2011	7.8 (204)	3.9 (43)	4.3 (37)
2012	10.5 (182)	6.7 (38)	5.1 (32)
2013	10.3 (79)	5.2 (35)	5.5 (27)
2014	12.0 (82)	3.0 (19)	4.1 (18)
2015	10.9 (73 SEGES + 29 AU)	9.1 (20)	7.3 (19)
2016	10.9 (59 SEGES + 34 AU)	8.0 (16 SEGES + 13 AU)	4.0 (11 SEGES + 10 AU)
2017	15.0 (94 SEGES + 55 AU)	10.4 (11 SEGES + 16 AU)	11.9 (11 SEGES + 14 AU)
2018	4.3 (24 SEGES + 21 AU)	3.6 (4 SEGES + 12 AU)	7.5 (2 SEGES + 12 AU)
2019	15.4 (28 SEGES + 24 AU)	11.6 (10 SEGES + 9 AU)	11.5 (6 SEGES + 6 AU)

Maize

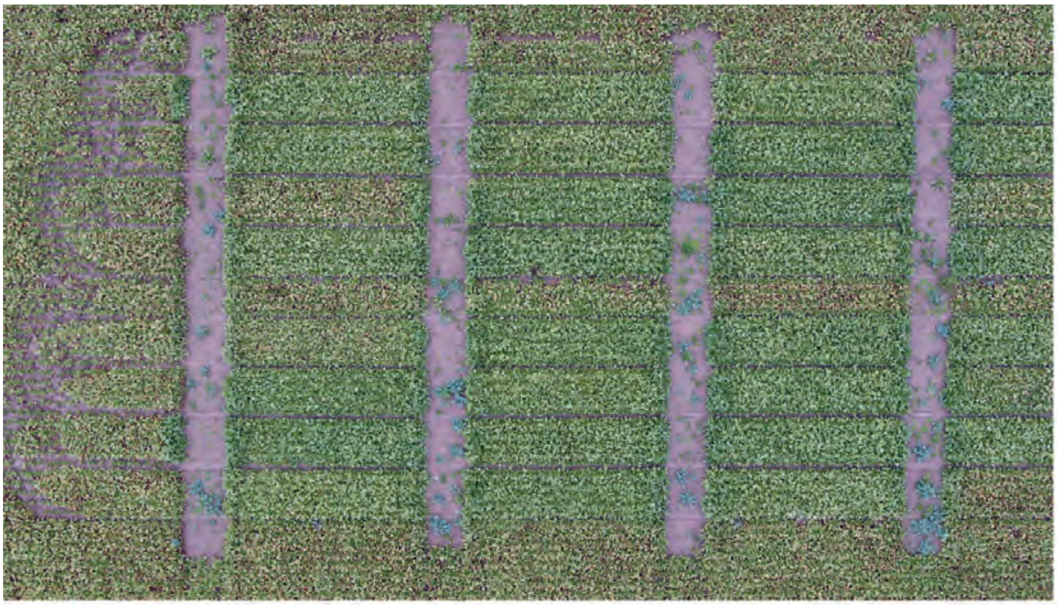
Eye spot (*Kabatielle zeae*). Minor and insignificant attacks of eye spot developed in the trials during the season. Attacks increased slowly during the summer, but due to the low level of the attack, the assessments gave poor opportunities for distinguishing between the performance of the products. The attacks on the lower leaves never increased above 17%. The attacks on the upper leaves increased to 8% in late September but had no significant effects on yield parameters.

Sugar beet

The season was very conducive to attacks of particularly mildew (*Erysiphe betae*) and rust (*Uromyces betae*). In September, also minor attacks of *Ramularia betae* and *Cercospora beticola* were found in the trials. Clear differences between treatments could be seen from drone photos taken late in the season.

Grass seed - ryegrass

A moderate attack of crown rust developed in ryegrass. The attack was well controlled by one treatment. No rust attacks developed during the summer season in *Poa pratensis*, where rust first appeared in the autumn. Trials with red fescue showed attacks of leaf spot diseases, but these symptoms were not controlled by spraying.



II Disease control in cereals

Lise Nistrup Jørgensen, Thies Marten Heick, Niels Matzen, Hans-Peter Madsen, Helene Saltoft Kristjansen, Sidsel Kirkegaard & Anders Almskou-Dahlgaard

Introduction

In this chapter, field trials with fungicides in cereals carried out in 2019 are described in brief and results are summarised. In graphs or tables are also included results from several years if the trial plan concerns several years. Included are the main results on major diseases from both protocols with new fungicides and protocols in which products applied at different dose rates and timings are compared. Some of the trial results are used as a part of the Biological Assessment Dossier, which the companies have to prepare for new products or re-evaluations of old products. Other parts of the results aim at solvingquestions related to optimised use of fungicides in common control situations for specific diseases.Apart from the tables and figures providing primary data, a few comments are given along with some concluding remarks. The majority of data summarised in this chapter are funded by the companies Bayer, BASF, Corteva, Adama and Syngenta, who pay for having their products tested. BASF has financed the activity organised under the umbrella of Eurowheat. The activity is organised by the Department of Agrocology at Aarhus University (AU) in collaboration with different organisations in other countries. Results from the SPOT-IT project are presented; this activity is financed by GUDP and activities are carried out in collaboration with other partners in Scandinavia and the Baltic States. All data from the project are analysed by AU. In several trial plans, individual treatments are included based on AU's initiative.

Methods

All field trials with fungicides are carried out as GEP trials. Most of the trials are carried out as field trials at AU Flakkebjerg. However, some trials are also sited in farmers' fields, at Jyndevad Experimental Station or near Horsens in collaboration with a GEP trial unit at the advisory group LMO. Trials are carried out as block trials with randomised plots and four replicates. Plot size varies from 14 to 35 m^2, depending on the individual unit's equipment. The trials are sited in fields with different moderately to highly susceptible cultivars, specifically chosen to increase the chances of disease development. Spraying is carried out using a self-propelled sprayer using atmospheric air pressure. Spraying is carried out using 150 or 200 l water per ha and a nozzle pressure of 1.7-2.2 bar.

Attacks of diseases in the trials are assessed at approximately 10-day intervals during the season. Per cent leaf area attacked by the individual diseases is assessed on specific leaf layers following EPPO guideline 1/26 (4) Foliar and ear diseases in cereals. At the individual assessments the leaf layer that provides the best differentiation of the performances of the fungicides is chosen. In most cases, this is the two upper leaves. In this publication, only some assessments are included - mainly the ones giving the best differentiation of the efficacy of the products.

Nearly all trials are carried through to harvest, and yield is adjusted to 15% moisture content. Quality parameters like specific weight, % protein, % starch and % gluten content are measured using NIT instruments (Foss, Perten) and thousand grain weight (TGW) is calculated based on 250 grains counted. In spring barley, which can potentially be used for malting, grain size fractions are also measured. For each trial, LSD95 values or specific letters are included. Treatments with different letters are significantly different, using the Student-Newman-Keuls model. When a net yield is calculated, it is converted to hkg/ha based on deducting the cost of used chemicals and the cost of driving. The cost of driving has been set at DKK 70 and the cost of chemicals extracted from the database at SEGES. The grain price used is 120 DKK/hkg (= dt).

1. Control of diseases in winter wheat

Inatreq (fenpicoxamid)

Inatreq (fenpicoxamid) represents a new mode of action for control of *Septoria* attack in winter wheat. The product is expected to reach the market in 2021. Inatreq has been tested as a solo product (GF-3308) and in mixture with prothioconazole (Univoq = GF-3307). The product has in wheat trials provided good control applied at different timings. Dose rates between 1.0 l and 2.0 l per ha have provided robust control and, in many cases, superior control and yield responses compared with current Danish standards. The product has shown both preventive and curative control.

Results with Univoq

Two trials were carried out in the cultivars Hereford (Flakkebjerg) and Kalmar (Horsens). The trials were treated at six different timings either as solo treatments or as combined strategies with Univoq (Figure 1; Table 1). At four timings, three different dose rates were tested and a clear dose-effect was seen. In two of the treatments an early treatment was also applied. Treatments at GS 37 provided the best control of *Septoria* on 2nd leaf while treatments at GS 39 provided the best control on flag leaves. Double treatments – having applied a low rate of Prosaro EC 250 at GS 30 – only lifted the control levels marginally compared to having just one treatment at a critical timing. Application at GS 33 and 51 did both generally provide too poor control of *Septoria* on the two upper leaves indicating that an increased dose rate will not compensate for less optimal timing. In this year's trials, the application at a full flag leaf emergence – GS 39 – provided the best yield responses, although the responses were not significantly better than the responses from the treatment at GS 37. At most timings, a clear dose-response was seen between using 0.75, 1.0 and 1.25 l/ha.

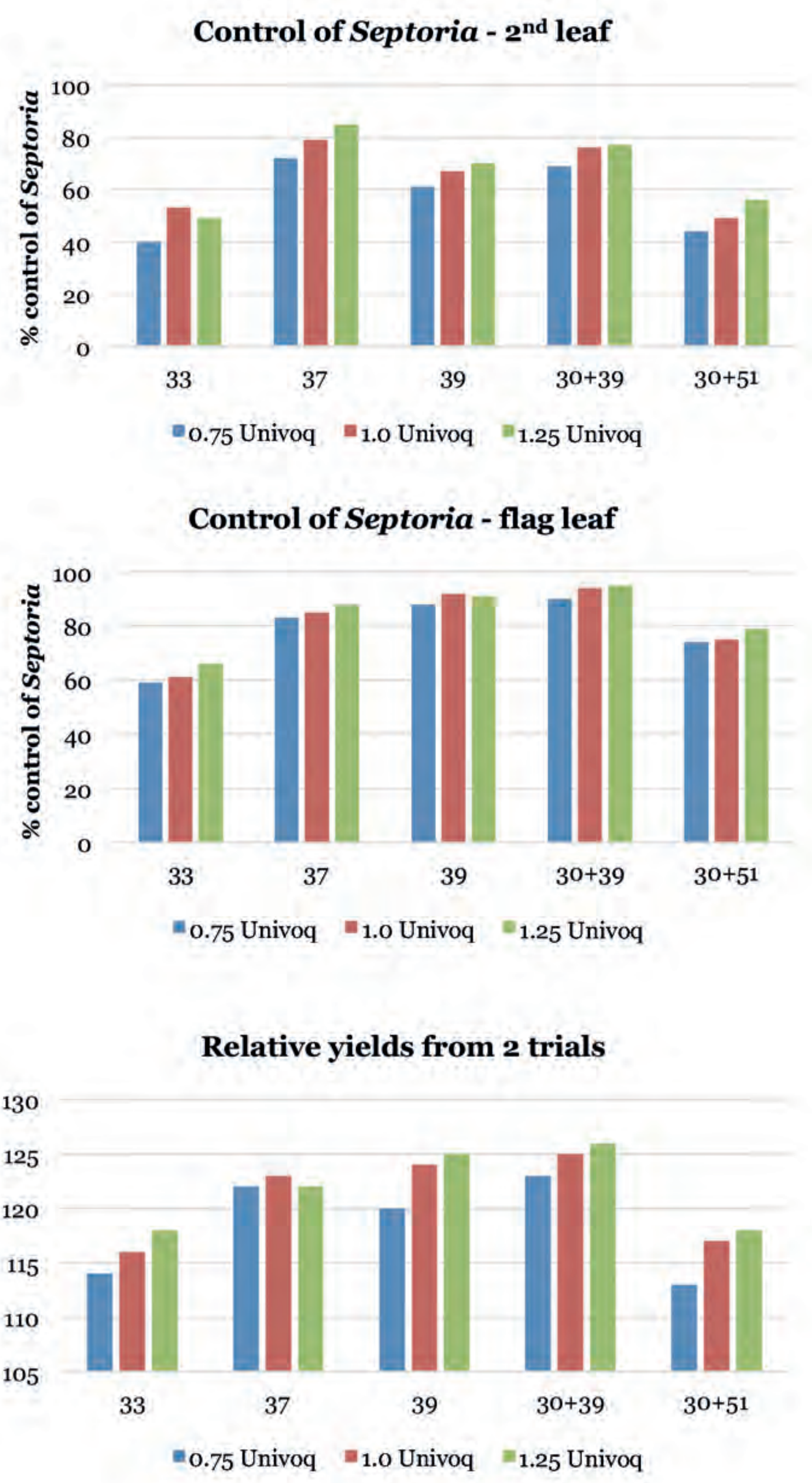
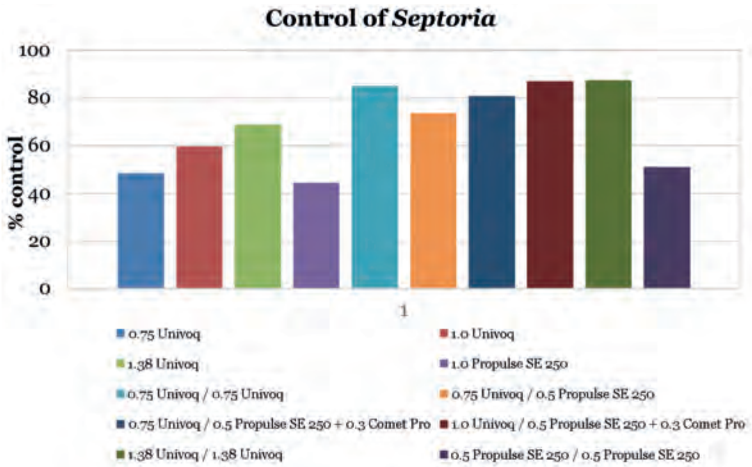


Figure 1. Control of *Septoria* in two trials testing different timings and dose rates (l/ha) of Univoq (19334).

Table 1. Application timings. Effects on *Septoria* and yield responses following 1-3 treatments in wheat (19334).

Treatments, l/ha						% *Septoria*	% *Septoria*	% GLA	Yield & yield increase hkg/ha	TGW g
GS 30	GS 33	GS 37	GS 39	GS 45	GS 51-55	GS 73 L1	GS 73 L2	GS 83 L 2		
1.	Untreated					53.2	76.9	3.8	75.3	36.2
2.	0.75 GF-3307				0.4 Propulse + 0.3 Comet Pro	38.9	38.9	31.3	10.1	38.9
3.		0.75 GF-3307			0.4 Propulse + 0.3 Comet Pro	40.1	40.1	42.6	15.7	40.1
4.			0.75 GF-3307		0.4 Propulse + 0.3 Comet Pro	38.5	38.5	50.7	14.9	38.5
5. 0.3 Prosaro			0.75 GF-3307		0.4 Propulse + 0.3 Comet Pro	39.9	39.9	45.0	16.3	39.9
6. 0.3 Prosaro				0.75 GF-3307 + 0.3 Comet Pro		39.2	39.2	38.8	9.6	39.2
7.	1.0 GF-3307				0.4 Propulse + 0.3 Comet Pro	38.9	38.9	33.2	11.6	38.9
8.		1.0 GF-3307			0.4 Propulse + 0.3 Comet Pro	39.7	39.7	34.0	17.0	39.7
9.			1.0 GF-3307		0.4 Propulse + 0.3 Comet Pro	39.9	39.9	62.5	17.6	39.9
10. 0.3 Prosaro			1.0 GF-3307		0.4 Propulse + 0.3 Comet Pro	40.7	40.7	63.8	17.8	40.7
11. 0.3 Prosaro				1.0 GF-3307 + 0.3 Comet Pro		39.1	39.1	51.3	12.2	39.1
12.	1.25 GF-3307				0.4 Propulse + 0.3 Comet Pro	39.0	39.0	34.4	12.6	39.0
13.		1.25 GF-3307			0.4 Propulse + 0.3 Comet Pro	40.9	40.9	40.0	16.2	40.9
14.			1.25 GF-3307		0.4 Propulse + 0.3 Comet Pro	39.9	39.9	68.8	18.6	39.9
15. 0.3 Prosaro			1.25 GF-3307		0.4 Propulse + 0.3 Comet Pro	41.8	41.8	63.8	19.3	41.8
16. 0.3 Prosaro				1.25 GF-3307 + 0.3 Comet Pro		39.1	39.1	50.7	13.4	39.1
No. of trials						2	2	2	2	2
LSD_{95} (excl. untr.)									4.5	2.1

In another trial plan (19333) with three trials, efficacy and yield responses following either one treatment or two treatments were compared testing different dose rates of Univoq alone or in combination with the current standard - Propulse SE 250 (Figure 2; Table 2). The trials were carried out in cultivars with different degrees of susceptibility/resistance: Informer (less susceptible), Torp (moderately susceptible) and Hereford (very susceptible). Overall, two treatments provided better control and higher yields compared with single treatments. Univoq generally provided better control than Propulse and a clear dose-response from Univoq was seen both when one or two treatments were applied. Minor differences were seen between using 0.75 l/ha Univoq and 1.38 l/ha Univoq in double strategy treatments.



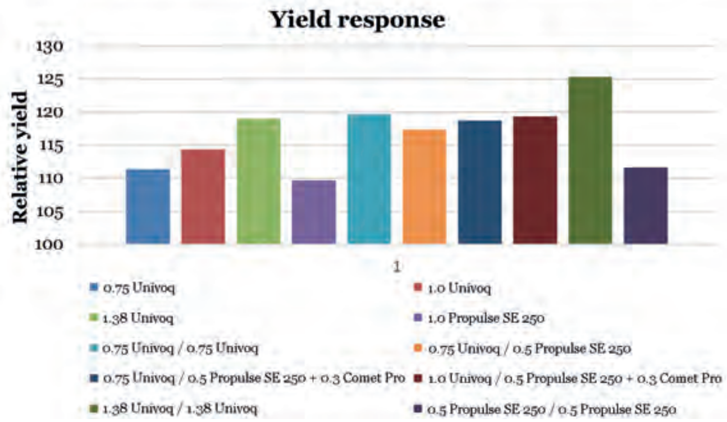


Figure 2. Control of *Septoria* on flag leaves and relative yield responses following either one treatment (GS 41-45) or two treatments (GS 37-39 & GS 61-65). Average data from 3 trials (19333).

Table 2. Application timings. Effects on *Septoria* and yield responses following 1-2 treatments in wheat (19333). Average of three trials.

Treatments, l/ha				% *Septoria* GS 71-73 L 2	% *Septoria*	Yield & yield increase hkg/ha	Net yield hkg/ha	TGW
GS 33	GS 37-39	GS 45-51	GS 55-61					
1. Untreated				41.1	47.5	86.2	-	38.5
2.		Univoq 0.75		22.1	8.5	9.0	5.8	41.1
3.		Univoq 1.0		17.0	5.3	12.1	8.0	42.5
4.		Univoq 1.0	Comet Pro 0.3	14.9	4.5	15.2	9.6	42.5
5.		Univoq 1.38		14.7	3.3	16.5	11.1	42.1
6.		Propulse SE 250 1.0		23.7	16.8	8.4	4.4	40.2
7. Univoq 0.75		Univoq 0.75		15.0	4.0	16.4	10.0	42.6
8.	Univoq 0.75		Univoq 0.75	7.1	1.3	16.8	10.4	42.2
9.	Univoq 0.75		Propulse SE 250 0.5	13.5	6.5	14.6	9.1	42.3
10.	Univoq 0.75		Propulse SE 250 + Comet Pro 0.5 + 0.3	10.1	4.8	16.0	9.6	41.9
11.	Univoq 1.0		Propulse SE 250 + Comet Pro 0.5 + 0.3	4.5	1.0	16.7	9.4	42.4
12.	Univoq 1.38		Univoq 1.38	6.0	1.0	21.8	11.0	43.8
13.	Propulse SE 250 0.5		Propulse SE 250 0.5	24.6	17.5	10.3	5.7	40.4
No. of trials				3	1	3	3	3
LSD_{95} (excl. untr.)					9.4	3.1		2.0

In a trial in Hereford, three different water volumes (100, 150 and 200 l/ha) were tested to see whether the efficacy of Univoq was influenced by the water volume applied per ha. The results are summarised in Table 3 and Figure 3. A clear difference was seen between the effects from the two tested fungicide rates, but no significant differences were seen between the tested water volumes, which indicates that the product is flexible concerning the chosen water volume.

Table 3. Effect of Univoq and Propulse SE 250 using different water volumes for control of *Septoria* in wheat, one trial (19332).

Treatments, l/ha		% *Septoria*				Yield & yield increase hkg/ha	TGW g
GS 32 (A)	GS 49-55 (B)	GS 73 L 1	GS 73 L 2	GS 75 L1	GLA L 1		
1. Propulse SE 250 (100 l/ha) 0.5	Propulse SE 250 (100 l/ha) 0.5	16.0	67.5	91.3	4.0 c	+9.7	35.7
2. Propulse SE 250 (200 l/ha) 0.5	Propulse SE 250 (200 l/ha) 0.5	22.3	77.5	92.5	3.3 c	+10.6	36.1
3. Univoq (100 l /ha) 0.7	Univoq (100 l/ha) 0.7	4.5	33.8	28.8	62.5 ab	+20.3	39.5
4. Univoq (100 l/ha) 1.38	Univoq (100 l/ha) 1.38	2.0	18.0	11.8	80.0 a	+27.6	42.4
5. Univoq (150 l/ha) 0.7	Univoq (150 l/ha) 0.7	6.0	35.0	38.8	53.8 b	+18.7	38.9
6. Univoq (150 l/ha) 1.38	Univoq (150 l/ha) 1.38	2.5	20.5	13.0	78.8 a	+23.9	41.4
7. Univoq (200 l/ha) 0.7	Univoq (200 l/ha) 0.7	7.5	50.0	46.3	46.3 b	+18.9	39.7
8. Univoq (200 l/ha) 1.38	Univoq (200 l/ha) 1.38	3.0	23.8	13.8	76.3 a	+24.6	41.1
9. Untreated	Untreated	50.0	85.0	93.8	2.0	69.7	33.3
LSD_{95}		12.5	21.5	21.1	22.9	5.1	2.3

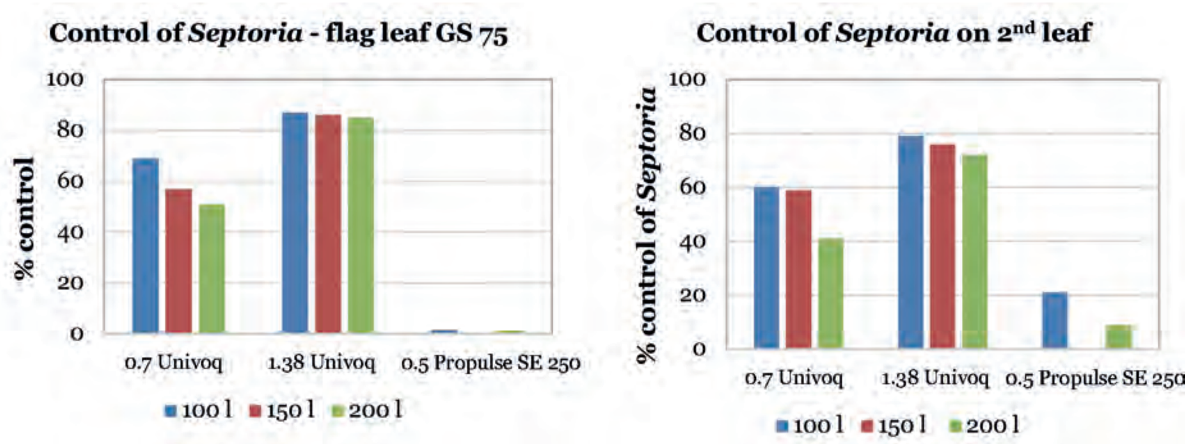


Figure 3. Control of *Septoria* using different water volumes (100, 150 and 200 l/ha). Treatments were applied at GS 32 and 49-55 (19332).

Results with Balaya and Revysol

Revysol (mefentrifluconazole) is a new azole from BASF, which has shown good control of particularly *Septoria* attack in winter wheat. The product is expected to reach the market in 2020. Revysol has been tested as a solo product and also in combination with other actives. Dose rates between 0.75 and 1.5 l per hectare have provided robust control and generally superior control and yield responses compared with other tested azoles and current Danish standards.

Revysol has been tested at AU Flakkebjerg for several years and shown very good control of particularly Septoria tritici blotch. The product is developed by BASF and is an innovative azole fungicide, which provides long-lasting and reliable control of *Septoria*. The product is an azole but has its own sub-group and has a molecular structure that provides a more flexible docking at the target site. The product is now listed in the EU and authorised in several of our neighbouring countries. It is expected to reach the Danish market by 2020.

One trial was carried out in winter wheat cv. Cleveland comparing the efficacy of Revysol with Proline EC 250 (Table 4). In the trial a moderate attack of *Septoria* developed, and clear and statistically significant differences were seen between control effects and yield increases of the two actives. The plan was identical to the plan tested also in 2017 and 2018.

Table 4. Control of *Septoria* and yield responses from treatments in winter wheat. One trial in 2019 (19331).

Treatments, l/ha		% *Septoria*			% GLA	Yield & yield increase hkg/ha
GS 32 (A)	GS 49-55 (B)	GS 65 L 2	GS 73 L 1	GS 73 L2	GS 75 L 1	
1. Untreated	Untreated	11.3	12.0	37.5	0.0	74.5
2. Proline EC 250 0.4	Proline EC 250 0.4	10.5	4.3	20.0	10.0	7.7
3. Proline EC 250 0.8	Proline EC 250 0.8	6.8	2.5	12.5	15.0	11.6
4. Revysol 0.75	Revysol 0.75	2.0	0.2	2.8	87.0	22.2
5. Revysol 1.5	Revysol 1.5	0.6	0.0	1.5	93.0	24.8
6.	Proline EC 250 0.8	9.3	3.3	13.8	30.0	7.9
7.	Revysol 1.5	3.0	0.2	2.5	90	16.9
No. of trials		1	1	1	1	1
LSD_{95}		4.3	2.3	5.5	8.5	8.9

Figure 4 summarises the effect and yields from the three seasons. The overall effects and relationships were very similar for the three seasons. At its best, Proline EC 250 provided approximately 40% control, while Revysol provided 80-90% control. This resulted in a yield difference above 1 tonne/ha between the two solutions.

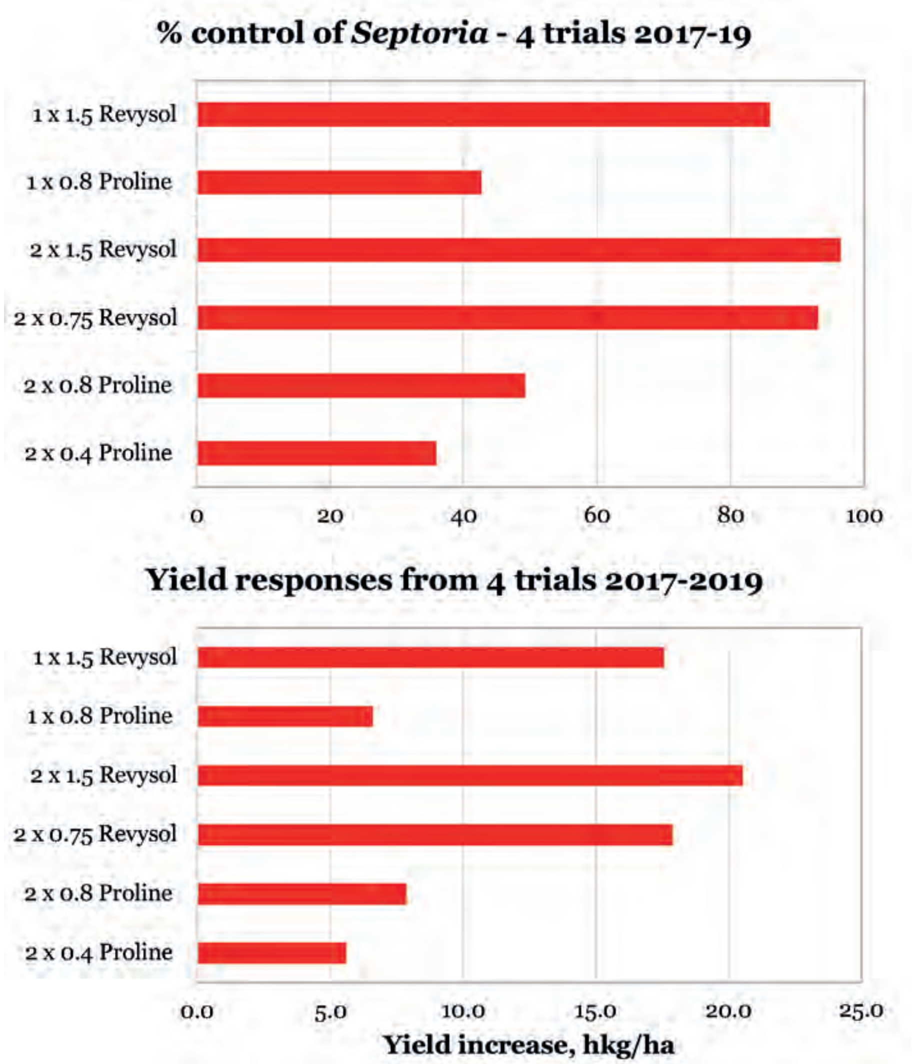


Figure 4. Control of *Septoria* and yield response from one or two treatments with Revysol and Proline EC 250. Results from 2017-2019. Four trials. LSD_{95} = 3.02.

Comparison of Revysol solutions with European standard solutions. In one trial, most of the important current European solutions for control of *Septoria* were tested and compared using full or half rates (19330). The trial was carried out in winter wheat cv. Cleveland with severe attacks of *Septoria*. Revytrex and the mixture Revysol + Imtrex provided the best control and also the highest yield increases (Table 5). Several of the treatments had a clear drop in efficacy when the dose rate was reduced from full to half rate (Figure 5). This was similarly seen for the yield responses. As most of these solutions are not available on the Danish market, net yields from treatments were not calculated.

Table 5. Effect of applications for control of *Septoria* in wheat. One trial (19330). All treatments were given a cover spray using 0.5 l/ha Ceando at GS 33-37.

Treatments, l/ha	% *Septoria*			% GLA	Yield & yield increase hkg/ha
GS 55	GS 69 L1	GS 69 L2	GS 75 L1	GS 77 L1	
1. Untreated	13.5	55.0	71.5	0.3	74.3
2. Revytrex 1.5	0.5	5.5	8.3	76.3	26.8
3. Revytrex 0.75	0.6	12.5	17.5	32.5	21.1
4. Balaya + Curbatur 1.0 + 0.5	1.1	14.3	23.8	41.3	19.9
5. Balaya + Curbatur 0.5 + 0.25	3.5	27.5	52.5	6.3	10.2
6. Balaya 1.5	1.4	10.5	18.8	58.8	18.6
7. Balaya 0.75	2.5	14.8	45.0	18.8	17.9
8. Balaya + Imtrex 1.0 + 1.0	0.6	5.8	7.5	71.3	23.0
9. Balaya + Imtrex 0.5 + 0.5	1.1	14.0	20.0	30.0	19.1
10.Balaya + Entargo 1.0 + 0.5	2.3	14.8	22.5	45.0	18.1
11. Balaya + Entargo 0.5 + 0.25	3.5	21.8	36.3	20.0	12.3
12. Elatus Era 1.0	1.8	15.0	22.5	63.8	17.1
13. Elatus Era 0.5	2.8	25.0	30.0	25.0	13.8
14. Ascra Xpro 1.5	0.9	5.3	12.5	68.8	21.0
15. Ascra Xpro 0.75	1.8	11.8	26.3	28.8	18.7
16. Propulse SE 250 1.0	5.3	31.3	80	1.0	12.5
17. Propulse SE 250 0.5	8.5	42.5	87.5	0.3	7.5
LSD_{95}	1.8	10.0	18.5	16.0	5.7

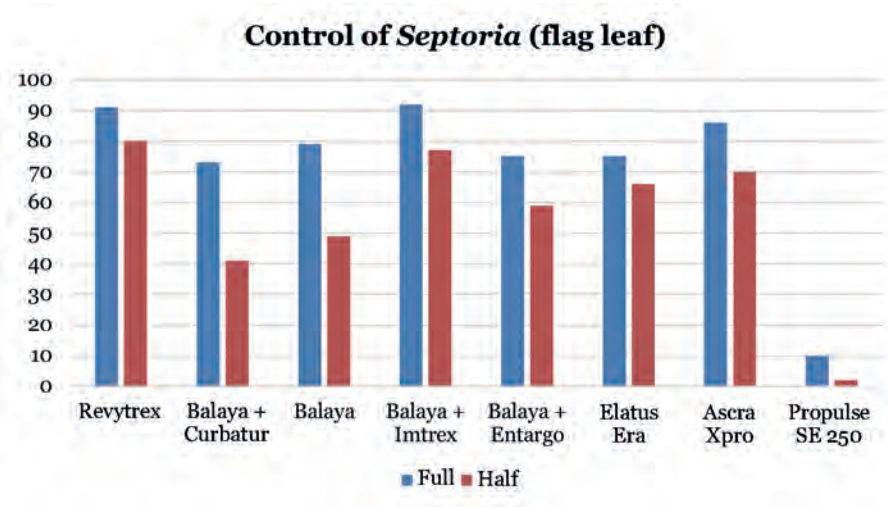


Figure 5. Control of *Septoria* following one treatment at GS 39-45 with different broad-spectrum solutions in winter wheat cv. Cleveland, trial 19330. All plots were treated with a cover spray at GS 32 using 0.5 l/ha Ceando.

As part of the EUROwheat activity – in which trials are located in different countries following the same protocol (Figure 6) – one trial was placed at Flakkebjerg in the cultivar Kalmar. The Danish trial developed moderate but still significant attacks of *Septoria* and yellow rust (Table 6). All treatments with the exception of Proline EC 250 provided quite similar and comparable control of *Septoria*. All treatments gave good control of yellow rust at similar levels, but Elatus Era gave slightly better control than the other products. The trial was treated on 14 May and the efficacy on the flag leaf reflected that the flag leaf was not fully unfolded at the time of application. Similar trials were conducted in other countries and showed distinct differences in levels of control depending on the locality. The ranking was similar but the control levels were clearly and consistently higher in Central Europe compared with Western Europe (Figure 7). One trial from the UK did not provide useable data.

Figure 6. Locations of eight trials carried out in 2019.

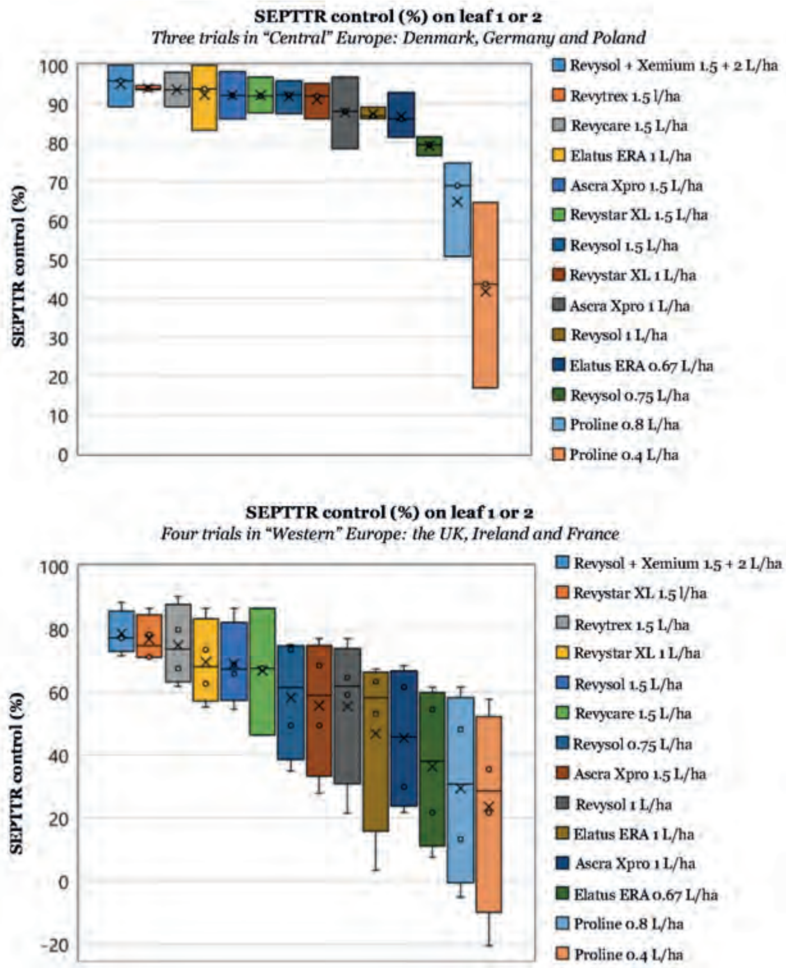


Figure 7. Control of *Septoria*. Most reliable effective assessments on leaf 1 or 2 were chosen. Assessments were carried out at GS 69-75, 31-52 DAA. Trials were divided into those located in "Central Europe" – three trials, or "Western Europe" – four trials.

Table 6. Effect of applications for control of *Septoria* in wheat. One trial (19341). Eurowheat.

Treatments, l/ha		% *Septoria*		% yellow rust	% GLA	Yield & yield increase hkg/ha
GS 37-39		GS 75 L2	GS 69 L1	GS 75 L1	GS 75 F1	
1. Untreated		81.3	10.5	22.5	28.8	74.0
2. Revysol	0.75	15.0	4.8	8.8	61.3	5.0
3. Revysol	1.0	11.3	4.0	11.3	63.8	8.4
4. Revysol	1.5	6.3	2.5	11.3	67.5	7.2
5. Proline	0.4	67.5	3.8	10.0	45.0	2.7
6. Proline	0.8	40.0	2.8	8.0	53.8	5.9
7. Revystar XL	1.0	11.3	3.3	11.3	66.3	6.0
8. Revystar XL	1.5	10.0	4.0	12.5	72.5	5.0
9. Revytrex	1.5	5.0	4.5	11.8	75.0	6.0
10. Revysol + Xemium	0.75 + 0.4	8.8	5.0	13.8	71.3	6.3
11. Elatus Era	0.67	11.3	2.0	6.3	72.5	7.6
12. Elatus Era	1.0	5.0	1.3	4.5	80.0	10.0
13. Ascra Xpro	1.0	17.5	3.5	11.3	71.3	4.0
14. Ascra Xpro	1.5	11.3	3.8	12.5	68.8	5.1
15. Revycare/Balaya	1.5	8.8	4.3	10.0	71.3	8.0
LSD_{95}		9.1	2.3	5.2	8.1	4.4

Screening of azole efficacy against *Septoria* in winter wheat

Septoria attacks in 2019 were significant in many trials due to conducive conditions. Severe attacks were seen on both second leaf and flag leaves. In line with previous seasons, the efficacy of prothioconazole and epoxiconazole again showed a reduced control compared with the efficacy in 2010-2012. The data from 2019 showed that the efficacy had reached a plateau of around 40-50% control. The efficacy of tebuconazole and metconazole performed slightly better than the other azoles.

Comparison of azoles (19329)

Two trials testing different azoles were carried out in the cultivars KWS Cleveland at AU Flakkebjerg and Hereford at Horsens. The trials included two treatments using two half rates applied at GS 33 and 45-51. Both trials developed significant attacks of *Septoria* and could be used for the ranking of the efficacy of the products. The ranking in efficacy is shown in Figure 8 and Table 7. The new azole product, Revysol, has been included in the testing since 2017. In all three seasons, this product showed outstanding control (approx. 90%) compared with the old solo azoles as well as the azole mixtures, which only provided *Septoria* control in the range of 30-50%. In the 2019 season, the performance of epoxiconazole was slightly inferior to that of prothioconazole at both sites. Generally, both epoxiconazole and prothioconazole are known to be significantly influenced by the changes in the CYP51 mutation profile. Data from all azoles across several years have shown a clear drop in efficacy from all azoles. Compared with previous years, the last four seasons showed reduced control from epoxiconazole and prothioconazole. The data from 2019 do, however, indicate that the products have reached a plateau, and a few of the azoles even seem to have performed a little better.

Looking at the performance of azoles during a longer time course, the drop in performance began in 2014, was less pronounced in 2015 but continued in 2016 (Figure 9). Some of the yearly variation can be linked to the levels of attack, but as discussed in chapter IV the *Septoria* populations have changed and do now include many more mutations than previously. The mutations are known to influence the sensitivity to azoles in general but are also seen to influence specific azoles differently. The drop in efficacy of tebuconazole has been known since about 2000. However, the drop in performance from tebuconazole used alone has changed since 2017, when tebuconazole was seen as the azole not dropping further. In fact, in 2019 tebuconazole and difenoconazole gained slightly better efficacy, which is seen as linked to higher proportions of D134G and V136A in the *Septoria* population. In both 2017 and 2018, it was seen that the mixtures prothioconazole + tebuconazole performed best as the two actives are seen to support each other when it comes to controlling the different strains with different mutations. However, this year's trials showed better control from tebuconazole alone compared to the mixture with Prosaro EC 250.

2 x 0.4 l/ha Proline EC 250.

2 x 0.75 l/ha Revysol.

Table 7. Attack of *Septoria* and yield responses from different treatments in winter wheat. Average of two trials in 2019 (19329).

Treatments, l/ha		% *Septoria*				Yield & yield increase hkg/ha	Net yield hkg/ha
GS 33	GS 51-55	GS 73 L1	GS 73 L2	GS 77 L1	GLA L3		
1. Rubric 0.5	Rubric 0.5	13.8	34.4	55.0	17.5	5.5	1.0
2. Proline EC 250 0.4	Proline EC 250 0.4	14.6	33.8	26.3	15.5	4.3	-0.2
3. Juventus 90 0.5	Juventus 90 0.5	9.8	24.7	15.0	22.5	7.8	4.6
4. Folicur EW 250 0.5	Folicur EW 250 0.5	10.0	25.3	17.5	22.5	9.1	5.7
5. Proline EC 250 0.4	MCW 406-s 0.25	9.8	30.0	26.3	15.5	7.8	-
6. Prosaro EC 250 0.5	Prosaro EC 250 0.5	8.9	25.1	40.0	17.5	8.5	4.4
7. Proline EC 250 0.4	Amistar Gold 0.5	12.0	29.4	31.3	15.0	7.9	3.6
8. Revysol 0.75	Revysol 0.75	4.4	8.8	11.3	35.0	21.5	-
9. Untreated	Untreated	32.3	47.9	67.5	0.0	68.5	-
No. of trials		2	2	1	1	2	2
LSD_{95}				12.7	9.5	3.8	-

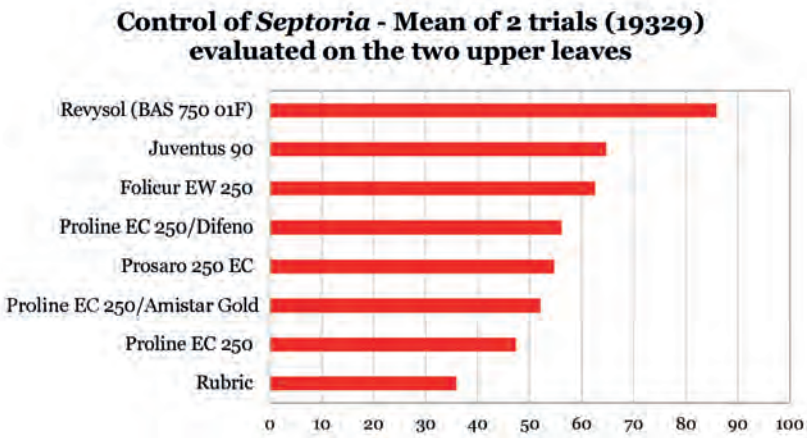


Figure 8. Per cent control of *Septoria* using two half rates of different azoles. Average of two applications at GS 33-37 and 51-55. Untreated with 54% *Septoria* attack on the two upper leaves. The data originate from two trials in 2019 (19329).

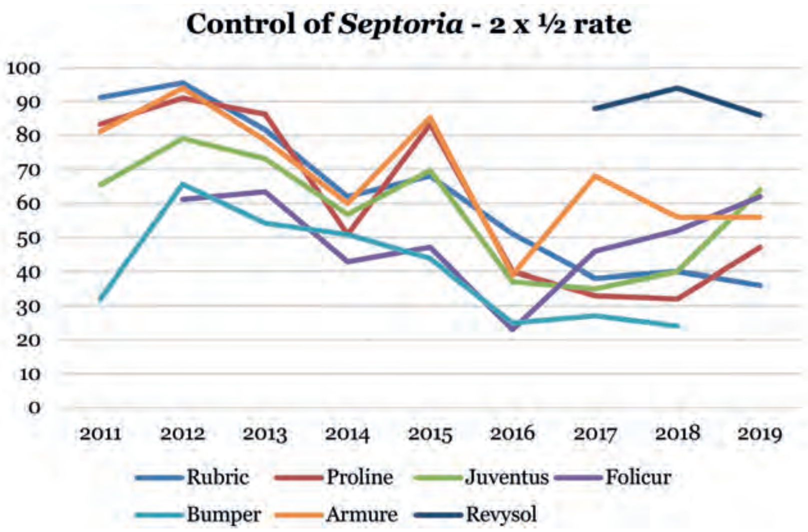


Figure 9. Per cent control of *Septoria* using two half rates of different azoles. Average of two applications at GS 33-37 and 51-55. Development of efficacy across years.

Comparison of available solutions for ear treatments in winter wheat (19325)

In line with trials from previous years, treatments with different fungicides were tested when applied during heading (GS 45-55) (Table 8). Three trials were carried out, but only two were usable and they were both placed at Flakkebjerg in Hereford and Cleveland. The Cleveland trial was unfortunately also hit by late attacks of take-all, which made the yield data too uncertain. A cover spray was applied at GS 32 using Prosaro EC 250 (0.35 l/ha).

Septoria developed, providing a significant attack on both 2nd and flag leaves. The control of *Septoria* on the upper leaves varied between 45 and 95% control (Figure 10). The products Balaya and Univoq with new actives provided the best control, while the older chemistry with Viverda and Propulse SE 250 clearly provided inferior control. As it was also seen in 2018, Propulse SE 250 benefited from mixing with Folicur Xpert. The benefit from adding SDHI, as seen in Propulse SE 250 and Viverda, was clear when compared to using azoles alone as in Prosaro EC 250 and Amistar Gold. In Hereford, the *Septoria* attack was severe and yield responses were similarly high, reflecting the levels of control. The better treatments, which all included new chemistry, increased yields by more than 2 tonnes/ha, while the older and weaker chemistry only increased yields by 5-10 dt/ha (Figure 11). The early season treatment (GS 32) increased yields by 3.6 dt/ha. Net yields were positive from all treatments. Good correlations were seen between TGW and yield increases (Figure 12).

Table 8. Effect of one ear application for control of *Septoria* in wheat. Two trials (19325). Yield response from only one trial in Hereford. Treatments 1-14 were all treated with 0.35 l/ha Prosaro EC 250 at GS 31-32.

Treatments, l/ha		% *Septoria*		% GLA	Yield & yield increase hkg/ha	Net yield hkg/ha	TGW g
GS 31-32	GS 51-55	GS 73 L1	GS 73 L2	GS 69 L3			
1. Prosaro EC 250 0.35	Amistar Gold 0.75	16.1	38.2	30.7	9.7	5.3	36
2. Prosaro EC 250 0.35	Prosaro EC 250 0.75	17.2	44.4	21.9	5.3	0.9	35
3. Prosaro EC 250 0.35	Propulse SE 250 1.0	9.6	28.2	31.9	11.7	6.1	37
4. Prosaro EC 250 0.35	Propulse SE 250 + Folicur Xpert 0.5 + 0.25	10.9	31.9	35.0	10.3	5.8	35
5. Prosaro EC 250 0.35	Propulse SE 250 + Folicur Xpert 0.75 + 0.25	5.7	24.3	35.7	15.2	9.8	38
6. Prosaro EC 250 0.35	Viverda + Ultimate S 0.75 + 0.75	13.9	38.2	28.8	11.9	6.6	36
7. Prosaro EC 250 0.35	Viverda + Ultimate S 1.25 + 1.0	2.8	22.9	28.9	16.0	8.8	38
8. Prosaro EC 250 0.35	Bell + Prosaro EC 250 0.75 + 0.25	6.9	29.7	28.2	12.5	6.6	37
9. Prosaro EC 250 0.35	Univoq 1.0	1.2	9.8	42.5	20.5	14.8	40
10. Prosaro EC 250 0.35	Univoq + Propulse SE 250 0.75 + 0.5	1.3	12.8	38.2	23.7	17.8	40
11. Prosaro EC 250 0.35	Balaya 1.125	0.6	8.0	46.3	23.4	16.3	41
12. Prosaro EC 250 0.35	Balaya + Bell 0.5 + 0.5	1.6	12.9	48.2	23.2	16.9	40
13. Prosaro EC 250 0.35	Balaya + Entargo 0.75 + 0.375	0.8	8.8	48.8	23.7	16.2	39
14. Prosaro EC 250 0.35	Untreated	36.3	68.2	14.4	3.6	2.0	35
15. Untreated	-	41.9	70.7	11.9	75.9	-	34
No. of trials		2	2	2	1	1	1
LSD_{95}					5.0		2.1

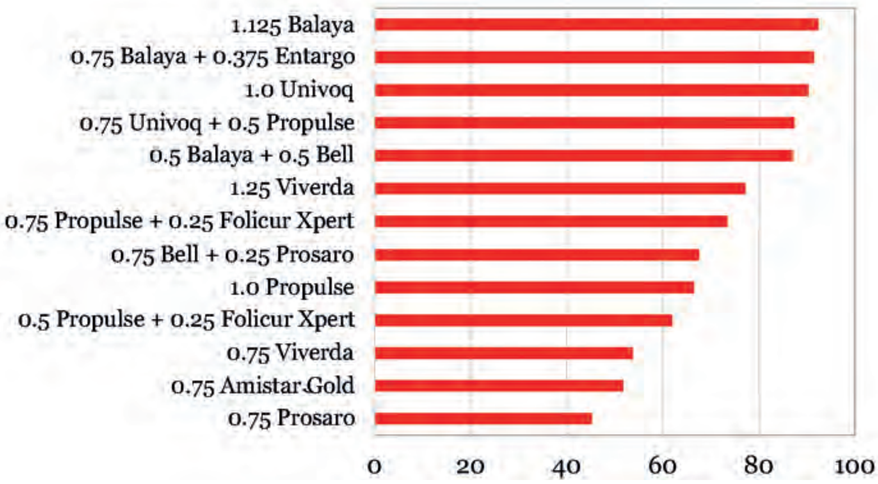


Figure 10. Per cent control of *Septoria* following treatments at GS 45-51. 56% attack in untreated of *Septoria* as an average of 2nd and flag leaf. Average of two trials (19325).

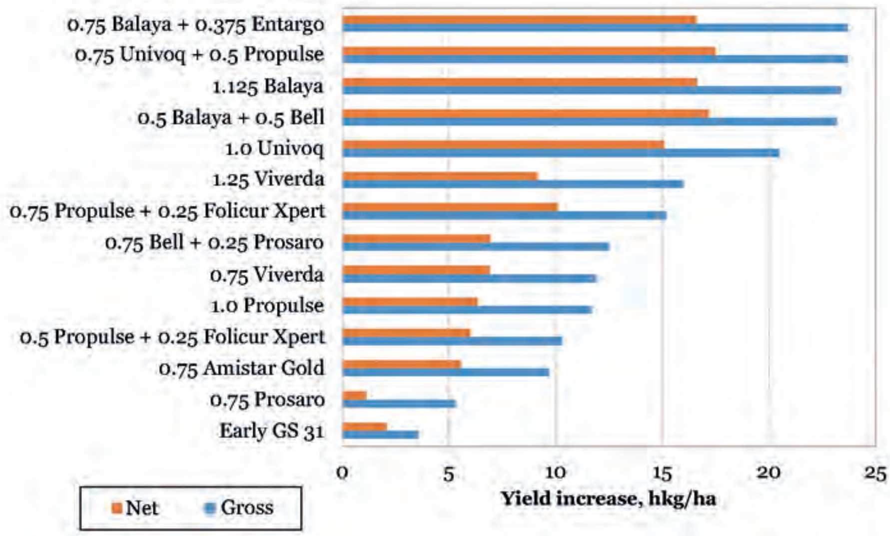


Figure 11. Yield increases in winter wheat (Hereford) from control of *Septoria* with treatments applied at GS 45-51. Results from one trial (19325-1). Early GS 31 covers the response from treatment 14 with Prosaro EC 250.

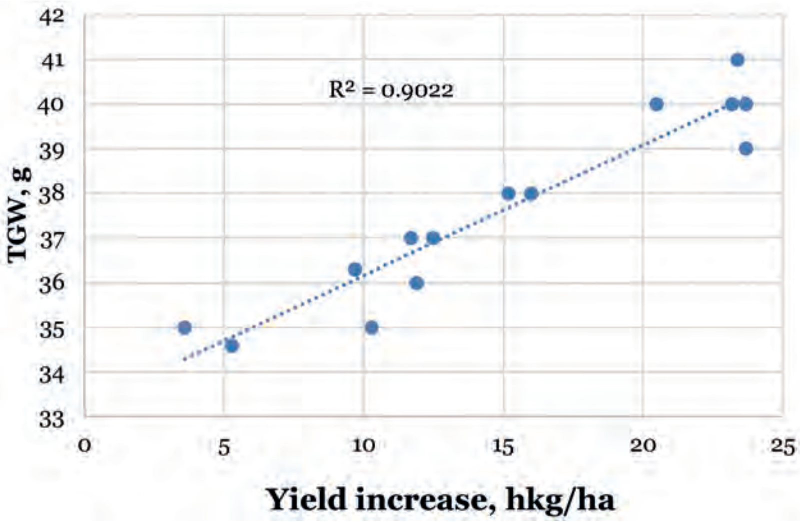


Figure 12. Correlation between yield increase and thousand grain weight (TGW) (g) in trial 19325-1.

Control strategies and their impact on fungicide selection in winter wheat (19328 & 19326)
Two trials were initiated following the trial plan 19328, but only one trial was conducted successfully. The trial compared different treatments using a split ear application applied at GS 37-39 and GS 51-55. At the first timing, 75% of a standard dose was applied and 50% at the second timing. The trial was treated on 10 May and again on 4 June. The included products were a mix of new and old chemistry.

The trial carried out in Hereford developed a severe attack, and major differences were seen between the tested solutions. The new actives generally provided much better control compared with old chemistry, as seen in Table 9 and Figure 13. Balaya followed by Univoq or Univoq followed by Balaya gave very similar control of *Septoria*. Both Propulse SE 250 + Folicur Xpert and Elatus Era followed by Balaya also gave very high levels and long-lasting control of *Septoria*.

Only solutions with high effects at the last timing provided sufficient control. Five treatments had Prosaro EC 250 as the last treatment and these treatments generally gave inferior control of *Septoria*.

Yield responses were high and significant, reflecting the levels of control obtained from the different solutions. Elatus Era followed by Balaya gave the highest yield increase of more than 3 tonnes/ha. Solutions that only included current chemistry (Viverda, Propulse SE 250 and Prosaro EC 250) gave in no case yield increases above 16 dt/ha, which illustrates the major differences in the potential control of the new chemistry compared with the old. The yield data from the trial 19328-1 showed a good correlation between green leaf area and yield increases as well as between yield increases and thousand grain weight (TGW) (Figure 14).

Table 9. Effect of two ear applications for control of *Septoria* and yield response in wheat. One trial (19328).

Treatments, l/ha		% *Septoria*			Yield & yield increase hkg/ha	Net yield hkg/ha
GS 37	GS 51-55	GS 71 L1	GS 71 L2	GS 73 L1		
1. Untreated	-	13.8	50.0	62.5	77.2	-
2. Prosaro EC 250 0.75	Prosaro EC 250 0.5	4.0	20.0	37.5	9.4	4.5
3. Viverda + Ultimate S 0.75 + 0.75	Prosaro EC 250 0.5	4.0	17.5	33.8	11.6	5.9
4. Viverda + Ultimate S 0.75 + 0.75	Amistar Gold 0.5	2.8	17.5	27.5	15.6	9.9
5. Univoq 1.0	Viverda + Ultimate S 0.6 + 0.6	1.0	4.0	5.0	24.6	17.5
6. Propulse SE 250 0.75	Prosaro EC 250 0.5	2.5	10.0	30.0	16.2	11.0
7. GF-3308 + Orius 200 EW 0.5 + 0.315	Prosaro EC 250 0.5	1.8	10.5	22.5	15.5	-
8. Propulse SE 250 + Folicur Xpert 0.5 + 0.25	Univoq 0.75	0.9	5.0	2.0	25.6	19.5
9. Balaya 1.0	Prosaro EC 250 0.5	1.6	3.8	21.3	21.2	14.2
10. Balaya + Entargo 0.75 + 0.25	Prosaro EC 250 0.5	1.4	3.3	18.8	21.4	14.2
11. Balaya 1.0	Propulse SE 250 0.5	0.8	2.8	13.8	25.4	18.4
12. Univoq 1.0	Balaya 0.75	0.2	2.0	1.8	27.6	19.6
13. Univoq 1.0	Propulse SE 250 0.5	0.6	2.8	3.8	21.3	14.9
14. Balaya 1.0	Univoq 0.75	0.9	2.3	1.9	26.6	18.4
15. Elatus Era 0.75	Balaya 0.75	0.3	1.8	0.9	32.1	-
LSD_{95}		5.2	8.52	10.51	6.1	-

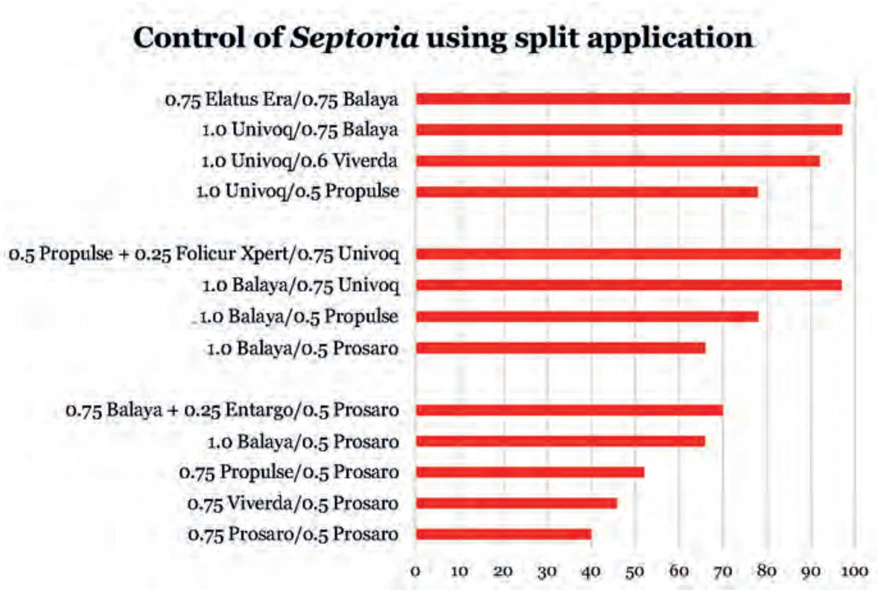


Figure 13. Per cent control of *Septoria* when treated at GS 37-39 and 51-55. 62% attack on flag leaf at GS 75 (19328).

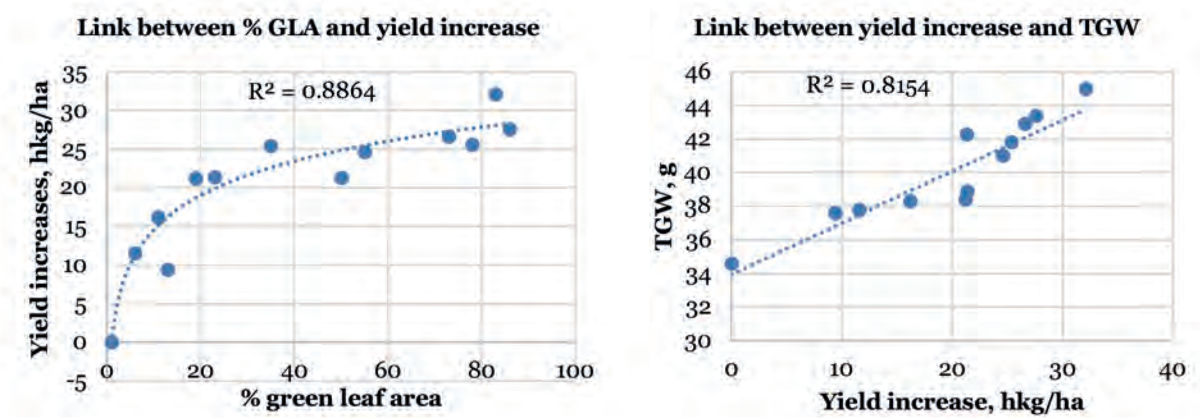


Figure 14. Link between green leaf area assessed at GS 83 and yield increases as well as yield increases linked to thousand grain weight (TGW) (19328-1).

In two trials (19326), double and solo ear applications were compared using new and old chemistry. Using solo applications, two rates (75% and 50%) of Balaya, Univoq and Propulse SE 250 + Folicur Xpert were compared (Table 10). Generally, the efficacy was good, and the dose-effect was not significantly different for control of *Septoria*. Balaya provided slightly better control than Univoq and Propulse SE 250 + Folicur Xpert. This was similarly seen for yield responses, where differences, however, were more pronounced and Univoq also performed better than Propulse SE 250 + Folicur Xpert. Several treatments with double treatments were compared and provided high levels of control although again slightly superior effects were seen from Balaya compared with Univoq and Propulse SE 250 + Folicur Xpert solutions (Figure 15). Treatments that included a low rate of Balaya (0.5 l/ha) mixed with Entargo or Proline EC 250 did, however, provide control that was inferior to other spray solutions, indicating that a very reduced rate of Balaya also has its limitations.

Table 10. Effect of one or two ear applications for control of *Septoria* and yield response in wheat. Two trials (19326).

Treatments, l/ha		% *Septoria*			Yield & yield increase hkg/ha	Net yield hkg /ha	TGW g
GS 37-39	GS 51-55	GS 73/75 L 1	GS 73/75 L 2	GS 73 L 3			
1. Untreated		17.7	43.1	46.1	78.7	-	35.9
2. Propulse SE 250 + Folicur Xpert 0.75 + 0.25		2.7	12.1	2.8	10.5	6.7	39.4
3. Propulse SE 250 + Folicur Xpert 0.5 + 0.25		3.2	11.6	4.3	7.5	4.6	37.0
4. Propulse SE 250 0.75		8.8	16.5	8.0	8.0	4.8	37.4
5. Univoq 1.125		2.1	9.6	6.7	14.1	9.6	40.0
6. Univoq 0.75		2.3	12.0	4.4	10.8	7.6	39.2
7. Balaya 1.125		0.8	4.5	1.4	16.2	10.7	39.6
8. Balaya 0.75		1.0	5.8	2.5	13.4	9.5	40.2
9. Propulse SE 250 + Folicur Xpert 0.5 + 0.25	Propulse SE 250 0.5	2.1	8.7	3.6	13.6	8.6	39.0
10. Propulse SE 250 + Folicur Xpert 0.5 + 0.25	Univoq 0.75	3.9	12.2	4.4	17.3	11.2	39.9
11. Propulse SE 250 + Folicur Xpert 0.5 + 0.25	Balaya 0.75	1.1	5.8	1.6	19.0	6.8	41.3
12. Univoq 0.75	Propulse SE 250 0.5	2.1	10.8	2.7	17.7	12.2	40.6
13. Balaya 0.75	Propulse SE 250 0.5	0.3	3.0	1.0	18.6	12.4	41.3
14. Balaya + Entargo 0.5 + 0.25	Balaya + Proline EC 250 0.5 + 0.25	1.7	5.9	5.0	12.3	4.4	40.6
No. of trials	2	2	2	1	2	2	2
LSD_{95} (excl. untr.)					3.5		

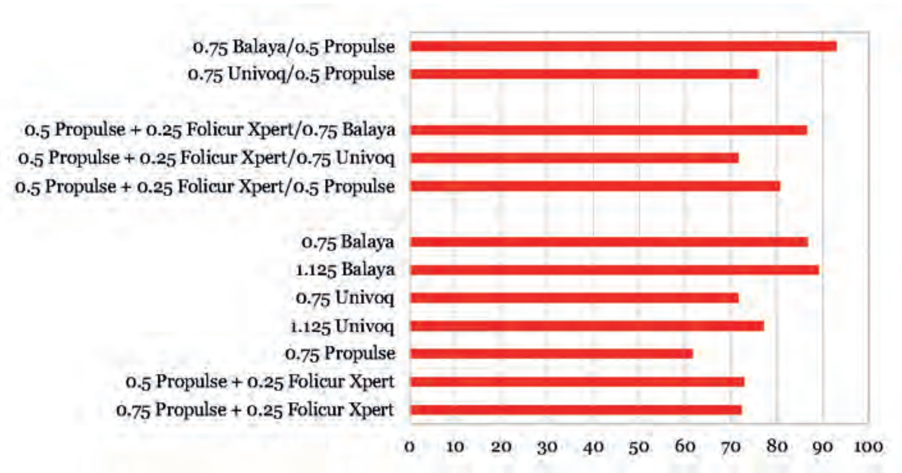


Figure 15. Per cent control of *Septoria* on 2nd leaf when treated at GS 37-39 and 51-55. 43% attack on 2nd leaf at GS 75 (19326) – Two trials.

Comparing effects of SDHIs

As part of the EUROwheat activity, seven trials were carried out following the same protocol. The trials were located in different countries. The focus of the trial was to investigate the efficacy of SDHIs in areas with different levels of resistance (Table 11). One trial was placed at Flakkebjerg in the cultivar Hereford and treated at GS 37-39 (25 May). The trial developed severe attacks of *Septoria*. Significant differences in control were seen in the Danish trial, where Imtrex performed best of the SDHI products tested followed by Thore. The performance of Entargo (boscalid) and Luna (fluopyram) was inferior to that of the better SDHIs, while the performance of Elatus Plus (solatanol) was less effective than expected (Figure 16). Proline EC 250 and Revysol were both included and provided low and high levels of control respectively.

Similar trials were conducted in other countries and showed distinct differences in levels of control depending on the locality. The average results from five European trials are shown in Figure 17. The effect in Ireland and the UK indicated less good control from SDHIs; here Revysol performed best. In the other trials, Imtrex performed better than Revysol.

Table 11. Effect of applications for control of *Septoria* in wheat. One trial (19309). Eurowheat.

Treatments, l/ha		% *Septoria*				% GLA	Yield & yield increase hkg/ha
GS 37-39		GS 69 L1	GS 69 L2	GS 73 L1	GS 73 L2	GS 75 F1	
1.Untreated		6.8	23.0	57.5	86.3	1.5	81.1
2. Imtrex (fluxapyroxad)	1.0	0.1	3.3	2.5	20.5	63.8	11.9
3. Imtrex (fluxapyroxad)	2.0	0.0	1.9	1.3	12.3	80.0	21.2
4. Luna (fluopyram)	0.1	5.3	19.3	33.8	81.3	2.3	0.7
5. Luna (fluopyram)	0.2	4.0	18.0	18.5	68.8	9.0	3.8
6. Thore (bixafen)	0.5	1.8	13.0	10.8	58.8	31.3	6.4
7. Thore (bixafen)	1.0	0.6	8.0	5.3	32.5	60.0	10.5
8. Elatus Plus (solatanol)	0.375	3.3	13.5	19.3	57.5	6.5	4.4
9. Elatus Plus (solatanol)	0.75	2.5	12.0	20.0	50.0	15.0	5.9
10. Proline EC 250	0.4	4.8	16.8	35.0	75.0	4.5	2.2
11. Proline EC 250	0.8	2.1	13.5	19.3	68.8	6.5	3.0
12. Revysol	0.75	0.4	5.5	5.0	25.0	57.5	15.4
13. Revysol	1.5	0.1	4.0	2.8	14.3	78.8	17.0
14. Entargo (boscalid)	0.7	5.5	21.3	27.5	76.3	3.3	2.7
LSD_{95}		1.1	6.5	7.8	16.4	3.3	7.3

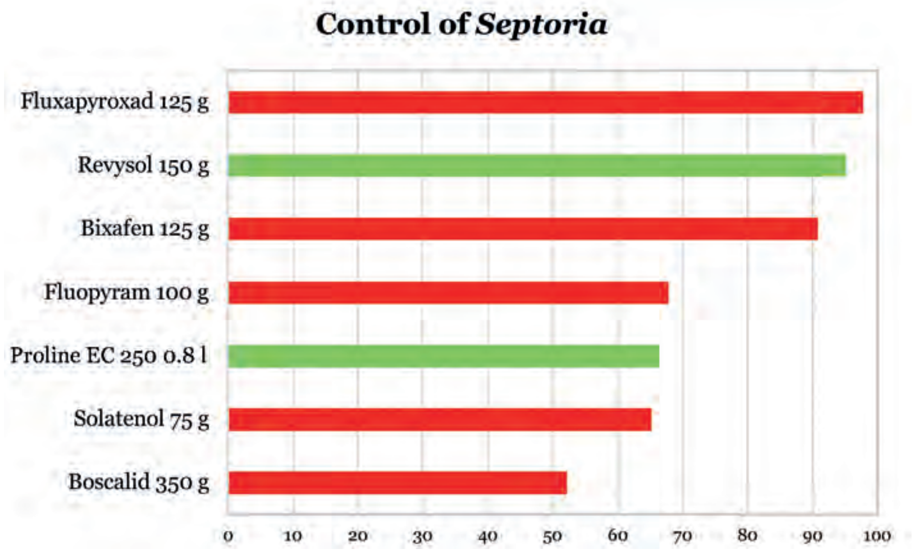


Figure 16. Control of *Septoria* (SEPTTR) (%) using different SDHIs (red) and two azoles (green) in the Danish trial. Assessments carried out at GS 73-75 on leaf 1 (19309-1).

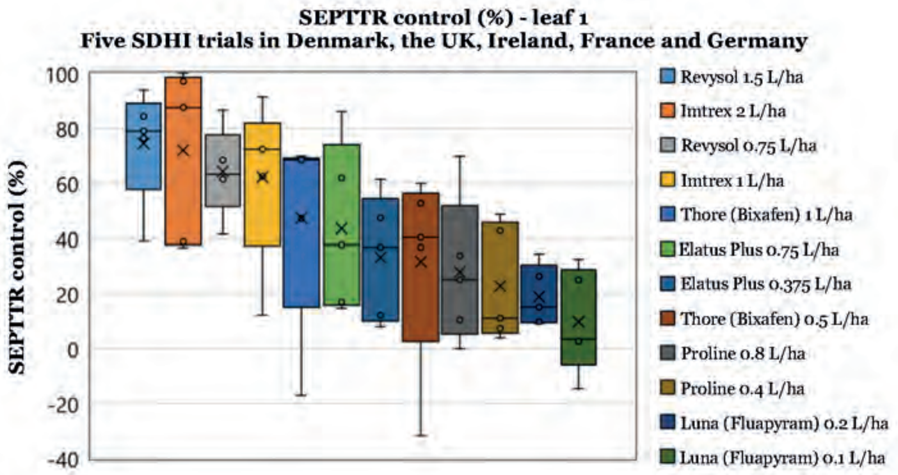


Figure 17. Control of *Septoria* (SEPTTR) (%). Assessments carried out at GS 73-75. 30-55 DAA on leaf 1 in five trials in different countries.

Comparison of new solutions using half rates

In three trials the efficacy from new chemistry was compared to old chemistry for control of the main target diseases in wheat (Figure 18; Table 12). The trials were either carried out in Substance (yellow rust and *Septoria*), Kalmar (*Septoria* and yellow rust) or Graham (tan spot). The trials showed a clear ranking of the efficacy of the three major diseases. For control of *Septoria*, Viverda and Propulse SE 250 + Folicur Xpert were inferior to Balaya, Ascra Xpro, Revysol and Univoq. For control of tan spot, products which included prothioconazole (Ascra Xpro, Propulse SE 250 + Folicur Xpert and Univoq) showed a performance superior to that of other products. For control of yellow rust, all products performed well although Revysol and Univoq were seen to be slightly inferior to the other solutions.

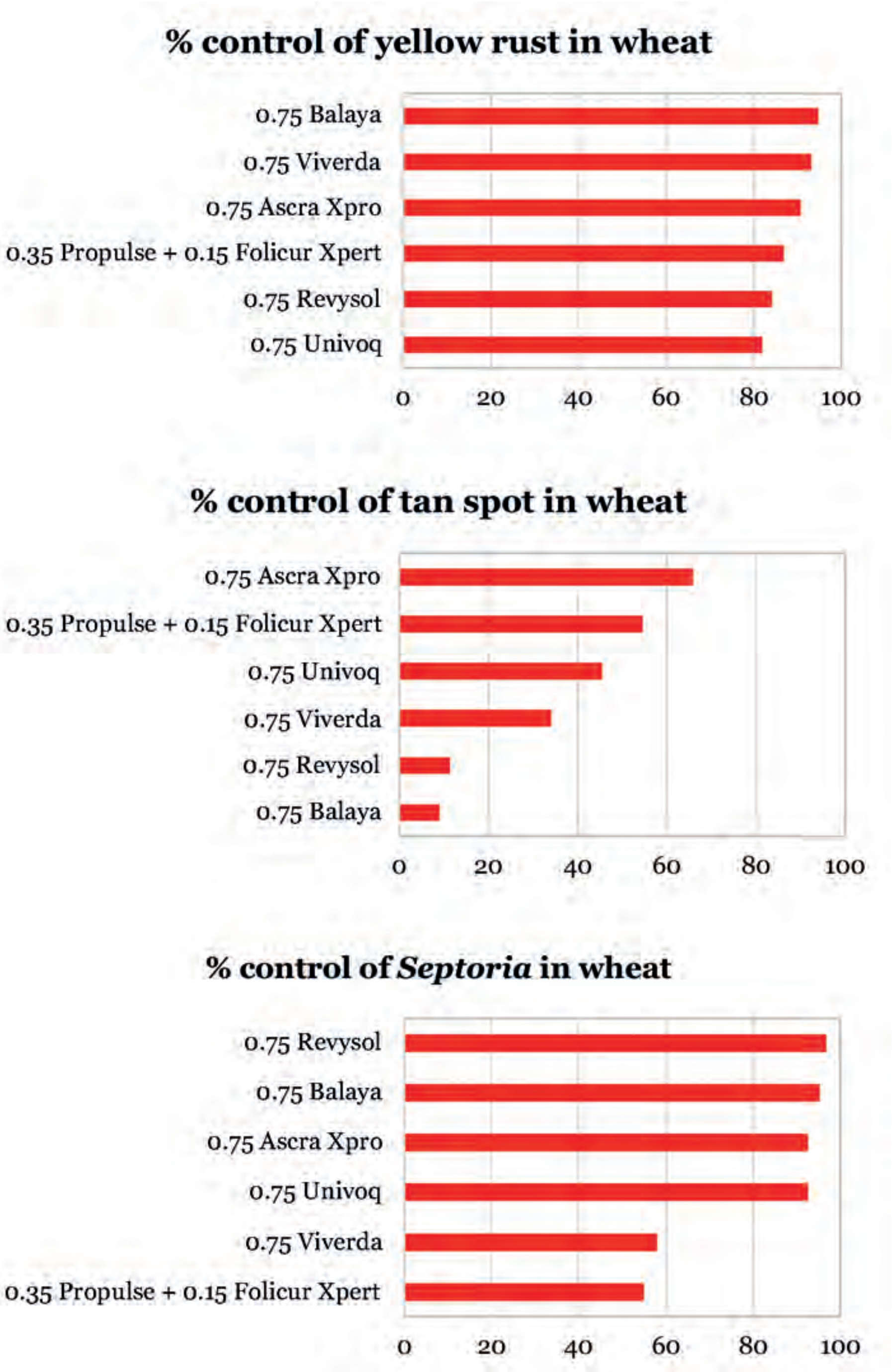


Figure 18. Control of *Septoria*, yellow rust and tan spot in trials using half rates of different solutions. The tan spot trial was sprayed three times, the other trials twice (19315).

Table 12. Effect of applications for control of tan spot, yellow rust and *Septoria* in wheat. Three trials (19315).

Treatments, l/ha (19315-1)		% tan spot				% GLA	Yield & yield increase hkg/ha
GS 32-33 & 51-55 + 69		GS 65 L1	GS 65 L2	GS 73 L1	GS 73 L2	GS 77 F1	
1. Propulse + Folicur Xpert	0.35 + 0.15	1.3	4.0	20.0	42.5	28	11.1
2. Viverda + Ultimate S	0.75 + 0.75	2.5	6.5	28.8	60.0	13	7.8
3. Revysol	0.75	3.3	9.3	38.8	77.5	2	2.5
4. Balaya	0.75	3.5	7.8	40.0	81.3	0	1.8
5. Univoq	0.75	2.3	6.5	23.8	45.0	36	12.3
8. Ascra Xpro	0.75	1.1	2.8	14.8	32.5	31	15.9
9. Untreated		5.8	11.3	43.8	86.3	0	0
No. of trials		1	1	1	1	1	71.1
LSD_{95}		1.2	2.6	4.4	12.1	17.0	4.3

Treatments, l/ha (19315-2)		% yellow rust		% *Septoria*		% GLA	Yield & yield increase hkg/ha
GS 32-33 & 51-55		GS 69 L1	GS 73 L1	GS 75 L1	GS 73 L2	GS 77 F1	
1. Propulse + Folicur Xpert	0.35 + 0.15	4.5	8.5	1.6	10.3	45	24.7
2. Viverda + Ultimate S	0.75 + 0.75	2.0	4.5	1.0	9.8	58	29.8
3. Revysol	0.75	4.8	10.3	1.3	0.9	81	25.5
4. Balaya	0.75	2.0	3.3	0.5	1.5	84	28.5
5. Univoq	0.75	3.3	10.0	1.8	1.5	45	21.7
8. Ascra Xpro	0.75	2.8	5.8	1.0	1.0	70	29.5
9. Untreated		20.8	43.8	17.5	20.0	8	62.9
LSD_{95}				2.3	2.5	21	8.3

Treatments, l/ha (19315-3)		% yellow rust		% *Septoria*		% GLA	Yield & yield increase hkg/ha
GS 32-33 & 51-55		GS 69 L1	GS 75 L1	GS 71 L1	GS 75 L1	GS 79 F1	
1. Propulse + Folicur Xpert	0.35 + 0.15	0	0.1	1.1	5.0	35	4.8
2. Viverda + Ultimate S	0.75 + 0.75	0	0	0.2	4.5	48	8.2
3. Revysol	0.75	0.1	0	0	0.2	95	9.1
4. Balaya	0.75	0	0.1	0.1	0.1	93	8.5
5. Univoq	0.75	0.2	1.8	0.2	1.0	65	7.6
8. Ascra Xpro	0.75	0	0.2	0.0	0.2	79	9.4
9. Untreated		7.0	21.3	7.3	15.0	4	71.1
LSD_{95}		2.7	2.4	1.1	1.3	8.8	5.0

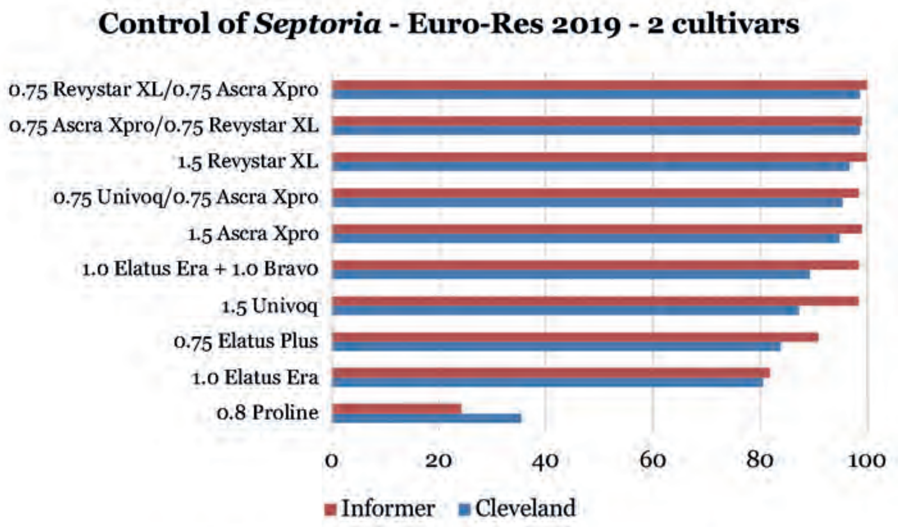
Euro–Res (19327)

A common EU project - Euro-Res - with partners from Sweden, Belgium, Germany, Ireland and Denmark carries out investigations of fungicide resistance in populations of *Zymoseptoria tritici*. The project aims at testing the sensitivity of populations to different fungicides using both leaf samples and air samples. The project also screens different strategies with the aim to investigate how different treatments and timings select for resistant mutations. The data from the first Danish trials in 2019 are shown in Table 13 and Figure 19.

Generally the two-spray strategy provided the best control. When single control strategies were compared, only the treatment with Proline 250 EC gave a very inferior control. Major differences were seen between both control of *Septoria* and yield responses in the two cultivars, Cleveland and Informer. Cleveland gave at the most 5 tonnes/ha in yield increase, while Informer still gave approx. 2 tonnes/ha despite very low levels of disease attack in the latter.

Table 13. Control of *Septoria* and yield responses in 1 trial (19327) in Cleveland and Informer at either one or two timings. Euro-Res project.

Treatments, l/ha			% *Septoria*		Yield & yield increase hkg/ha	
	GS 33-37	GS 55	GS 75 F1 Cleveland	GS 75 F1 Informer	Informer	Cleveland
1.	Untreated		93.8	18.8	102.4	55.3
2.	Proline 250 EC 0.8		77.5	11.3	3.9	13.2
3.	Elatus Era 1.0		41.3	0.6	14.1	29.5
4.	Elatus Era + Bravo 1.0 + 1.0		27.5	0.3	12.2	29.0
5.	Elatus Plus 0.75		38.8	0.6	11.5	27.1
6.	Revystar XL 1.5		8.8	0.1	15.5	43.1
7.	Univoq 1.5 1.5		22.5	0.8	10.3	34.0
8.	Ascra Xpro 1.5		15.0	0.8	8.2	34.8
9.	Univoq 0.75	Ascra Xpro 0.75	18.8	0.6	14.1	37.5
10.	Ascra Xpro 0.75	Revystar XL 0.75	5.8	0.3	18.8	44.9
11.	Revystar XL 0.75	Ascra Xpro 0.75	4.5	0	19.1	50.0
LSD_{95}			4.4	4.4	5.7	5.7



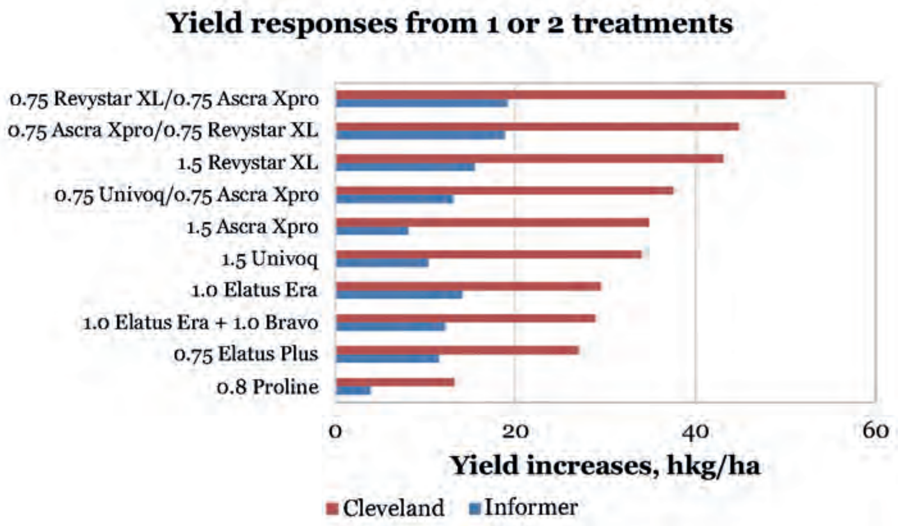


Figure 19. Control of *Septoria* and yield responses using half dose rate in either one or two sprays with different solutions in the two cultivars Cleveland and Informer (19327).

2. Control of *Fusarium* in winter wheat using fungicides

In four trials different solutions were tested for control of Fusarium head blight (FHB). As a reference in the trials, either Proline EC 250 or Prosaro EC 250 was used. In two of the four trials, a lower rate of Proline EC 250 was applied, and in one trial two different timings were applied on 11 and 18 June. The trials were inoculated on 11 and 14 June. Trial 19349 was inoculated with a lower concentration of FHB an only at one timing (11 June).

In summary, as an average of the three trials where a full rate of of Proline EC 250 was used a 69% reduction of Fusarium head blight and a 73% reduction in DON level were achieved (Table 14). The control of *Fusarium* was less when Proline EC 250 was applied at a later timing and also at reduced rates where 46% and 52% control were obtained from 0.6 and 0.4 l/ha Proline EC 250 respectively. The effect on *Septoria* was also significant and 61% control was obtained as an average of the three trials. Most treatments provided significant yield increases from the control of FHB and *Septoria*. Grain was analysed for mycotoxins using HPLC-MS, and the levels reflect that the crop was inoculated with a mixture of *F. culmorum* and *F. graminearum* which both produce DON, NIV and Zea.

Table 14. Control of Fusarium head blight and *Septoria* in 4 different trials, where Proline EC 250 was the reference product. The yield and the grain content of the mycotoxin DON were also measured in the trials.

	% Fusarium head blight					% *Septoria* GS 77, flag leaf				
	19343	19349	19335	19308	Average	19343	19349	19335	19308	Average
Untreated	52.0	38.8	27.5	50.0	38.8 a	7.5	76.6	38.8	77.5	64.3 a
Proline GS 61-65 0.8		5	8	23	11.9 b		31.3	11.8	31.3	24.8 b
Prosaro GS 61-65 1.0			5					6.5		
Proline GS 61-65 0.6	28					3.8				
Proline GS 69 0.6	41					2.5				
Proline GS 61-65 0.4		19					37.3			

	Yield & yield increase, hkg/ha					DON ppb				
	19343	19349	19335	19308	Average	19343	19349	19335	19308	Average
Untreated	92.7	74.3	97.9	74.0	82.1 a	2057	344	1856	1587	1262 a
Proline GS 61-65 0.8		16.4	11.4	10.8	12.9 b		70	422	547	346 b
Prosaro GS 61-65 1.0			14.9					503		
Proline GS 61-65 0.6	0.2					677				
Proline GS 69 0.6	7.6					1378				
Proline GS 61-65 0.4		11.2					123			
No of trials					3					3

Wheat inoculated with Fusarium head blight. The plot to the left is untreated and the plot to the right is treated with 1.0 l/ha Prosaro EC 250.

Control of *Septoria* – using models

In line with previous seasons, several control models were tested in order to be better at using decision support as a tool for deciding on whether to spray or not. This activity is part of the C-IPM funded project SPOT IT, which aims at testing and implementing new models in the Nordic and Baltic regions. AU tested the models in two trials with different cultivars (Hereford and Informer). Results from the trials are shown in Table 16. Using reference treatments applied at different timings, it was compared whether the models provided similar or better control. The data from 2019 recommended two treatments using the humidity model (Figure 20) and 1 to 2 treatments using the Crop Protection Online (CPO) model (Table 15). A cover spray was applied in case of problems with rust and powdery mildew. The humidity model provided very good control and yield responses in the two trials. This model benefited from the fact that two times Ascra Xpro was recommended, whereas the CPO recommended less effective fungicides. At SEGES, 10 trials were carried out also testing the two models. A summary of data from the two seasons is presented in Table 17.

Table 15. Fungicide input recommended by the two models tested during the 2019 season.

Cultivar and model	Treatments products, dose and timing
Informer (CPO)	GS 45-52 Viverda + Ultimate S 0.5 + 0.5
Informer (humidity model)	GS 37-39 Ascra Xpro 0.5 GS 51-55 Ascra Xpro 0.5
Hereford (CPO)	GS 31 Prosaro EC 250 0.45 GS 45-51 Viverda + Ultimate S 0.6 + 0.6
Hereford (humidity model)	GS 37-39 Ascra Xpro 0.5 GS 55 Ascra Xpro 0.5

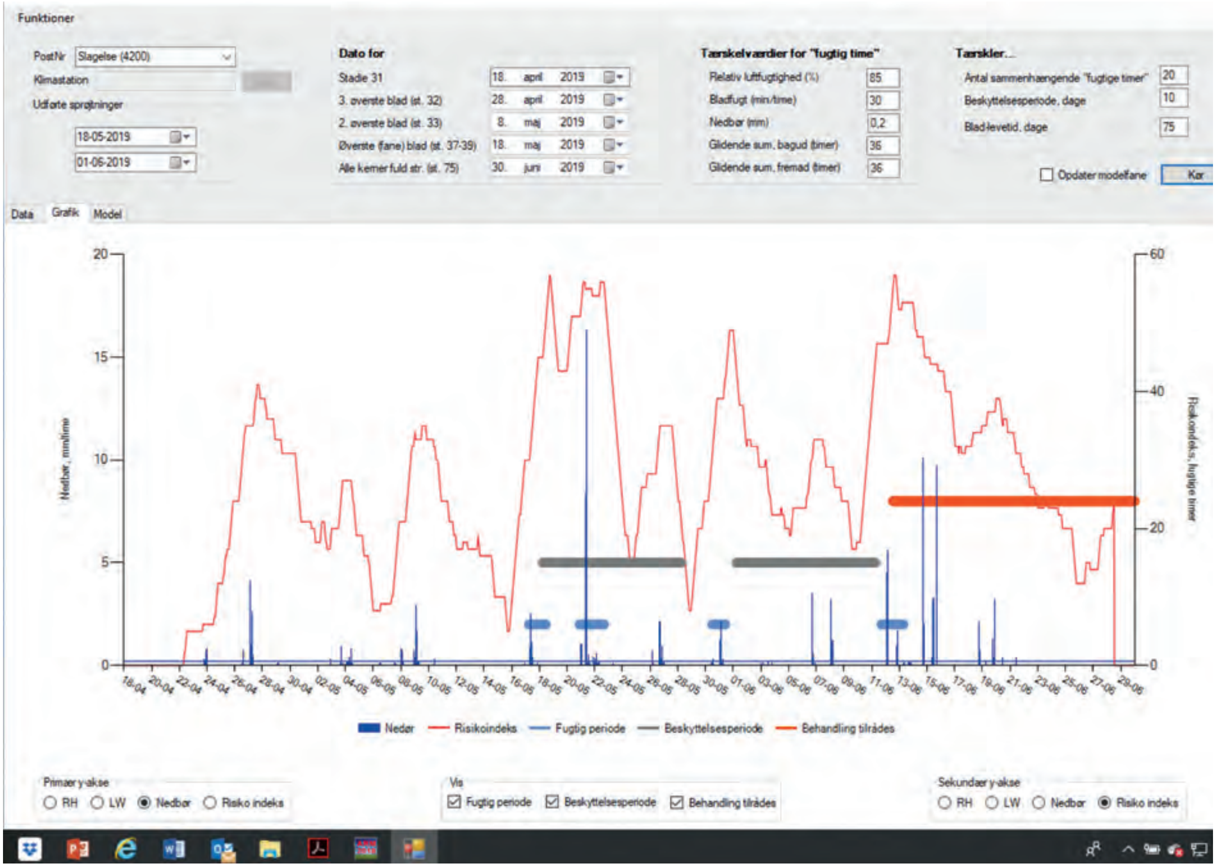


Figure 20. Screenshot from the humidity model showing risk of *Septoria* in Slagelse during the 2019 season.

Table 16. Effect of applications for control of tan spot, yellow rust and *Septoria* in wheat, two trials (19300).

Treatments, l/ha		% *Septoria*			GLA	TGW g	Yield & yield increase hkg/ha	Net increase hkg/ha
		GS 69 L1	hkg/ha	g	GS 75 L1			
1. Untreated		12.3	41.9	67.9	28.8	41.7	90.7	-
2. Ascra Xpro GS 37-39	0.5	1.9	5.8	26.0	47.2	44.0	14.5	11.9*
3. Ascra Xpro GS 51-55	0.5	3.0	16.8	23.6	51.3	44.5	16.1	13.5*
4. Prosaro EC 250 GS 32 Ascra Xpro GS 55	0.5 0.5	1.8	10.8	14.9	63.8	44.1	17.1	12.5*
5. Ascra Xpro GS 37 Prosaro EC 250 GS 55	0.5 0.5	1.4	54.0	19.1	50.8	46.7	18.6	14.0*
6. Humidity model		0.3	3.0	5.0	79.0	46.3	24.0	18.9*
7. CPO model		3.4	17.5	32.5	45.9	42.7	12.4	-
No. of trials		2	2	2	2	2	2	2
LSD_{95}						1.9	3.4	

*Estimated price of Ascra Xpro = DKK 450/l.

In this table, it was also assessed which of the treatments provided a correct recommendation based on the following criteria:

a) The model prevented treatments with no or negative effect on net yield
b) The model increased net yield relative to standard treatments
c) A higher application frequency increased net yield by more than 0.5 dt/ha

In 2016 and 2017, 7 trials were carried out as part of a project financed by the Danish Environmental Protection Agency. These trials similarly showed that the model provided a good guidance on when there is a risk of *Septoria* attack. As also provided from the current project, CPO and the humidity model have given quite similar levels of control.

Table 17. Number of correct treatments assessed in trials from 2018 and 2019. Data include trials from both SEGES and AU.

	Untreated		Reference		Humidity model		CPO model	
	2018	2019	2018	2019	2018	2019	2018	2019
No. of treatments per season	-	-	21	34	2	27	6	25
Average treatments pre season			2.1	2.8	0.3	2.2	0.6	2.1
% *Septoria* at GS 73-75	3.8	21.5	1.6	7	3.8	8	3.6	8
% yellow rust GS 73-75	-	11.8	-	1	-	2	-	2
Gross yield, hkg/ha	82.7	83.6	2.6	13.3	-0.1	13.9	0.6	13.1
Net yield, hkg/ha			-1.4	8.7	-0.8	9.9	-0.7	8.8
Correct recommendations			1/1*	3/5*	9	9	9	7
% correct treatments			10%/10%	25%/42%	90%	75%	90%	58%
No. of treatments	10	12	10	12	10	12	10	12
*Reference versus humidity/reference versus CPO.								

3. Cultivar susceptibility to Fusarium head blight in winter wheat

In a project partly financed by the breeders, the Department of Agroecology, Aarhus University, Flakkebjerg, has in line with previous years investigated the susceptibility to Fusarium head blight (FHB) and tan spot of the cultivars most commonly grown in Denmark. In this year's trials, 22 cultivars were included. One trial was inoculated during flowering; the other trial was inoculated with grain placed on the ground during heading.

Trial with inoculation during flowering. Two rows of 1 metre were sown in the autumn per cultivar and four replicates were included. The trial was inoculated three times on 9, 11 and 14 June, using a spore solution consisting of both *Fusarium culmorum* and *Fusarium graminearum*. To stimulate the development of the disease the trial was irrigated by a mist irrigation system two times per day. Wheat is most susceptible during flowering, and at the time of inoculation the degree of flowering was assessed to ensure that all cultivars were inoculated during flowering. Approximately 15 days after inoculation, the first symptoms of FHB were seen. The trial was assessed counting the attack on 100 ears per cultivar per replicate. Also, the degree of attack was scored as an average of the ears attacked. The results are shown in Figure 21 and Table 18. As seen in Figure 21, the cultivars KWS Cleveland, Pistoria, Torp and Nuffield had the most severe attacks. The least attack was seen in Creator, Benchmark, Sheriff and Elixer. The cultivars Ritmo and Oakley were used as susceptible reference cultivars and Olivin and Skalmeje as the most resistant references.

The small plots in both trials were hand harvested and grains were tested for the content of the mycotoxins deoxynivalenol (DON), nivalenol (NIV), zearalenone (ZEA), HT-2 and T-2. The contents of HT-2 and T-2 were very low in the trials and therefore not included (Figure 22). All cultivars had DON levels much higher than the maximum acceptable limit of 1250 ppb. The ranking of the cultivar content of mycotoxins is shown in Figure 21. There was quite a good correlation between the degree of attack and the content of DON and between the contents of DON and NIV (Figure 23).

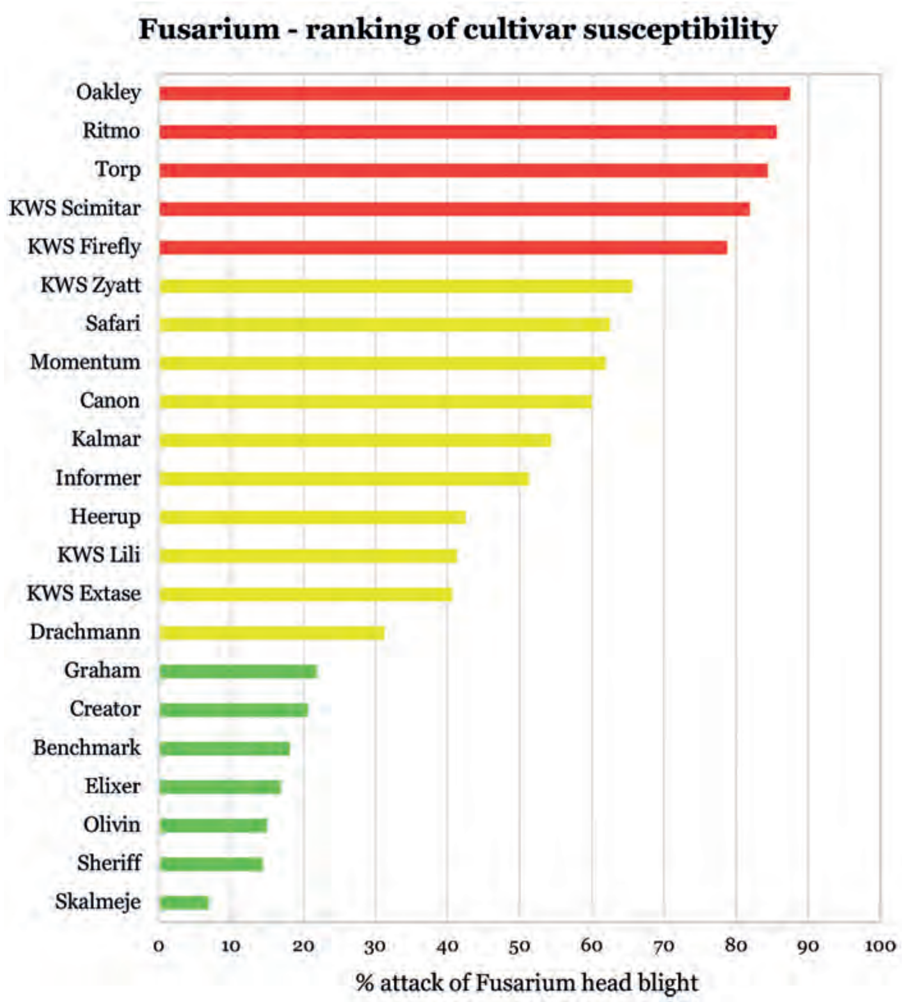


Figure 21. Per cent attack of Fusarium head blight in late July. Average of both trials. The LSD_{95} value = 5.5.

In Table 18, the ranking of cultivars to FHB susceptibility is summarised, including also data from previous years in the final ranking. The results from the trials were published in July together with SEGES in order to make the data available for the cultivar choice in autumn 2019.

Table 18. Grouping of cultivars by susceptibility to Fusarium head blight. Based on results from both 2019 and previous years.

Low susceptibility	Moderate to high susceptibility	High susceptibility
Benchmark, Creator, Elixer, Sheriff	Informer, KWS Extase, KWS Lili, Graham, KWS Zyatt, Canon, Momentum, Drachmann, Heerup, Safari	Kalmar, Torp, Oakley, Ritmo, KWS Firefly, KWS Scimitar

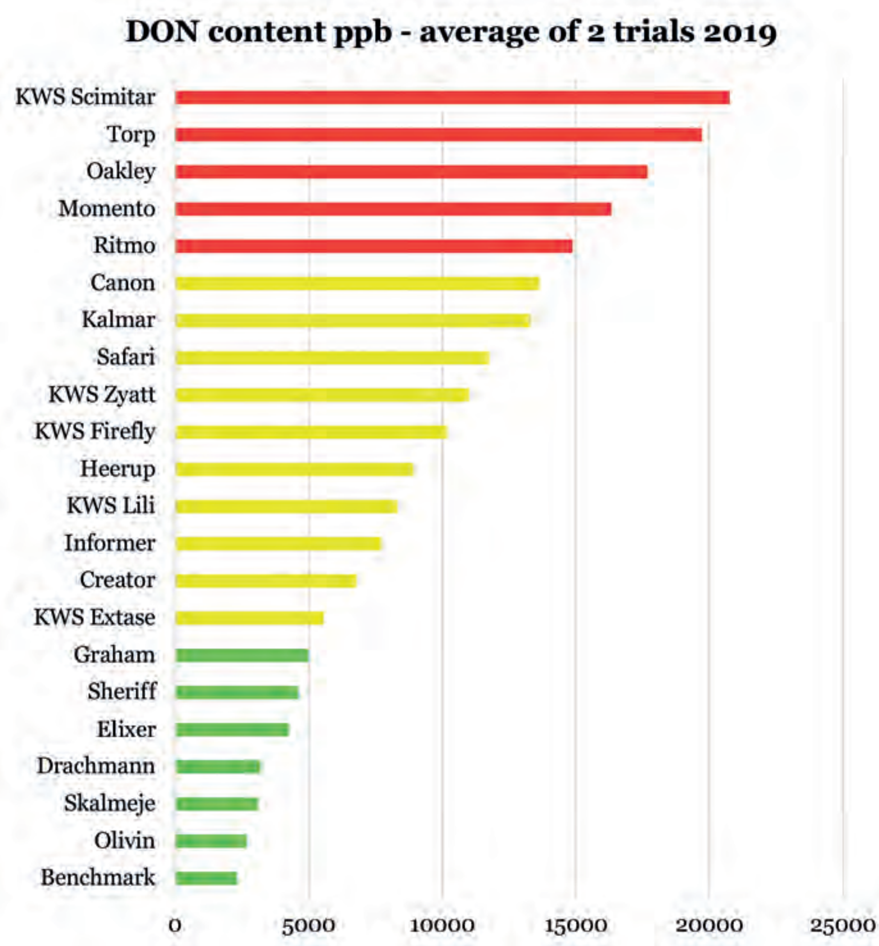


Figure 22. Content of DON in the grain samples. Average of two trials.

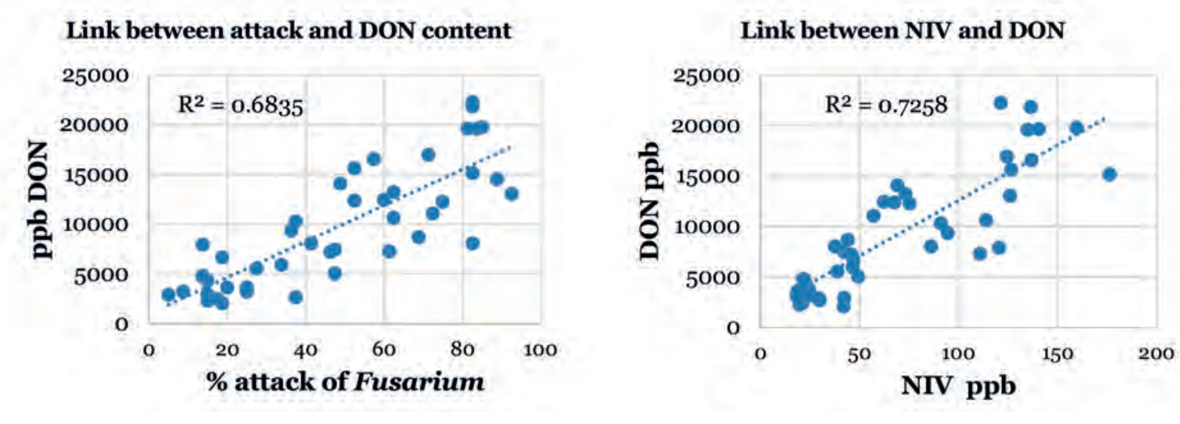


Figure 23. Correlation between % heads attacked by *Fusarium* and content of DON measured in harvested grain (left). Correlations between the two mycotoxins DON and NIV (right). Data from two trials in 2019.

Tan spot (DTR) in wheat

The trial was organised similarly to the *Fusarium* trials with four replicates and 2 x 1 m row per plot. The area was inoculated with debris with tan spot inoculum in the autumn, which is known to provide severe attack the following season. The trial in 2019 was attacked by severe infections of tan spot and almost no *Septoria*. The trial was sprayed with Comet Pro to ensure that the attack of yellow rust did not disturb the infection. The trial was assessed at three timings (GS 32, 73 and 77) during the season. The weather was generally very conducive to the development of attack – both wet and warm.

Most cultivars are known to be quite susceptible to tan spot and only two of the tested cultivars had a significantly lower level of attack than the average. In Figure 24 the AUDPC for tan spot is used for ranking the cultivars according to susceptibility. Only Creator and Informer showed a clearly better level of control.

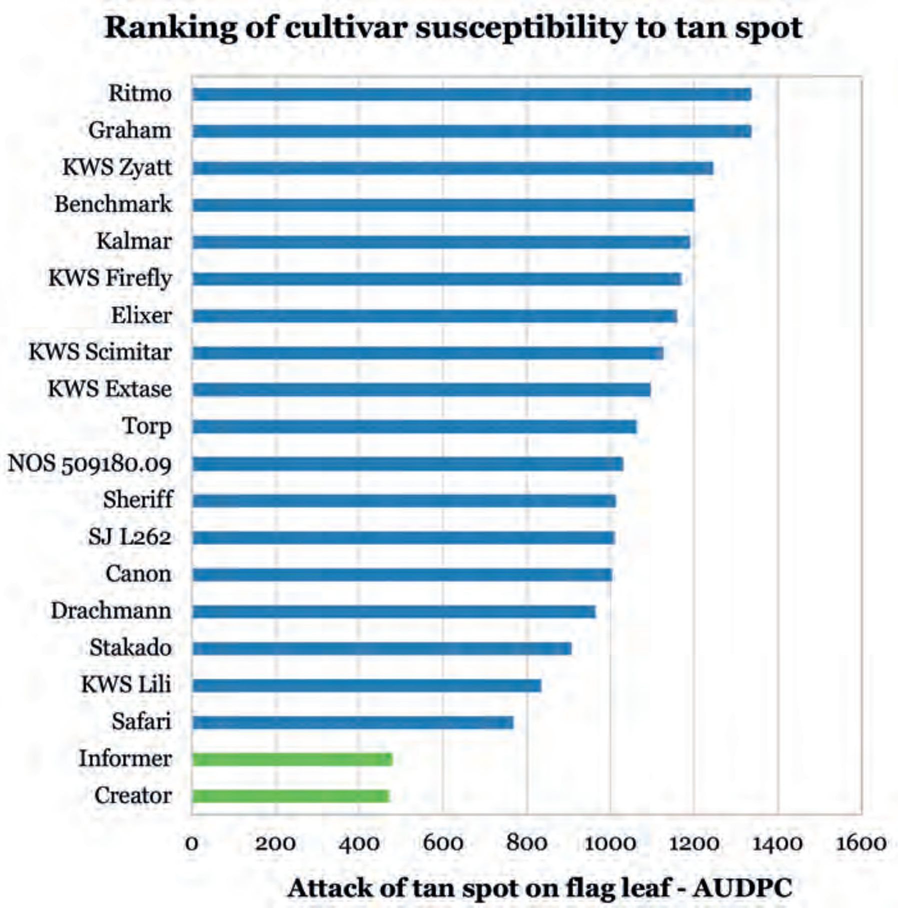


Figure 24. Attack of tan spot in different winter wheat cultivars. AUDPC on flag leaf is used as the separating parameter based on three assessments on the flag leaf.

4. Results from fungicide trials in spring barley

Significant attacks of brown rust and net blotch are the most severe diseases in spring barley. Many combinations of fungicides using azoles and strobilurins provide similar control and yield responses. In most seasons, one treatment at GS 37-39 will provide sufficient control using approximately 33-50% of the approved rates. In the case of early and severe attacks of net blotch, scald and brown rust and late attack of *Ramularia* two treatments might be needed.

In three trials in spring barley, different fungicide solutions using 50-75% of standard rates were compared for control of specific diseases in 2019. Results from the three trials are shown in Table 19. One trial was carried out in the mildew susceptible cultivar Milford, which developed a minor to moderate attack of powdery mildew (*Blumeria graminis*). Two trials developed moderate attacks of brown rust (*Puccinia hordei*) and net blotch (*Pyrenophora teres*) and were placed in Laurikka and KWS Irina. As shown in Table 19 and Figure 25, most of the tested solutions provided very similar and good control of all assessed diseases. Overall, the new test product Elatus Era provided the best control of rust, *Ramularia* and net blotch. Yield responses were moderate to high but did not differ significantly for most treatments (Figure 26).

Table 19. Disease control using different fungicides applied at GS 33-37 in spring barley. Three trials 2019 (19376).

Treatments, l/ha (19376)		% *Ramularia*	% net blotch	% rust	% GLA	TGW g	Yield & yield increase hkg/ha	Net increase hkg/ha
GS 37-39		GS 73-75 L1	GS 73-75 L2	GS 73-75 L2	GS 77-83 L2			
1. Untreated		36.3	18.1	34.2	6.4	40.4	55.8	-
2. Proline Xpert + Bell	0.25 + 0.375	11.7	4.5	6.9	30.3	44.9	8.5	5.5
3. Propulse SE 250 + Folicur Xpert	0.5 + 0.25	13.1	3.5	7.0	33.2	45.1	8.7	5.7
4. Bell + Comet Pro	0.375 + 0.31	19.2	3.5	9.8	32.9	44.6	7.9	6.3
5. Viverda + Ultimate S	0.75 + 0.75	12.8	1.9	6.8	42.9	45.8	10.2	6.4
6. Balaya + Curbatur	0.5 + 0.25	11.8	2.9	7.1	40.0	45.6	9.9	5.9
7. Propulse SE 250 + Comet Pro	0.5 + 0.2	18.2	2.9	8.6	35.4	45.6	8.9	3.0
8. Elatus Era	0.5	5.2	2.0	3.4	62.3	46.3	12.9	-
9. Balaya	0.75	17.2	2.9	8.9	35.3	45.2	8.8	4.8
10. Balaya + Entargo	0.5 + 0.25	13.4	2.9	7.4	37.6	45.4	8.4	1.7
No. of trials		2	3	3	3	3	3	3
LSD_{95}						1.3	2.6	

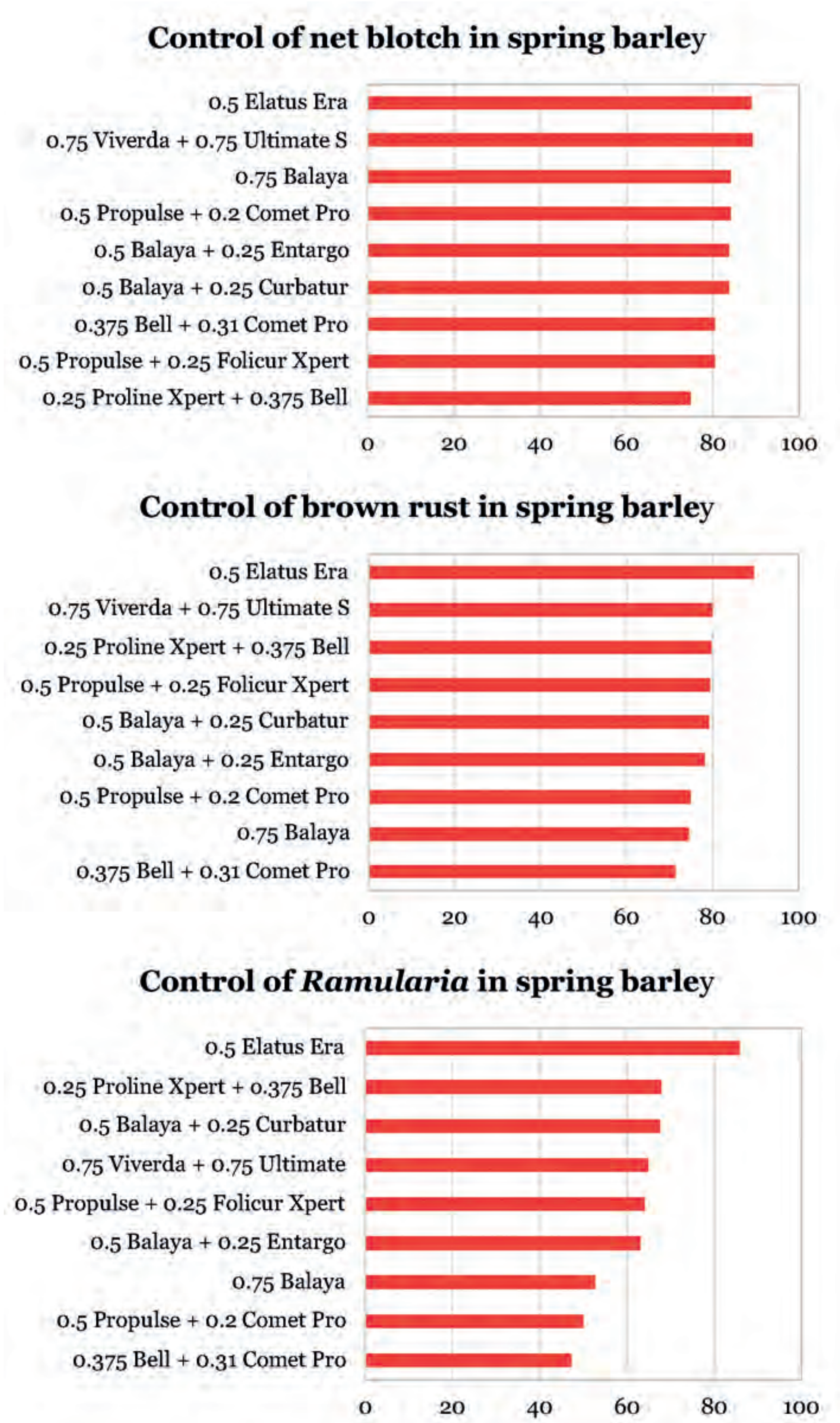


Figure 25. Control of rust, net blotch and *Ramularia* in spring barley (19376). Average of three trials: 34% with rust, 18% with net blotch and 34% with *Ramularia* in untreated.

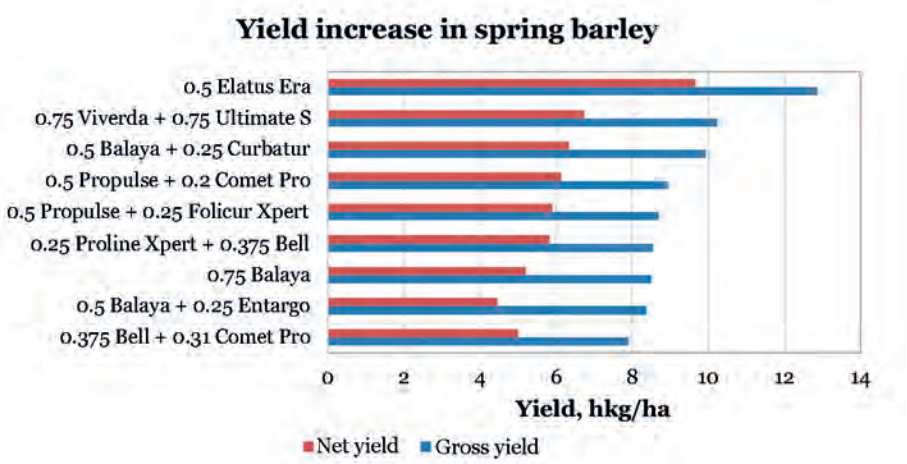


Figure 26. Yield increase from different solutions in spring barley (19376). Average of three trials, 56 hkg/ha in untreated.

In another trial, half standard rates of all relevant products were applied and compared (Table 20). This trial showed inferior control of rust and net blotch from Revysol and Univoq. All solutions which included pyraclostrobin gave good control of both rust and net blotch and so did Ascra Xpro. Balaya provided clearly better control of both rust and net blotch compared with Revysol used alone. The trial rovided high levels of yield increases, which reflected the levels of disease control.

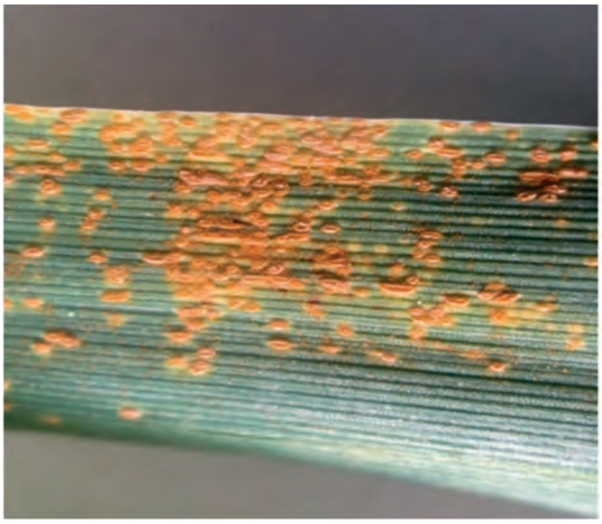
Table 20. Disease control using different fungicides applied at GS 33-37 in spring barley. One trial 2019 (19365).

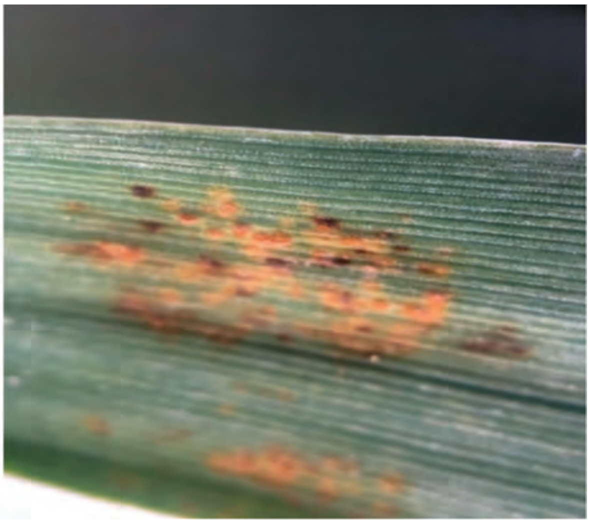
Treatments, l/ha (19365-1)		% rust	% net blotch	% *Ramularia*	TGW g	Yield & yield increase hkg	Net increase hkg
GS 37-39		GS 75 L2	GS 75 L2	GS 75 L 2			
1. Untreated		27.5	30.0	10.0	38.6	54.0	-
2. Propulse + Comet Pro	0.38 + 0.15	1.1	3.4	2.3	43.5	13.4	10.9
3. Viverda + Ultimate S	0.75 + 0.75	0.6	1.1	3.0	45.0	14.5	10.7
4. Revysol (Myresa)	0.75	3.7	8.0	1.6	43.4	10.7	-
5. Balaya	0.75	0.7	1.6	2.1	44.3	13.5	9.5
6. Univoq	0.75	3.7	7.6	1.8	42.9	8.5	3.4
7. Prosaro 250 EC	0.5	1.6	7.0	2.4	42.3	7.6	5.4
8. Comet Pro	0.6	1.4	2.9	3.3	44.7	13.9	11.4
9. Ascra Xpro	0.75	1.0	1.3	2.3	43.0	15.8	-
LSD_{95}		13.5	15.0	3.8	9.2	5.9	

In two trials, the focus was on control of Ramularia leaf blotch. The trials was treated initially with Comet Pro to ensure control of early attack of rust and net blotch (Table 21). One trial was carried out in spring barley and one in winter barley. The trials only developed low to moderate levels of Ramularia leaf blotch late in the season. Ascra Xpro and Propulse SE 250 provided the best control, but also Revysol as a solo treatment provided control in line with Bravo (chlorothalonil). Alternative chemistry like Dithane NT, Kumulus S and Folpan did in this trial only provide modest control in line with Proline EC 250. Azole resistance has been found to develop in the *Ramularia* population, which is seen as the main course of the reduced control. SDHIs still seem to provide relatively good control although also resistance challenges are known to this group. Yield responses from this late application were not very high and did in most cases not provide positive net yield increases.

Table 21. Disease control using different fungicides applied at GS 45-51 in spring and winter barley. Two trials 2019 (19390). The trials were treated with a cover spray using 0.5 l/ha Comet Pro at GS 32-33.

Treatments, l/ha (19390)	% rust		% net blotch	% net blotch	% *Ramularia*	TGW g	Yield & yield increase hkg/ha	Net increase hkg/ha
GS 45-51	GS 71/73 L2	GS 77 L2	GS 73 L2	GS 77 L2	GS 77 L 2			
1. Untreated	5.3	25.0	26.3	26.3	20.7	43.7	70.3	-
2. Ascra Xpro 0.75	0.1	1.8	2.0	2.3	1.3	46.1	10.0	-
3. Propulse SE 250 0.8	0.4	4.5	3.5	6.0	3.8	44.9	7.4	1.7
4. Proline EC 250 0.4	1.0	4.5	12.5	15.0	10.9	44.2	5.0	0.5
5. Bravo 1.0	3.6	18.8	16.3	22.5	4.8	44.0	3.1	-
6. Univoq 0.75	0.6	8.8	15.0	18.8	7.2	43.9	6.8	1.2
7. Dithane NT 1.5	4.9	21.3	20.0	26.3	13.8	44.3	1.9	-3.2
8. Kumulus S 4.0	4.9	15.0	25.0	18.8	11.7	43.6	2.1	-5.6
9. Folpan 500 SC 1.0	6.4	15.0	26.3	22.5	10.4	43.1	2.4	-1.9
10. Revysol 0.75	1.7	12.5	16.3	25.0	5.4	45.1	5.5	-
No. of trials	2	1	1	1	2	2	2	2
LSD_{95}	1.9	4.3	6.0	3.7	3.7	1.7	2.6	





Brown rust developed very early in the season and the photo shows the visual differences between untreated and treated rust attack. Following treatments, necrotic spots developed and the spore production was clearly inhibited.

In two trials, two different models were used to help decide whether not treatments against net blotch and *Rhynchosporium* were necessary. The humidity model - using the same models as in wheat - recommended two treatments in both cultivars, which proved to be an acceptable solution compared with reference treatments (Table 22). Treatments were only recommended if also attacks of net blotch or *Rhynchosporium* were present at the site. CPO provided control and yields in line with the humidity model; both models recommended two sprays.

Spring barley treated according to the humidity model and compared with untreated. The crop was severely infected with net blotch and rust.

Table 22. Disease control using different fungicides applied at different timing and compared with recommendations given by the humidity model and CPO in spring barley. GLA = Green Leaf Area. Two trials 2019 (19399).

Treatments, l/ha		% rust	% net blotch	% GLA	TGW g	Yield & yield increase hkg/ha	Net increase hkg/ha
		GS 57 L2	GS 73 L2	GS 77 L2			
1. Untreated		1.0	61.9	0.8	37.2	51.8	-
2. Ascra Xpro GS 37-39	0.5	0.1	4.5	31.9	45.5	14.2	11.5*
3. Ascra Xpro GS 51-55	0.5	0.3	21.9	25.7	45.0	9.9	7.2*
4. Prosaro EC 250 GS 32 Ascra Xpro GS 55	0.5 0.5	0.0	11.8	26.9	45.8	15.5	10.7*
6. Humidity model		0.0	3.4	38.2	46.5	17.1	11.6*
7. CPO model		0.0	3.7	48.4	46.3	17.8	12.4
LSD_{95}					4.4	3.5	
*Estimated price of Ascra Xpro = DKK 450/l.							

5. Results from fungicide trials in winter barley

Brown rust and net blotch are the most severe diseases in winter barley. Many combinations of fungicides using triazoles and strobilurins provide similar control and yield responses. In most seasons one treatment at GS 37-39 will provide sufficient control using approximately 33-50% of standard rates. In the case of early and severe attacks of net blotch, scald, and brown rust and late attack of *Ramularia* two treatments might be needed.

In 2019, three trials in winter barley were carried out testing different combinations of fungicide solutions against specific diseases. Treatments were applied at GS 37-39 using 50-75% of standard rates, which have typically been seen as economically optimal solutions. Results from the trials are shown in Table 23. The trials in 2019 were dominated by brown rust (*Puccinia hordei*) and a late moderate attack of Ramularia leaf spot (*Ramularia collo-cygni*). As shown in Table 23 and Figure 27 most of the tested solutions provided very similar and good control of all assessed diseases. With the exception of Proline Xpert all treatments gave good control of brown rust. The level of *Ramularia* control was quite moderate, partly due to the early timing relative to the late development, and no clear differences could be seen between the tested products. Yield increases varied between 9 and 12 hkg/ha.

Table 23. % control of net blotch and brown rust in winter barley using different azoles. GLA: Green leaf area, yield and yield increase (19383).

Treatments, l/ha (19383)		% brown rust			% *Ramularia*	% GLA	TGW g	Yield & yield increase hkg/ha	Net increase hkg/ha
GS 37-39		GS 71 L2	GS 73-75 L1	GS 73-75 L2	GS 71 L1	GS 77-83 L2			
1. Proline Xpert	0.5	3.8	6.3	5.2	3.8	21.8	36.3	9.0	6.7
2. Bell + Comet Pro	0.375 + 0.31	0.8	5.0	2.8	2.5	27.0	37.6	10.8	7.7
3. Viverda + Ultimate S	0.75 + 0.75	0.1	2.8	1.0	1.1	51.0	37.6	12.2	9.2
4. Propulse SE 250 + Folicur Xpert	0.5 + 0.25	0.9	5.6	3.1	2.5	33.5	37.3	11.6	8.6
5. Balaya + Proline Xpert	0.5 + 0.25	3.5	6.2	4.9	3.0	34.7	36.6	9.8	5.8
6. Propulse + Comet Pro	0.5 + 0.2	2.5	5.4	3.8	2.3	32.3	36.7	10.4	7.4
7. Ascra Xpro	0.75	0.6	2.8	1.8	4.3	50.2	38.0	11.3	-
8. Balaya	0.75	1.1	5.0	3.0	2.0	34.5	37.2	10.5	6.5
9. Balaya + Entargo	0.5 + 0.25	0.7	5.3	3.0	1.8	40.3	37.4	10.5	6.2
10. Untreated		23.8	18.9	21.4	7.5	5.0	35.3	62.8	-
No. of trials		1	3	3	1	3	3	3	3
LSD_{95}		1.4			3.0		1.2	4.8	

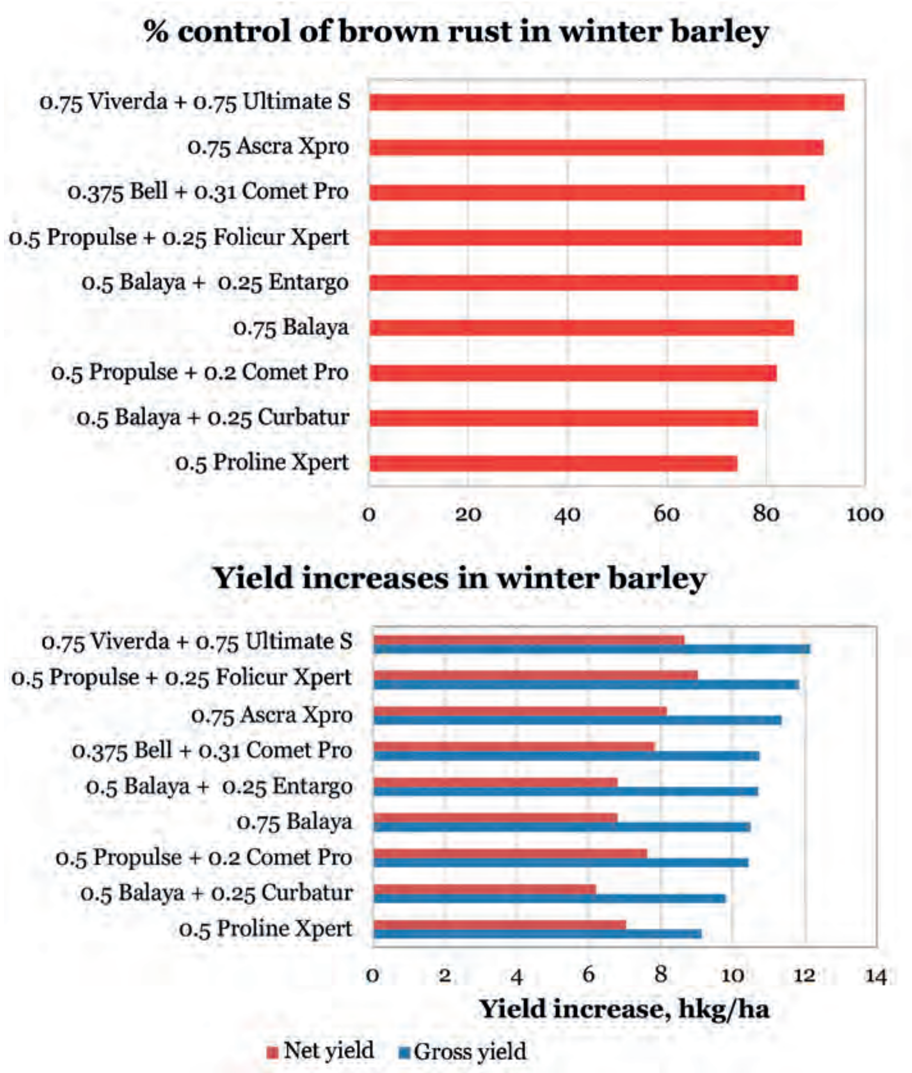


Figure 27. Control of brown rust and yield increases from different solutions in winter barley (19383). Average of three trials. 22% attack in untreated and 62.7 hkg/ha in untreated.

6. Results from fungicide trials in triticale, winter rye and oats

Two trials were carried out following the same trial plan, one in triticale and one in rye. Two timings were applied in triticale (GS 32 and 45) and one timing in winter rye (GS 39).

In triticale, severe attacks of yellow rust developed already from the early spring and the growth was very advanced already in early April. Good control was achieved by most treatments (Table 24) although Revysol and Univoq were less effective compared to other treatments. This was also reflected in the yield responses. Viverda + Ultimate S was the solution providing the best control and also the best yield response, increasing yields by 115% (5 tonnes/ha).

Table 24. Per cent control of yellow rust in triticale (Neogen) using different solutions. Green leaf area, yield and yield increase (19364-1).

Treatments, l/ha (19364-1)		% yellow rust				% GLA	TGW g	Yield & yield increase hkg/ha	Net increase hkg/ha
GS 32-33 & 51-55		GS 55 L2-3	GS 65 L2-3	GS 65 L1	GS 73 L1	hkg			
1. Propulse SE 250	0.5	6.5	6.3	1.8	6.3	63	42.8	+39.7	34.7
2. Viverda + Ultimate S	0.75 + 0.75	0.2	2.3	0.5	2.5	93	44.6	+51.2	43.2
3. Revysol	0.75	12.5	15.0	4.5	15.0	79	45.7	+36.0	
4. Balaya	0.75	1.6	3.8	2.0	5.5	88	44.0	+44.6	36.1
5. Univoq	0.75	8.5	6.8	2.5	8.0	75	43.1	+37.9	30.9
6. Prosaro EC 250	0.75	2.0	2.5	1.0	5.0	70	43.4	+42.0	35.9
7. Comet Pro	0.6	2.5	3.8	2.5	6.3	88	45.6	+44.7	39.4
8. Ascra Xpro	0.75	3.0	3.3	1.0	4.5	89	46.4	+46.2	-
9. Untreated		75.0	82.5	35.0	81.3	34	40.5	44.4	-
LSD_{95}		4.1	3.5	6.0	3.0	22.9	2.5	5.7	

In rye, moderate attacks of *Rhynchosporium* developed followed by severe attacks of brown rust developing after heading. Propulse SE 250 and Revysol were both inferior to other treatments. Viverda provided the best control followed by Balaya and Comet Pro, which had a good effect on brown rust (Table 25). Despite severe attacks of brown rust, yield increases were still relatively moderate. With the exception of Revysol all treatments provided significant yield increases. Viverda, Comet Pro and Ascra Xpro provided the best yield increases.

Table 25. % control of leaf diseases in winter rye using different solutions. Green leaf area, yield and yield increase (19364-1).

Treatments, l/ha (19364-2)		% *Rhyncosporium*		% brown rust			% GLA	TGW g	Yield & yield increase hkg	Net increase hkg/ha
GS 32-33 & 51-55		GS 65 L5	GS 69 L3-4	GS 69 L 2-4	GS 77 L1	GS 77 L2	hkg/ha			
1. Propulse SE 250	0.5	5.3	5.0	6.5	21.3	55.0	55	35.8	2.9	-2.2
2. Viverda + Ultimate S	0.75 + 0.75	3.5	1.3	0.5	5.8	15.0	85	35.4	8.5	0.5
3. Revysol	0.75	5.8	7.3	8.5	20.0	62.5	38	35.3	4.4	-
4. Balaya	0.75	5.8	2.8	0.4	8.5	25.0	78	34.7	6.9	1.6
5. Univoq	0.75	5.8	2.8	1.0	13.3	37.5	73	35.4	5.2	-1.8
6. Prosaro EC 250	0.75	4.0	4.0	3.3	13.8	47.5	73	35.2	7.0	0.9
7. Comet Pro	0.6	5.8	3.0	0.8	9.5	28.8	78	35.3	8.7	3.4
8. Ascra Xpro	0.75	5.8	2.0	0.7	8.3	30.0	83	35.3	8.7	-
9. Untreated		10.0	12.0	12.0	38.8	75.0	13	34.3	90.8	-
LSD_{95}		1.98	1.9	2.15	6.97	11.29	12.8	1.67	5.17	

Two trials were also carried out in spring oats to test different new products. The trials were carried out in the cultivar Poseidon and treatments were applied at GS 37-39. Severe attacks of powdery mildew and leaf spots developed in both trials. Proline EC 250 provided good control of both diseases (Table 26). Despite the severe attack of the two diseases, the yield increases were still relatively moderate.

Table 26. % control of leaf diseases in spring oats. Data from the reference treatments (19370-1; 19371-1).

Treatments, l/ha (19364-2)		% mildew		% leaf spot		Yield & yield increase hkg/ha		Average
GS 32-33 & 51-55		Trial 1	Trial 2 2nd leaf	Trial 1 Flag leaf	Trial 2 Flag leaf	Trial 1	Trial 2	
Untreated		43	50.0	7	17.5	60.2	60.5	60.4
Proline EC 250	0.8	0	0.8	3	2.5	2.0	+7.8	4.9
Aviator Xpro	1.0	0	-	1	-	7.4		-
LSD_{95}				1.6	4.4	4.5	5.2	

III Control strategies in different cultivars

Lise Nistrup Jørgensen, Niels Matzen, Thies Marten Heick, Hans-Peter Madsen, Helene Saltoft Kristjansen, Sidsel Kirkegaard, Anders Almskou-Dahlgaard & Rose Kristoffersen

Different strategies tested in 6 wheat cultivars
Eight different control strategies were compared in 6 different wheat cultivars. The three first cultivars were ranked as susceptible (Benchmark, Torp, Hereford), while the last three were regarded as resistant (Informer, Sheriff, Creator). The two mixtures included either susceptible or resistant cultivars. One of the treatments included the use of the decision support system Crop Protection Online (CPO) to evaluate the need for treatments. Comparisons with typical reference treatments using one, two or three treatments were made in the trials. The trials this year were located at two sites – one at AU Flakkebjerg in Zealand and one near Horsens at LMO, Jutland.

The following strategies were tested:
1. Untreated
2. 1.25 l/ha Viverda + 1.0 l/ha Ultimate S (GS 45-51) (TFI=1.3)
3. 0.6 l/ha Viverda + 0.6 l/ha Ultimate S / 0.3 l/ha Bell + 0.15 l/ha Proline EC 250 (GS 37-39 & 55-61) (TFI=1.25)
4. 0.35 l/ha Prosaro EC 250 / 0.6 l/ha Viverda + 0.6 l/ha Ultimate S / 0.3 l/ha Bell + 0.15 l/ha Proline EC 250 (GS 32/37-39 & 55-61) (TFI=1.65)
5. 0.35 l/ha Prosaro EC 250 / 1.25 l/ha Viverda + 1.0 l/ha Ultimate S / 0.6 l/ha Bell + 0.3 l/ha Proline EC 250 (GS 32/37-39 & 55-61) (TFI=3.0)
6. Crop Protection Online (CPO) (Table 1)

The trials developed significant attacks of *Septoria* but also yellow rust was particularly pronounced in Benchmark. There was a clear benefit from all fungicide treatments (Table 2). The efficacy was slightly better from the highest input; this was particularly clear in the two most susceptible cultivars, Benchmark and Hereford. When it came to yield and net yields, most treatments provided a similar output. It was, however, seen that the yield responses reflected the level of diseases in the individual cultivars. The inputs following CPO varied a lot between the included cultivars. The fungicide input was higher at Flakkebjerg compared with the LMO trial, where the most susceptible cultivars were treated 3 times. The level of *Septoria* attack in the untreated plots of the 6 cultivars is shown in Figure 1 and the level of yield in Figure 2.

Table 1. Treatments applied following recommendations from Crop Protection Online. Flakkebjerg (19350-1) and Horsens (19350-2).

Cultivars (19350-1)	Date	Products, l/ha	TFI	Costs, hkg/ha
Susceptible mixture (Mixture S)	10-05-2019 27-05-2019 13-06-2019	Prosaro EC 250 0.45 Propulse SE 250 + Orius 200 EW 0.5 + 0.5 Prosaro EC 250 0.44	0.51 0.39 0.5	1.92 3.05 1.89
Resistent mixture (Mixture R)	27-05-2019	Propulse SE 250 + Orius 200 EW 0.4 + 0.2	0.64	2.26
Benchmark	10-05-2019 23-05-2019 27-05-2019 13-06-2019	Prosaro EC 250 0.45 Propulse SE 250 + Comet Pro 0.4 + 0.2 Propulse SE 250 + Orius 200 EW 0.5 + 0.5 Prosaro EC 250 0.44	0.51 0.61 0.39 0.5	1.92 2.57 3.05 1.89
Torp	10-05-2019 27-05-2019 13-06-2019	Prosaro EC 250 0.45 Propulse SE 250 + Orius 200 EW 0.5 + 0.5 Prosaro EC 250 0.44	0.51 0.39 0.5	1.92 3.05 1.89
Hereford	10-05-2019 27-05-2019 13-06-2019	Prosaro EC 250 0.45 Propulse SE 250 + Orius 200 EW 0.5 + 0.5 Prosaro EC 250 0.44	0.51 0.39 0.5	1.92 3.05 1.89
Sheriff	23-05-2019 13-06-2019	Propulse SE 250 + Comet Pro 0.4 + 0.2 Prosaro EC 250 0.34	0.61 0.39	2.57 1.6
Informer	27-05-2019	Propulse SE 250 + Orius 200 EW 0.4 + 0.2	0.48	2.26
Creator	27-05-2019	Propulse SE 250 + Orius 200 EW 0.4 + 0.2	0.64	2.26

Cultivars (19350-2)	Date	Products, l/ha	TFI	Costs, hkg/ha
Susceptible mixture (Mixture S)	29-05-2019	Propulse SE 250 + Orius 200 EW 0.5 + 0.2	0.72	2.6
Resistant mixture (Mixture R)	29-05-2019	Propulse SE 250 + Orius 200 EW 0.4 + 0.2	0.64	2.3
Benchmark	29-05-2019	Propulse SE 250 + Orius 200 EW 0.5 + 0.2	0.72	2.6
Torp	29-05-2019	Propulse SE 250 + Orius 200 EW 0.5 + 0.2	0.72	2.6
Hereford	29-05-2019	Propulse SE 250 + Orius 200 EW 0.5 + 0.2	0.72	2.6
Sheriff	29-05-2019	Propulse SE 250 + Orius 200 EW 0.4 + 0.2	0.64	2.3
Informer	29-05-2019	Propulse SE 250 + Orius 200 EW 0.4 + 0.2	0.64	2.3
Creator	29-05-2019	Propulse SE 250 + Orius 200 EW 0.4 + 0.2	0.64	2.3

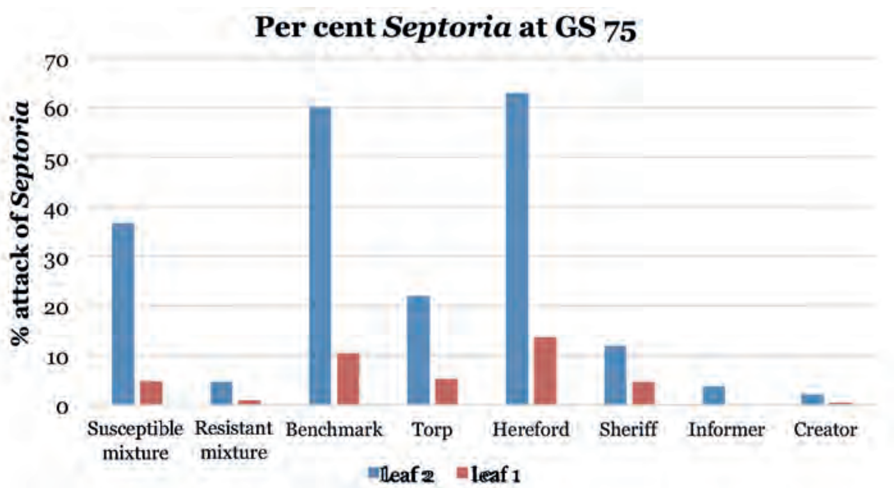


Figure 1. Data from untreated plots in the cultivar trials at both Flakkebjerg (19350-1) and LMO (19350-2), which show a variation in susceptibility to *Septoria* and overall lower level of attack in mixtures compared with single cultivars.

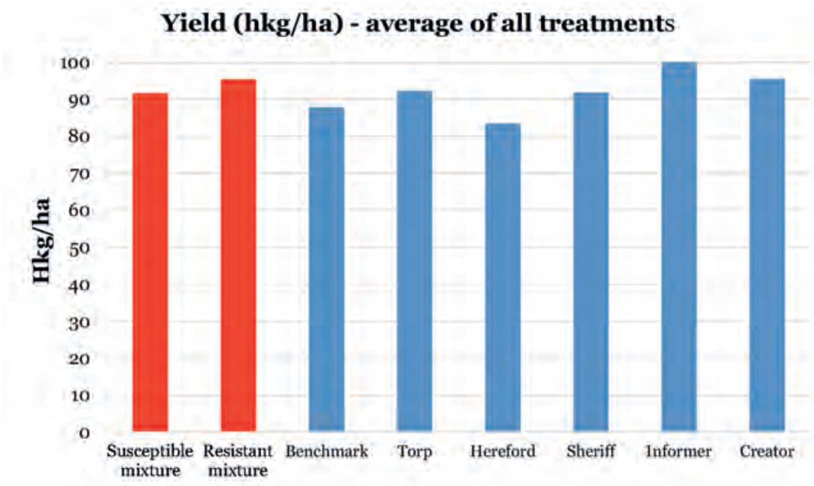


Figure 2. Data from cultivar trials at both Flakkebjerg (19350-1) and Horsens (19350-2), which show the overall yield level across treatments. Yields in mixtures were in susceptible cultivars better than the average of the individual cultivars. In resistant cultivars, the yield was similar or slightly inferior to the best of the component cultivars.

Drone photo from trial 19350-1, which included 6 cultivars and 2 cultivar mixtures. Eight different treatments were tested within each cultivar block.

Table 2. Per cent attack of *Septoria*, yellow rust, green leaf area and yield increases. Average of 2 trials (Flakkebjerg and Horsens) with 6 winter wheat cultivars, using 5 different fungicide treatments (19350). CPO = Crop Protection Online. Treatments with different letters are significantly different.

Cultivars	% *Septoria*, leaf 1, GS 75						% *Septoria*, leaf 2, GS 75					
	Untr.	1.25 Viverda + 1.0 Ultimate S	0.6 Viverda + 0.6 Ultimate S / 0.3 Bell + 0.15 Proline	0.35 Prosaro / 0.6 Viverda + 0.6 Ultimate S / 0.3 Bell + 0.15 Proline	0.35 Prosaro / 1.25 Viverda + 1.0 Ultimate S / 0.6 Bell + 0.3 Proline	CPO	Untr.	1.25 Viverda + 1.0 Ultimate S	0.6 Viverda + 0.6 Ultimate S / 0.3 Bell + 0.15 Proline	0.35 Prosaro / 0.6 Viverda + 0.6 Ultimate S / 0.3 Bell + 0.15 Proline	0.35 Prosaro / 1.25 Viverda + 1.0 Ultimate S / 0.6 Bell + 0.3 Proline	CPO
Mixture S	4.8	2.7	2.4	1.8	1.2	1.2	36.7	15.9	18.3	13.9	16.2	9.3
Mixture R	1.0	0.4	0.2	0.6	0.0	0.2	4.7	3.2	2.5	2.5	1.5	2.5
Benchmark	10.5	5.2	9.3	5.0	3.5	3.0	60.0	46.7	50.0	27.2	21.2	19.8
Torp	5.2	1.7	2.0	1.3	0.9	0.6	22.0	14.0	12.5	9.8	7.9	6.5
Hereford	13.7	4.0	5.2	4.0	1.7	2.0	63.3	31.7	38.3	29.2	17.3	17.5
Sheriff	4.7	1.3	1.2	1.2	0.8	1.2	12.5	7.3	6.5	7.3	4.7	7.0
Informer	0.2	0.1	0	0	0	0	3.7	3.2	2.4	3.2	1.7	3.0
Creator	0.5	0.2	0.3	0.2	0	0.1	2.1	1.2	1.8	1.7	1.2	1.4
Average	5.1 a	2.0 b	2.6 b	1.8 b	1.0 c	1.0 c	25.6 a	15.4 b	16.5 b	11.9 b	9.0 cd	8.4 cd
No. of trials	2						2					

Table 2. Per cent attack of *Septoria*, yellow rust, green leaf area and yield increases. Average of 2 trials (Flakkebjerg and Horsens) with 6 winter wheat cultivars, using 5 different fungicide treatments (19350). CPO = Crop Protection Online. Treatments with different letters are significantly different. (Continued)

Cultivars (19350-1)	% yellow rust, leaf 1, GS 61						% yellow rust, leaf 1, GS 75					
	Untr.	1.25 Viverda + 1.0 Ultimate S	0.6 Viverda + 0.6 Ultimate S / 0.3 Bell + 0.15 Proline	0.35 Prosaro / 0.6 Viverda + 0.6 Ultimate S / 0.3 Bell + 0.15 Proline	0.35 Prosaro / 1.25 Viverda + 1.0 Ultimate S / 0.6 Bell + 0.3 Proline	CPO	Untr.	1.25 Viverda + 1.0 Ultimate S	0.6 Viverda + 0.6 Ultimate S / 0.3 Bell + 0.15 Proline	0.35 Prosaro / 0.6 Viverda + 0.6 Ultimate S / 0.3 Bell + 0.15 Proline	0.35 Prosaro / 1.25 Viverda + 1.0 Ultimate S / 0.6 Bell + 0.3 Proline	CPO
Mixture S	0.2	0	0	0	0	0	5.7	0	0	0	0	0
Mixture R	1.0	0	0	0	0	0.3	1.7	0	0	0	0	0
Benchmark	10.3	3.3	0	0	0	0	26.7	6.7	5.0	0	0	3.3
Torp	0	0	0	0	0	0	0	0	0	0	0	0
Hereford	0	0	0	0	0	0	0	0	0	0	0	0
Sheriff	0	0	0	0	0	0	0	0	0	0	0	0
Informer	0	0	0	0	0	0	0	0	0	0	0	0
Creator	0	0	0.3	0.2	0	0	1.3	0	0	0	0	0
Average	1.3	0.4	0.0	0.0	0	0	4.4	0.8	0.6	0	0	0.4
No. of trials	1						1					

Table 2. Per cent attack of *Septoria*, yellow rust, green leaf area and yield increases. Average of 2 trials (Flakkebjerg and Horsens) with 6 winter wheat cultivars, using 5 different fungicide treatments (19350). CPO = Crop Protection Online. Treatments with different letters are significantly different. (Continued)

Cultivars	% green area, leaf 1, GS 85						TGW, g					
	Untr.	1.25 Viverda + 1.0 Ultimate S	0.6 Viverda + 0.6 Ultimate S / 0.3 Bell + 0.15 Proline	0.35 Prosaro / 0.6 Viverda + 0.6 Ultimate S / 0.3 Bell + 0.15 Proline	0.35 Prosaro / 1.25 Viverda + 1.0 Ultimate S / 0.6 Bell + 0.3 Proline	CPO	Untr.	1.25 Viverda + 1.0 Ultimate S	0.6 Viverda + 0.6 Ultimate S / 0.3 Bell + 0.15 Proline	0.35 Prosaro / 0.6 Viverda + 0.6 Ultimate S / 0.3 Bell + 0.15 Proline	0.35 Prosaro / 1.25 Viverda + 1.0 Ultimate S / 0.6 Bell + 0.3 Proline	CPO
Mixture S	0	0	0	3.3	53.3	0	36.8	40.4	39.3	40.2	43.3	41.4
Mixture R	41.7	33.3	23.3	17.3	31.7	31.7	40.0	41.6	42.9	42.8	44.7	41.7
Benchmark	0	0	25.0	3.3	3.3	0	33.2	36.2	37.5	38.9	41.6	40.6
Torp	5.0	25.0	3.3	15.0	16.7	16.7	36.2	38.7	39.6	39.3	40.3	40.3
Hereford	0	3.3	0	0	10.0	6.7	36.4	40.1	39.5	40.1	41.8	41.6
Sheriff	25.0	21.7	16.7	20.0	56.7	38.3	36.6	39.0	40.2	40.3	41.6	38.4
Informer	46.7	53.3	56.7	56.7	76.7	46.7	47.3	51.5	50.7	52.4	51.4	49.4
Creator	30.0	55.0	43.3	43.3	26.7	8.3	44.3	45.3	44.0	45.8	47.6	44.4
LSD_{95}							3.3					
Average	18.6 a	24.0 b	21.0 b	19.9 b	34.4 c	18.6 b	38.9 a	41.6 b	41.7 b	42.5 b	44.0 c	42.2 b
No. of trials	1						2					

Table 2. Per cent attack of *Septoria*, yellow rust, green leaf area and yield increases. Average of 2 trials (Flakkebjerg and Horsens) with 6 winter wheat cultivars, using 5 different fungicide treatments (19350). CPO = Crop Protection Online. Treatments with different letters are significantly different. (Continued)

Cultivars	Yield and increase, hkg/ha						Net increase, hkg/ha				
	Untr.	1.25 Viverda + 1.0 Ultimate S	0.6 Viverda + 0.6 Ultimate S / 0.3 Bell + 0.15 Proline	0.35 Prosaro / 0.6 Viverda + 0.6 Ultimate S / 0.3 Bell + 0.15 Proline	0.35 Prosaro / 1.25 Viverda + 1.0 Ultimate S / 0.6 Bell + 0.3 Proline	CPO	1.25 Viverda + 1.0 Ultimate S	0.6 Viverda + 0.6 Ultimate S / 0.3 Bell + 0.15 Proline	0.35 Prosaro / 0.6 Viverda + 0.6 Ultimate S / 0.3 Bell + 0.15 Proline	0.35 Prosaro / 1.25 Viverda + 1.0 Ultimate S / 0.6 Bell + 0.3 Proline	CPO
Mixture S	76.9	12.4	13.5	11.2	18.9	17.7	6.8	8.1	4.1	7.5	13.0
Mixture R	84.6	9.2	11.1	10.6	13.5	9.4	3.7	5.7	3.5	2.1	7.1
Benchmark	60.7	16.5	17.6	26.7	31.2	29.8	10.9	12.2	19.6	19.8	23.8
Torp	77.3	12.8	12.9	12.8	18.6	18.1	7.2	7.5	5.7	7.1	13.4
Hereford	67.6	14.4	10.7	15.1	19.8	21.1	8.8	5.3	8.0	8.4	16.4
Sheriff	82.5	8.2	9.3	8.9	13.5	6.7	2.6	3.9	1.8	2.1	3.5
Informer	92.7	6.5	7.5	8.5	11.6	3.7	0.9	2.1	1.4	0.2	1.4
Creator	86.3	9.5	9.4	6.6	13.4	5.6	4.0	4.0	-0.5	2.0	3.3
LSD_{95}	6.8										
Average	78.6 a	11.2 b	11.5 b	12.6 b	17.6 c	14.0 c	5.6	6.1	5.5	6.2	10.2
No. of trials	2						2				

Untr. = Untreated; 1.25 l/ha Viverda + 0.1 l/ha Ultimate S, GS 45-51 (costs = 5.6 hkg/ha); 0.6 l/ha Viverda + 0.6 l/ha Ultimate S, GS 37-39 / 0.3 l/ha Bell + 0.15 l/ha Proline EC 250, GS 55-61 (costs = 5.4 hkg/ha); 0.35 l/ha Prosaro EC 250, GS 32 / 0.6 l/ha Viverda + 0.6 l/ha Ultimate S, GS 37-39 / 0.3 l/ha Bell + 0.15 l/ha Proline EC 250, GS 55-61 (costs = 7.1 hkg/ha); 0.35 l/ha Prosaro EC 250, GS 32 / 1.25 l/ha Viverda + 1.0 l/ha Ultimate S, GS 37-39 / 0.6 l/ha Bell + 0.3 l/ha Proline EC 250, GS 55-61 (costs = 11.4 hkg/ha); CPO = Crop Protection Online.

Summary of results from 12 seasons validating Crop Protection Online

The trials validating the recommendations from CPO have been carried out during many seasons. A summary of data from 2008 to 2019 is shown in Figures 3-4. Each year 1-2 split plot trials were carried out including 6 different cultivars varying from susceptible to less susceptible cultivars. The data include the results from a susceptible and a resistant cultivar in each trial; in total 21 trials and 42 cultivars. The recommendations from CPO were compared with a one-, two- or three-spray strategy. Examples of strategies are shown below.

Strategy 1: One treatment using 33-75% standard rates (GS 39-45)
Strategy 2: Two treatments using 2 x 50% standard rates (GS 37-39 & 59-61)
Strategy 3: Three treatments using 3 x 50% standard rates (first treatment often mildew active) (GS 31-32, 37-39 & 59-61)

CPO input based on weekly assessments varies from 1-3 treatments with 35-50% standard rate depending on cultivar and year.

The following overall conclusions from the testing can be highlighted.

- The control of *Septoria* from all strategies was significant. A one-spray strategy was similar to a split strategy and a three-spray strategy slightly superior assessed on the 2nd leaf. CPO gave comparable control to fixed strategies although a bit more variable.
- Gross yield from strategies was very similar, although a more detailed analysis showed differences when cultivar susceptibility was included. As an average of the whole data set the one-spray strategy gave 8.1 hkg/ha, the two-spray strategy 9.3 hkg/ha, the three-spray strategy 10 hkg/ha and CPO 9.1 hkg/ha. Net yields were correspondingly 3.8, 3.8, 4.0 and 4.8 hkg/ha, respectively.
- When it comes to measuring the fungicide input from the different strategies, the input from CPO was in general lower and more variable, going from 0 to 2.9 TFI. The average input from the different strategies was 1.02, 1.39, 1.60 and 0.87 TFI, respectively, from the four strategies.
- Across the different seasons and cultivars CPO provided a comparable net yield, using 37% less fungicide compared with a two-spray strategy.

Septoria was the dominant disease in the trials testing Crop Protection Online during 12 seasons. The resistance level in the cultivars has a major impact on the cultivars' need for fungicide input. To the left a photo of a resistant cultivar and to the right a photo of a susceptible cultivar at GS 75.

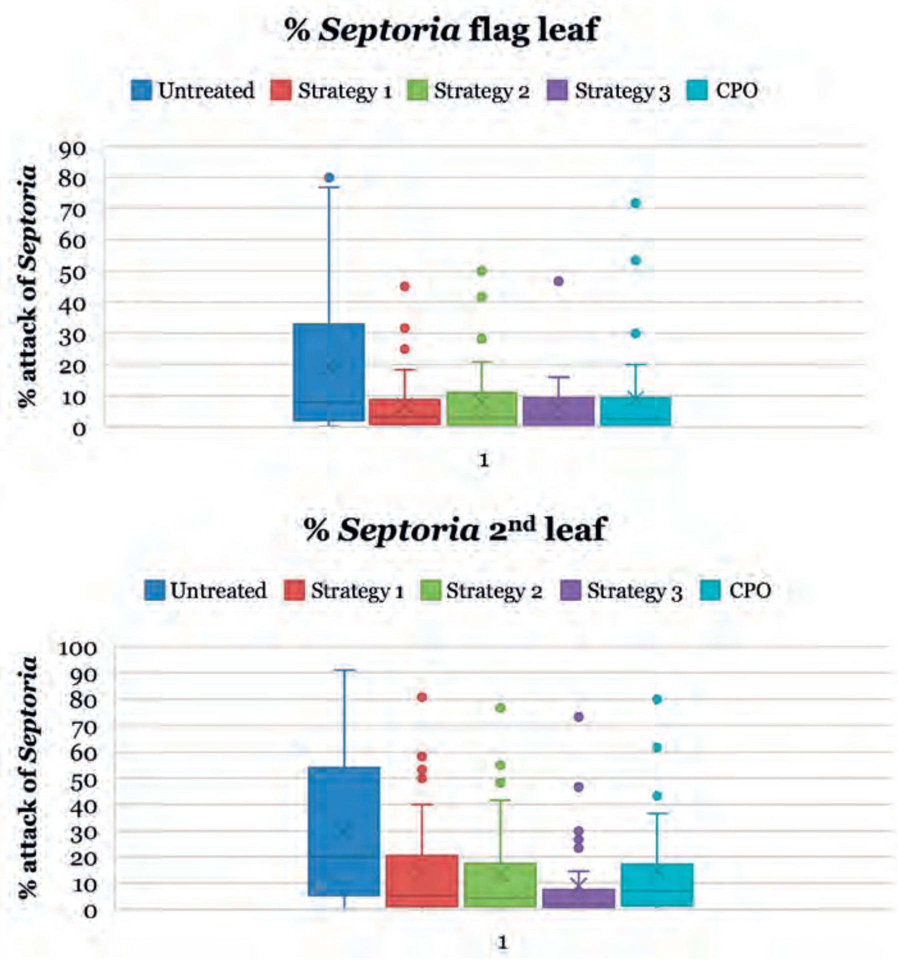


Figure 3. Data from 21 trials with 2 cultivars comparing 3 different strategies with CPO recommendations. Data show control of *Septoria* on the flag leaf and the 2nd leaf. Vertical lines indicate the median and "X" the mean.

Diseases in winter wheat	Examples of thresholds in CPO
Eyespot	>35% plants attacked at GS 30-32
Mildew	>10% plants attacked from GS 29 (Susceptible) >25% plants attacked from GS 29 (Resistant) After GS 40 no recommendations
Septoria	4 days with precipitation from GS 32 (S) 5 days with precipitation from GS 37 (R) Or attack on third leaf from GS 45-60
Brown rust	>25% plants attacked in susceptible cultivars
Yellow rust	GS 29-60 1% plants attacked in susceptible cultivars

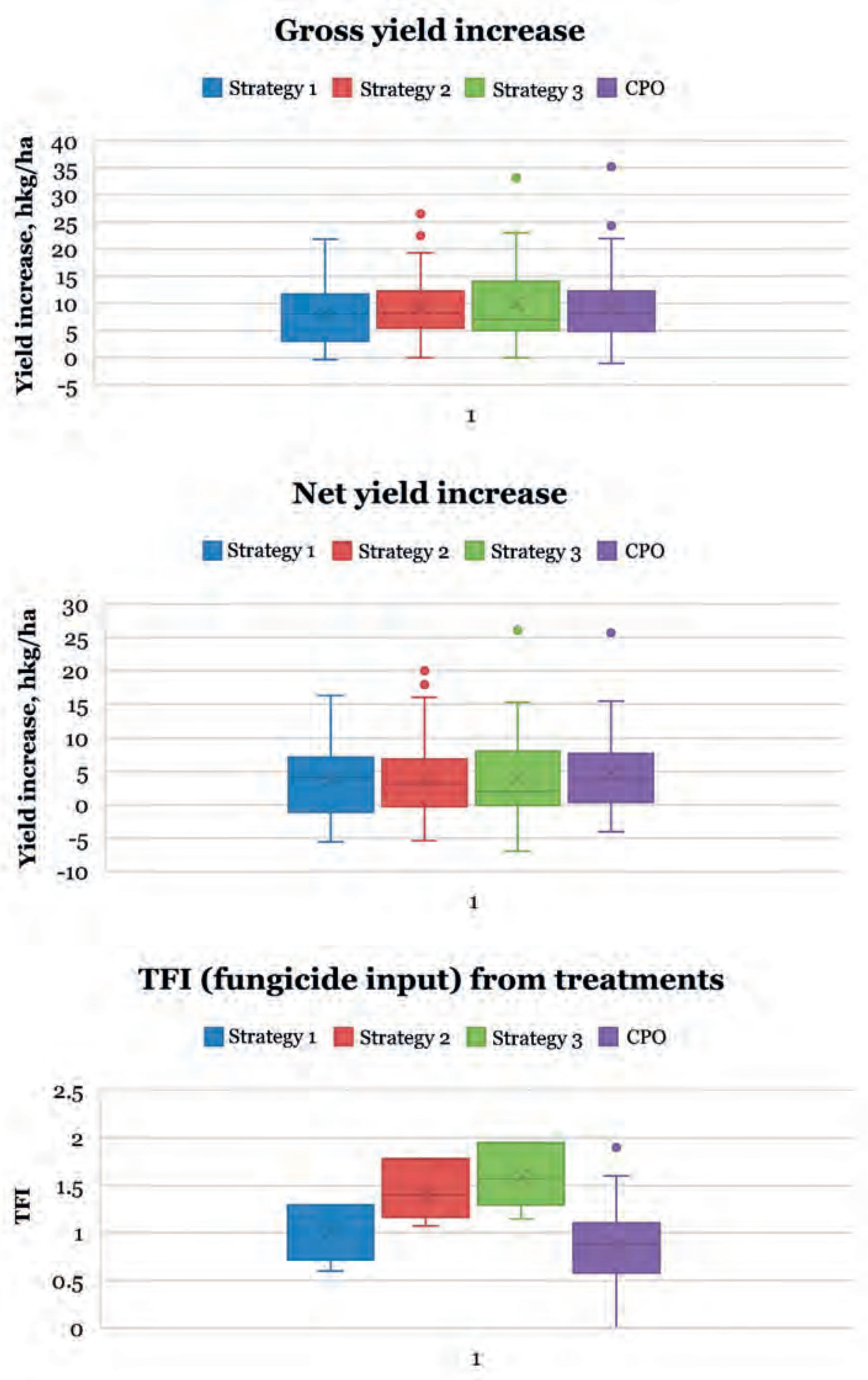


Figure 4. Data from 21 trials with 2 cultivars comparing 3 different strategies with CPO recommendations. Data show gross yield, net yield from treatments and the input of fungicides (TFI) from the different control strategies. Vertical lines indicate the median and “X” the mean.

Control strategies in different winter barley cultivars

Five different control strategies including a control and recommendations from Crop Protection Online were tested in four winter barley cultivars. One trial was located at Flakkebjerg and one at LMO near Horsens. The treatments given below were tested in the two trials (Table 3). Table 4 shows the results from the testing.

1. Untreated
2. 0.35 l/ha Prosaro EC 250 / 0.4 l/ha Balaya + 0.2 l/ha Entargo (GS 32 + GS 51) (TFI=1.11)
3. 0.5 l/ha Balaya + 0.25 l/ha Entargo (GS 37-39) (TFI=1.03)
4. 0.35 l/ha Prosaro EC 250 / 0.5 l/ha Propulse SE 250 + 0.3 l/ha Comet Pro (GS 32 + GS 51) (TFI= 1.21)
5. Crop Protection Online

The overall disease control of brown rust and net blotch from the different control strategies was satisfactory, including the CPO treatments, which performed slightly better for control of brown rust compared with other fixed strategies. The yield responses from treatments were relatively similar (8.8-10.6 hkg/ha), and overall the strategies provided very comparable gross and net yields (Figure 5).

Table 3. Treatments applied following recommendations from Crop Protection Online. Flakkebjerg (19351-1) and Horsens (19351-2).

Cultivars (19351-1)	Date	Products	TFI	Costs, hkg/ha
Frigg	25-04-2019 23-05-2019	Comet Pro + Propulse SE 250 0.21 + 0.26 Bell 0.5	0.17 + 0.29 0.6	4.9
Memento	25-04-2019	Comet Pro + Propulse SE 250 0.21 + 0.26	0.17 + 0.29	2.2
Celtic	25-04-2019 15-05-2019	Comet Pro + Propulse SE 250 0.21 + 0.26 Comet Pro + Propulse SE 250 0.28 + 0.34	0.17 + 0.29 0.23 + 0.38	4.9
Matros	25-04-2019	Comet Pro + Propulse SE 250 0.21 + 0.26	0.17 + 0.29	2.2

Cultivars (19351-2)	Date	Products	TFI	Costs, hkg/ha
Frigg	05-05-2019 15-05-2019	Comet Pro + Propulse SE 250 0.25 + 0.3 Comet Pro + Propulse SE 250 0.2 + 0.25	0.2 + 0.34 0.16 + 0.28	4.6
Memento	05-05-2019 15-05-2019	Comet Pro + Propulse SE 250 0.25 + 0.3 Comet Pro + Propulse SE 250 0.2 + 0.25	0.2 + 0.34 0.16 + 0.28	4.6
Celtic	05-05-2019 15-05-2019	Comet Pro + Propulse SE 250 0.25 + 0.3 Comet Pro + Propulse SE 250 0.2 + 0.25	0.2 + 0.34 0.16 + 0.28	4.6
Matros	05-05-2019 15-05-2019	Comet Pro + Propulse SE 250 0.25 + 0.3 Comet Pro + Propulse SE 250 0.2 + 0.25	0.2 + 0.34 0.16 + 0.28	4.6

Table 4. Control of diseases in winter barley and yield increases from 2 trials in 4 winter barley cultivars using 4 different strategies (19351). Treatments with different letters are significantly different.

Cultivars	% brown rust, leaf 1, GS 69					% brown rust, leaf 2, GS 69/71				
	Untr.	0.35 Prosaro / 0.4 Balaya + 0.2 Entargo	0.5 Balaya + 0.25 Entargo	0.35 Prosaro / 0.5 Propulse + 0.3 Comet Pro	CPO	Untr.	0.35 Prosaro / 0.4 Balaya + 0.2 Entargo	0.5 Balaya + 0.25 Entargo	0.35 Prosaro / 0.5 Propulse + 0.3 Comet Pro	CPO
Frigg	2.4	0.7	0.4	0.4	0.1	10.5	5.4	2.8	1.3	0.9
Memento	2.0	1.3	2.2	1.2	0.9	9.9	2.2	3.2	4.3	4.0
Celtic	11.7	6.7	1.5	6.3	0.7	26.7	8.5	6.7	9.7	5.0
Matros	1.5	1.3	0.2	0.8	0.2	11.7	1.9	1.7	1.8	1.7
Average	4.4	2.5	1.1	2.2	0.5	14.7	4.5	3.6	4.3	2.9
No. of trials	1					2				

Cultivars	% net blotch, leaf 2-3, GS 71					% green leaf area, leaf 2, GS 75				
	Untr.	0.35 Prosaro / 0.4 Balaya + 0.2 Entargo	0.5 Balaya + 0.25 Entargo	0.35 Prosaro / 0.5 Propulse + 0.3 Comet Pro	CPO	Untr.	0.35 Prosaro / 0.4 Balaya + 0.2 Entargo	0.5 Balaya + 0.25 Entargo	0.35 Prosaro / 0.5 Propulse + 0.3 Comet Pro	CPO
Frigg	1.8	7.9	0.5	0.2	0.2	3.0	42.0	30.0	50.0	43.0
Memento	3.2	1.2	1.0	1.9	0.7	0.0	38.0	27.0	30.0	20.0
Celtic	10.7	4.7	2.0	3.0	1.7	0.0	28.0	22.0	30.0	50.0
Matros	5.0	1.2	1.3	0.8	0.8	0.0	47.0	42.0	53.0	0.0
Average	5.2	3.8	1.2	1.5	0.9	0.8	38.8	30.3	40.8	28.3
No. of trials	1					1				

Cultivars	Yield and yield increase, hkg/ha					Net increase, hkg/ha			
	Untr.	0.35 Prosaro / 0.4 Balaya + 0.2 Entargo	0.5 Balaya + 0.25 Entargo	0.35 Prosaro / 0.5 Propulse + 0.3 Comet Pro	CPO	0.35 Prosaro / 0.4 Balaya + 0.2 Entargo	0.5 Balaya + 0.25 Entargo	0.35 Prosaro / 0.5 Propulse + 0.3 Comet Pro	CPO
Frigg	70.8	15.8	5.9	8.2	8.8	10.6	1.6	3.2	4.0
Memento	74.6	3.8	5.4	6.9	6.0	-1.4	1.1	1,9	2.6
Celtic	58.0	11.8	14.3	14.2	17.8	6.6	10.0	9.2	13.0
Matros	66.8	8.6	9.4	11.7	9.6	3.4	5.1	6.7	6.2
LSD_{95}	4.6 (2 trials)								
Average	67.6 a	10.0 b	8.8 b	10.3 b	10.6 b	4.8	4.5	5.3	6.5
Untr. = Untreated; 0.35 l/ha Prosaro EC 250, GS 32 / 0.4 l/ha Balaya + 0.2 l/ha Entargo, GS 51 (costs = 5.2 hkg/ha); 0.5 l/ha Balaya + 0.25 l/ha Entargo, GS 37-39 (costs = 4.3 hkg/ha); 0.35 l/ha Prosaro EC 250, GS 32 / 0.5 l/ha Propulse SE 250 + 0.3 l/ha Comet Pro, GS 51 (costs = 4.8 hkg/ha); CPO = Crop Protection Online.									

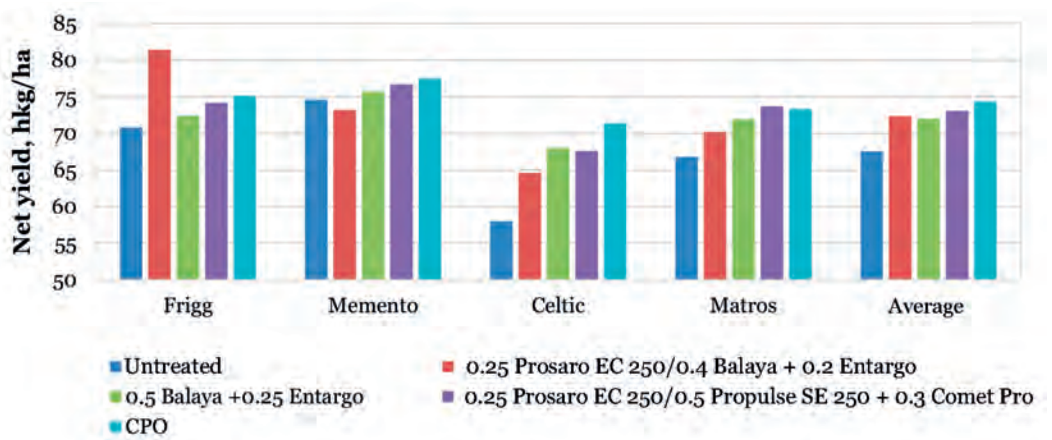


Figure 5. Net yield from different control strategies in 4 winter barley cultivars. Average of 2 trials (19351).

Control strategies in different spring barley cultivars

Five different control strategies including control and Crop Protection Online (CPO) were tested in four spring barley cultivars. One trial was located at Flakkebjerg and one at LMO near Horsens. The treatments given below were tested in the two trials. Table 5 shows the input recommended by CPO, and Table 6 shows a summary of the two trials.

1. Untreated
2. 0.35 l/ha Prosaro EC 250 / 0.4 l/ha Balaya + 0.2 l/ha Entargo (GS 31 + GS 51) (TFI=1.11)
3. 0.5 l/ha Balaya + 0.25 l/ha Entargo (GS 37-49) (TFI=1.03)
4. 0.35 l/ha Prosaro EC 250 / 0.5 l/ha Propulse SE 250 + 0.3 l/ha Comet Pro (GS 31 + GS 51) (TFI=1.21)
5. Crop Protection Online (CPO)

The overall disease control from the different control strategies was satisfactory including the CPO treatments. However, the performance of the CPO treatments was slightly inferior to strategies 2 and 4 for control of brown rust. The yield responses from the treatments were relatively similar but the two-spray strategies were better than the one-spray strategy as a result of the severe attack of brown rust. A look at the specific data from the Horsens trial (19352-2) indicates that two sprays should have been applied at this locality also.

Table 5. Treatments applied following recommendations from Crop Protection Online. Flakkebjerg (19352-1) and Horsens (19352-2).

Cultivars (19352-1)	Date	Products, l/ha	TFI	Costs, hkg/ha
Crossway	07-06-2019	Propulse SE 250 + Comet Pro 0.34 + 0.28 Propulse SE 250 + Comet Pro 0.3 + 0.3	1.16	5.36
Laurikka	07-06-2019	Propulse SE 250 + Comet Pro 0.34 + 0.28 Propulse SE 250 + Comet Pro 0.3 + 0.3	1.16	5.36
Evergreen	07-06-2019	Propulse SE 250 + Comet Pro 0.22 + 0.2 Propulse SE 250 + Comet Pro 0.3 + 0.3	0.96	4.68
KWS Irina	07-06-2019	Propulse SE 250 + Comet Pro 0.34 + 0.28 Propulse SE 250 + Comet Pro 0.3 + 0.3	1.16	5.36

Cultivars (19352-2)	Date	Products, l/ha	TFI	Costs, hkg/ha
Crossway	24-06-2019	Propulse SE 250 + Comet Pro 0.3 + 0.3	0.47	2.64
Laurikka	24-06-2019	Propulse SE 250 + Comet Pro 0.3 + 0.3	0.47	2.64
Evergreen	24-06-2019	Propulse SE 250 + Comet Pro 0.3 + 0.3	0.47	2.64
KWS Irina	24-06-2019	Propulse SE 250 + Comet Pro 0.3 + 0.3	0.47	2.64

Table 6. Control of diseases in spring barley and yield increases from 2 trials in 4 different spring barley cultivars using 5 different strategies. Untr. = Untreated. CPO = Crop Protection Online (Flakkebjerg (19352-1) and Horsens (19352-2). Treatments with different letters are significantly different.

Cultivars	% brown rust, leaf 2, GS 69/61					% brown rust, leaf 2, GS 73				
	Untr.	0.35 Prosaro / 0.4 Balaya + 0.2 Entargo	0.5 Balaya + 0.25 Entargo	0.35 Prosaro / 0.5 Propulse + 0.3 Comet Pro	CPO	Untr.	0.35 Prosaro / 0.4 Balaya + 0.2 Entargo	0.5 Balaya + 0.25 Entargo	0.35 Prosaro / 0.5 Propulse + 0.3 Comet Pro	CPO
Crossway	76.7	4.9	9.0	2.8	13.0	33.3	23.3	15.0	14.0	12.7
Laurikka	50.0	1.8	12.2	1.5	11.4	31.7	18.3	23.3	23.3	28.3
Evergreen	42.5	1.4	7.9	0.8	4.4	40.0	23.3	30.0	28.3	8.3
KWS Irina	48.3	9.2	19.2	4.5	17.5	21.7	23.3	25.0	26.7	36.7
LSD_{95}	-					15.8				
Average	54.4	4.3 a	12.1 b	2.4 a	11.6 b	31.7	22.1	23.3	23.1	21.5
No. of trials	2					1				

Cultivars	% net blotch, leaf 2, GS 73					% *Ramularia*, leaf 2/4, GS 73/61				
	Untr.	0.35 Prosaro / 0.4 Balaya + 0.2 Entargo	0.5 Balaya + 0.25 Entargo	0.35 Prosaro / 0.5 Propulse + 0.3 Comet Pro	CPO	Untr.	0.35 Prosaro / 0.4 Balaya + 0.2 Entargo	0.5 Balaya + 0.25 Entargo	0.35 Prosaro / 0.5 Propulse + 0.3 Comet Pro	CPO
Crossway	8.3	5.0	4.0	2.7	2.7	27.5	28.7	18.4	12.4	10.8
Laurikka	7.0	5.0	5.0	4.0	6.7	23.3	10.0	11.7	11.7	15.3
Evergreen	8.3	3.0	4.0	5.7	3.0	24.2	11.7	20.9	14.2	8.4
KWS Irina	5.7	5.0	4.0	6.7	8.3	15.9	11.8	18.4	13.5	23.0
LSD_{95}	4.7					-				
Average	7.3 a	4.5 b	4.3 b	4.8 b	5.2 b	22.7 a	15.6 b	17.4 b	13.0 b	14.4 b
No. of trials	1					2				

Cultivars	GLA %, leaf 1, GS 73/77					TGW, g/1000				
	Untr.	0.35 Prosaro / 0.4 Balaya + 0.2 Entargo	0.5 Balaya + 0.25 Entargo	0.35 Prosaro / 0.5 Propulse + 0.3 Comet Pro	CPO	Untr.	0.35 Prosaro / 0.4 Balaya + 0.2 Entargo	0.5 Balaya + 0.25 Entargo	0.35 Prosaro / 0.5 Propulse + 0.3 Comet Pro	CPO
Crossway	28.5	58.4	53.3	56.7	52.5	44.5	50.3	46.3	49.5	48.6
Laurikka	37.5	50.0	46.7	38.3	32.5	39.5	42.9	41.5	45.3	42.7
Evergreen	21.9	55.0	36.7	50.0	56.7	46.1	47.3	47.5	48.4	49.1
KWS Irina	41.7	54.2	49.2	29.2	26.2	43.2	47.4	45.3	50.0	47.7
LSD_{95}	15.5					2.7				
Average	32.4 a	54.4 b	46.5 b	43.5 ab	42.0 ab	43.3a	47.0 b	45.2 ab	48.3 b	47.0 b
No. of trials	1					2				

Cultivars	Yield and yield increase, hkg/ha					Net increase, hkg/ha			
	Untr.	0.35 Prosaro / 0.4 Balaya + 0.2 Entargo	0.5 Balaya + 0.25 Entargo	0.35 Prosaro / 0.5 Propulse + 0.3 Comet Pro	CPO	0.35 Prosaro / 0.4 Balaya + 0.2 Entargo	0.5 Balaya + 0.25 Entargo	0.35 Prosaro / 0.5 Propulse + 0.3 Comet Pro	CPO
Crossway	50.8	13.8	9.2	14.2	7.1	8.1	4.9	9.2	3.1
Laurikka	43.7	23.7	18.2	23.9	18.7	18.0	13.9	18.9	14.7
Evergreen	50.2	14.5	11.6	12.30	14.9	8.8	7.3	7.3	11.2
KWS Irina	45.6	14.4	7.6	18.1	10.8	8.7	3.3	13.1	6.8
LSD_{95}	6.9					-			
Average	47.6 a	16.6 b	11.7 c	17.1 b	12.9 c	11.4	7.4	12.1	8.9
No. of trials	2					2			

0.35 l/ha Prosaro EC 250, GS 31 / 0.4 l/ha Balaya + 0.2 l/ha Entargo, GS 51 (costs = 5.2 hkg/ha); 0.5 l/ha Balaya + 0.25 l/ha Entargo, GS 37-49 (costs = 4.3 hkg/ha); 0.35 l/ha Prosaro EC 250, GS 31 / 0.5 l/ha Propulse SE 250 + 0.3 l/ha Comet Pro, GS 51 (costs = 4.8 hkg/ha); CPO = Crop Protection Online.

IV Diseases in red fescue

Lise Nistrup Jørgensen, Hans Peter Madsen, Mogens Nicolaisen & Rumakanta Sapkota

During spring 2018 and 2019, 63 fields with red fescue distributed across Falster, Zealand and Funen were monitored for attacks of leaf diseases. The focus was to assess for leaf blotch diseases like Ascochyta leaf spot, causing different degrees of senescence in the crops. The attacks were frequent with attack typically in the range of 1-10%. The attack in 2019 was more severe than in 2018. The attack in 2nd and 3rd year crops was more severe than in 1st year crops. DNA analysis of the fungi populations on the leaf samples verified a wide range of fungi present in the fields. Application of fungicides has so far not proved to reduce attacks effectively.

Red fescue is grown on large areas every year, especially in the Eastern part of Denmark. The total area with red fescue typically varies between 15,000 and 20,000 ha per year. Traditionally, we have considered red fescue one of our healthiest herbage grass crops, which is rarely affected by serious disease attacks, and this has therefore also rarely responded positively to fungicide treatments. In recent years, however, positive yield responses from fungicide application were seen in some cases where a significant attack of leaf spot diseases was present.

In order to gain insight into how many fields are affected by leaf spot diseases, AU-Flakkebjerg investigated how commonly and severely fields were affected by leaf disease during two growing seasons. In addition, specific experiments were carried out to investigate whether one or two fungicide treatments in the spring can reduce the attacks of leaf spot and improve yield. The activity was funded by "Frøafgiftsfonden".

Diseases of importance

Apart from powdery mildew and rust diseases, Ascochyta leaf spot was the main focus of the investigation. The *Ascochyta* fungus is characterised by production of black spores (pycnidia), which typically form when the leaves wither. By microscopy of infected leaves, two cellular spores can be seen, which are spread from the spore housings.

During two growing seasons (2018 and 2019), monitoring was conducted and levels of leaf diseases in red fescue fields were assessed. The fields were chosen in collaboration with consultants from the seed companies. In addition to information on locality it was also recorded which varieties were cultivated and whether the fields were 1st, 2nd or 3rd year fields. In 2018, 30 fields were surveyed and 33 in 2019, divided into 3 regions with typically 10 fields per region (West Zealand, South Zealand + Falster, Funen + Tåsinge and Langeland). The data collected showed great variation in the incidence of attacks. For all the fields visited, an assessment was made of the attack rate at 10-20 spots at a cross-section of the field. In both seasons the fields were visited twice, the first time in April and the second time in June.

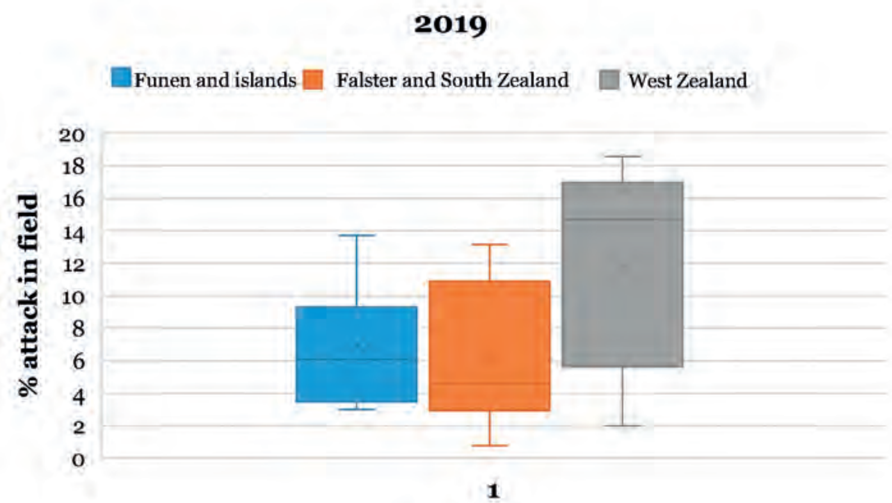
In general, the attacks in 2019 were significantly more severe than in 2018 (Table 1). Approximately 40% of all fields had more than 10% attack in 2019; the corresponding figure for 2018 was 13% of the fields. The attacks were most prevalent in South Zealand and Falster in 2018 and most prevalent in West Zealand in 2019. Data are summarised in Table 1 and Figure 1.

The monitoring included 8 1st year fields, 43 2nd year fields and 12 3rd year fields. Attack rates were on average 1%, 6% and 10% attacks, respectively. Thus, there was a tendency to stronger attacks in 2nd and 3rd year fields, indicating that the infection built up over time. The monitoring was carried out in more than 20 different varieties, and it was not possible to extract a clear picture of whether there was any variation of susceptibility depending on the actual cultivar.

Neither 2018 nor 2019 showed a clear development in the disease attacks from April to June. The 2018 season was extremely dry and conditions were generally not good for disease development. The 2019 season was more normal weather-wise, but no development was observed in the attacks in the season either going from April to June.

Table 1. Main data from monitoring attacks of leaf spot in red fescue fields assessed during two seasons. The numbers are frequency of fields attacked in the different categories.

Degree of attack in the field	Frequency of fields in the different categories	
	2018	2019
More than 10% leaf area attack	13	39
1-10% attack	60	58
< 1% attack	27	3
Number of fields	30	33



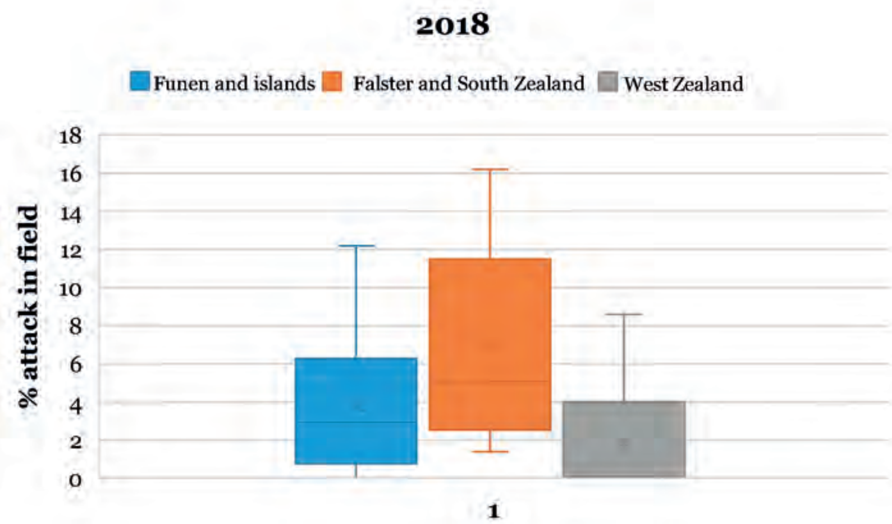


Figure 1. Percentage of leaf area attacked in red fescue fields monitored during 2018 and 2019.

Ascochyta disease is difficult to determine

From the literature, it is known that the *Ascochyta* fungus can also attack other grasses, i.a. Kentucky bluegrass (*Poa pratensis*). From the United States, it is described that the fungus survives on dead plant material or traces of trimming or cutting. The pycnidia are drought resistant, and the spores spread in humid weather conditions, including ”splash” from rain. But even in the United States, it is not clear which factors are the most important for epidemic attacks.

The symptoms of *Ascochyta* in the field are seen as dry leaves that can easily be mistaken for attack by other diseases or for drought stress. As part of the project, plant specimens with infestations were sampled during the monitoring. The samples were subsequently investigated in the laboratory to provide a better understanding of the diseases that appear and dominate in the studied fields.

Even after microscopy, it was not possible to distinguish clearly whether the leaf spot attacks were in all cases caused by *Ascochyta*, or whether other leaf spot fungi, e.g. infestation of fungi belonging to the *Helmintosporium* spp. group, were involved. As other leaf fungal species can easily be mistaken for *Ascochyta*, DNA was extracted from infected leaves and DNA libraries were prepared for DNA barcoding and sequenced. By comparing DNA sequences to existing DNA libraries, it was possible to get an overview of the fungi populations found on the ”diseased leaves”. The method provided information on the family and genus of the leaf fungal species. Only in few cases was it possible to track information to specific taxonomic species. The analysis covered all fungi on the leaves, not just those which we regarded as plant pathogens.

In total 41 samples from the two seasons were analysed using this technique. Many genera of fungi could be found from the leaf samples. Most dominant in the samples were *Oculimacula* (closely related to eyespot in cereals), *Neoascochyta* (= *Ascochyta*), *Cladosporium*, *Alternaria*, *Stagonospora*, *Microdochium* and *Puccinia* as well as various yeast fungi (Figure 2).

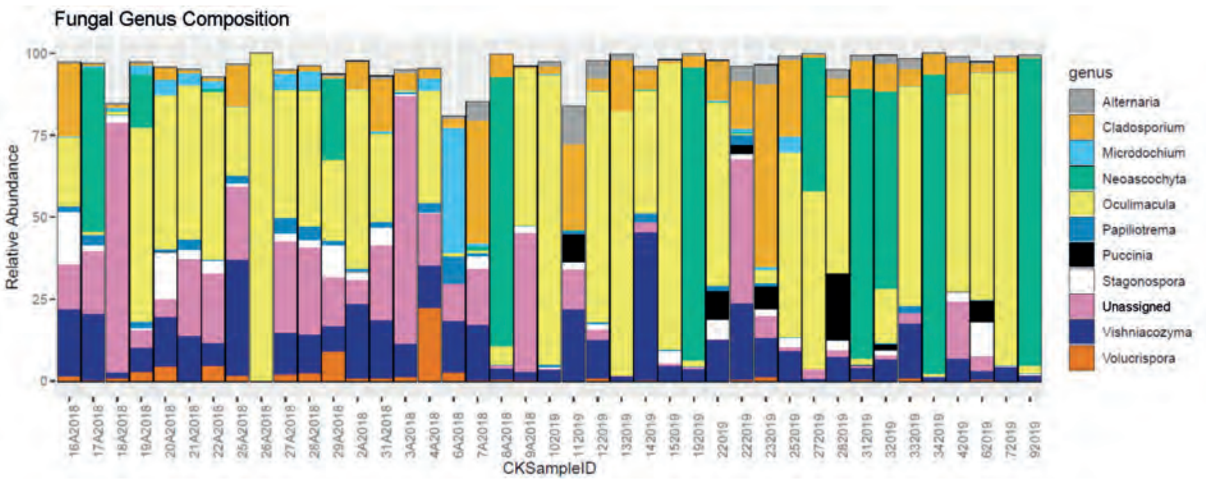
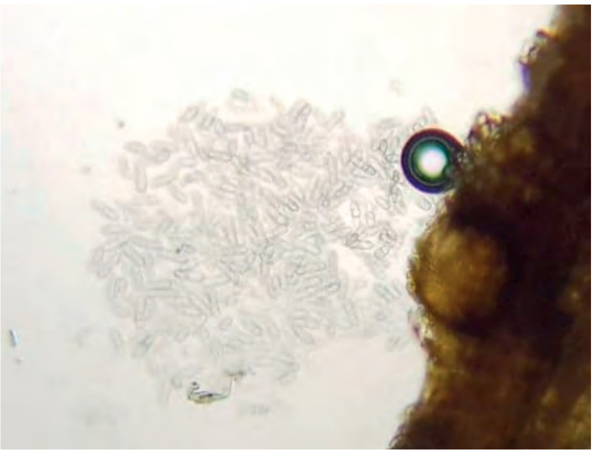


Figure 2. Distribution of dominant fungal genera in 41 samples harvested from 2 seasons assessed following DNA extraction and sequencing: *Oculimacula*, *Neoascochyta*, *Cladosporium*, *Stagonospora* along with some yeast fungi, plus other more rare genera.

Field trials with fungicides

In both growing seasons, trials were conducted to investigate if fungicides could control the attack. The trials were located in selected fields where leaf spot infestation was detected in early spring. In the experiments, broad-spectrum solutions including pyraclostrobin + boscalid (Bell) + pyraclostrobin (Comet Pro) were sprayed at two different times, at early spring and during stretch growth. After spraying, disease attacks were assessed in the trials, but it was not possible to see a clear visual reduction of the attacks in the treated plots compared to untreated plots, nor were significant additional yields obtained after treatment (Table 2). Monitoring for leaf spot diseases in red fescue will continue in 2020.



Spores from pycnidia spores of Ascochyta leaf spot can be seen in microscopy. (Photo: Ghita C. Nielsen).

Attack of Ascochyta leaf spot in red fescue. Necrotic leaves with dark lesions. (Photo: Lise Nistrup Jørgensen).

Field with 15% disease attack. (Photo: Hans-Peter Madsen).

Field with 1% disease attack. (Photo: Hans-Peter Madsen).

Table 2. Yield responses in 4 trials carried out in red fescue and sprayed during 2018 and 2019 (kg seeds/ha).

Fungicide treatments		2018		2019		
GS 33-37	GS 51-55	18398-1	18398-2	19398-1	19398-2	Average
Untreated		2223	1953	1380	1856	1853
Bell + Comet Pro 0.75 + 0.5		2297	1988	1312	1755	1838
Bell + Comet Pro 0.375 + 0.25		2219	1898	1413	1781	1828
Bell + Comet Pro 0.375 + 0.25	Bell + Comet Pro 0.375 + 0.25	2234	1932	1335	1828	1832
	Bell + Comet Pro 0.375 + 0.25	2258	1953	1425	1894	1883
Propulse SE 250 0.5	Bell + Comet Pro 0.375 + 0.25	2208	1904	1375	1947	1858
Comet Pro 0.63		2291	1963	1323	1741	1855
	Comet Pro 0.63	2269	1930	1447	1845	1873
Propulse SE 250 0.5	Comet Pro 0.63	2398	2070	1351	1897	1917
		NS	NS	NS	107	NS
NS: Not significant						

V Fungicide resistance-related investigations

Thies Marten Heick, Lise Nistrup Jørgensen, Hanne-Birgitte Christiansen & Birgitte Boyer Frederiksen

Fungicide resistance of *Zymoseptoria tritici* in Denmark and Sweden

The resistance level of the wheat pathogen *Zymoseptoria tritici* (*Z. tritici*) against the azoles epoxiconazole and prothioconazole and the SDHI fluxapyroxad was tested *in vitro* to survey the sensitivity of the Danish-Swedish *Z. tritici* population. Each year, leaf samples with apparent symptoms of *Z. tritici* are collected at growth stage 73-77 in collaboration with SEGES, Jordbruksverket in Sweden and local advisors. The resistance testing is carried out at AU Flakkebjerg. In 2019, a total of 209 Danish isolates from 21 sites and 341 Swedish isolates from 31 sites were investigated for sensitivity to prothioconazole-desthio and fluxapyroxad (Tables 1 and 4). The disease pressure was medium to high in 2019.

The sensitivity testing was carried out on microtitre plates. Single pycnidium isolates were used to produce spore suspensions by scraping off six-day-old *Z. tritici* spores and transferring them into Milli-Q water. Spore suspensions were homogenised and adjusted to a spore concentration of 2.4 x 10^4 spores ml^{-1}. Technical duplicates of each isolate were included in the study. Stock solutions of all three fungicides were made by dissolving the active ingredients (Sigma) in 80% ethanol. Those stock solutions were then utilised to prepare 2 x potato dextrose broth (PDB) mixtures to obtain the following final microtitre plate fungicide concentrations (ppm): 30, 10, 3.3, 1.0, 0.3, 0.1, 0.33, 0 (epoxiconazole), 6.0, 2.0, 0.6, 0.2, 0.07, 0.008, 0.002, 0 (prothioconazole-desthio) and 3.0, 1.0, 0.3, 0.1, 0.03, 0.01, 0.0033, 0 (fluxapyroxad). A total of 100 µl of spore suspension and 100 µl of fungicide solution were added to a 96-deep well microtitre plate. Microtitre plates were wrapped in tinfoil and incubated at 20°C for six days in the dark. Plates were visually analysed in an Elisa reader at 620 nm. Fungicide sensitivities were calculated as the concentration of a fungicidal compound, at which fungal growth *in vitro* is inhibited by 50% (EC_{50}) by a non-linear regression (curve fit) using GraphPad Prism (GraphPad Software, La Jolla, CA, USA). The isolates IPO323 and OP15.1 were used as reference isolates.

Results - *Denmark*

Prothioconazole-desthio has been included in the testing since 2016 to replace prothioconazole. In 2019, the average EC_{50} value for the Danish *Z. tritici* isolates with 0.26 ppm was slightly lower than in 2018 (0.33 ppm) (Figure 1; Table 2). The resistance factor (RF; EC_{50} value isolate/EC_{50} value reference isolate) for prothioconazole-desthio was 26 compared to 35 and 32 in the years before. It is difficult to compare results for prothioconazole from previous years, as there are no clear correlations between those two chemical compounds. Furthermore, there was no clear cross-resistance between epoxiconazole and prothioconazole-desthio in previous years. From 2017 to 2018, a significant shift in azole sensitivity took place for epoxiconazole (EC_{50} in 2016: 1.39 ppm; 2017: 1.81 ppm; 2018: 4.52 ppm; Table 2). Only a subset of 18 Danish *Z. tritici* isolates was tested for sensitivity towards epoxiconazole in 2019. No further shift has occurred, and the average EC_{50} for epoxiconazole was lower than in 2018 (2.03 ppm). However, all isolates tested still had an EC_{50} value of > 1 ppm.

The resistance levels of the SDHI fluxapyroxad were at the same low level in 2019 as in 2018 with an average resistance factor of 2, indicating that the Danish *Z. tritici* population remains sensitive towards SDHI fungicides (Table 1; Figure 2).

Table 1. Mean EC_{50} values and resistance factors (RF) for prothioconazole-desthio and fluxapyroxad from different sites in 2019 for *Z. tritici* screened.

Location			EC_{50} (ppm)				Number
			Prothio-desthio	RF	Fluxa	RF	
19-ZT-DK-	1	Horsens,LMO	0.37	37	0.20	1	18
19-ZT-DK-	2	Flakkebjerg	0.14	14	0.15	1	20
19-ZT-DK-	3	Sejet	0.77	77	0.23	1	10
19-ZT-DK-	4	Falster	0.24	24	0.63	4	1
19-ZT-DK-	5	Skive	0.22	22	0.15	1	10
19-ZT-DK-	6	Djursland	0.38	38	0.06	0	10
19-ZT-DK-	7	Ringsted	0.11	11	0.08	1	8
19-ZT-DK-	8	Brønderslev	0.71	71	0.51	3	10
19-ZT-DK-	9	Vollerup	0.11	11	0.07	0	2
19-ZT-DK-	10	Odense	0.23	23	0.06	0	10
19-ZT-DK-	11	Vojens	0.09	9	0.15	1	10
19-ZT-DK-	12	Odense	0.20	20	0.64	4	8
19-ZT-DK-	13	Odense	0.21	21	0.25	2	9
19-ZT-DK-	14	Åbenrå	0.26	26	1.52	9	10
19-ZT-DK-	15	Rønnede	0.09	9	0.08	0	9
19-ZT-DK-	16	Ålborg	0.12	12	0.27	2	9
19-ZT-DK-	17	Rønde	0.13	13	0.07	0	10
19-ZT-DK-	18	Rønne	0.40	40	0.09	1	9
19-ZT-DK-	19	Rønne	0.27	27	0.21	1	10
19-ZT-DK-	20	Horsens	0.10	10	0.20	1	10
19-ZT-DK-	21	Spøttrup	0.44	44	0.23	1	7
19-ZT-DK-	22	Vojens	0.20	20	0.15	1	9
Average			0.26	26	0.27	2	209

Table 2. Summary of mean EC_{50} (ppm) values and resistance factors (RF) for epoxiconazole, prothioconazole-desthio and fluxapyroxad assessed for *Z. tritici* in Denmark. The total numbers of isolates tested are given in brackets.

Year	Epoxiconazole	RF	Prothio-desthio	RF	Fluxapyroxad	RF
2012	0.30 (40)	15	-	-	-	-
2013	0.36 (133)	18	-	-	-	-
2014	0.50 (290)	25	-	-	-	-
2015	0.45 (262)	17	-	-	-	-
2016	1.39 (220)	66	0.13 (26)	17	-	-
2017	1.81 (272)	94	0.32 (263)	32	-	-
2018	4.52 (155)	212	0.33 (155)	35	0.26 (155)	2
2019	2.03 (18)	102	0.26 (209)	26	0.27 (209)	2
Ref. IPO323	0.02 - 0.03	-	0.01	-	0.10 - 0.20	-

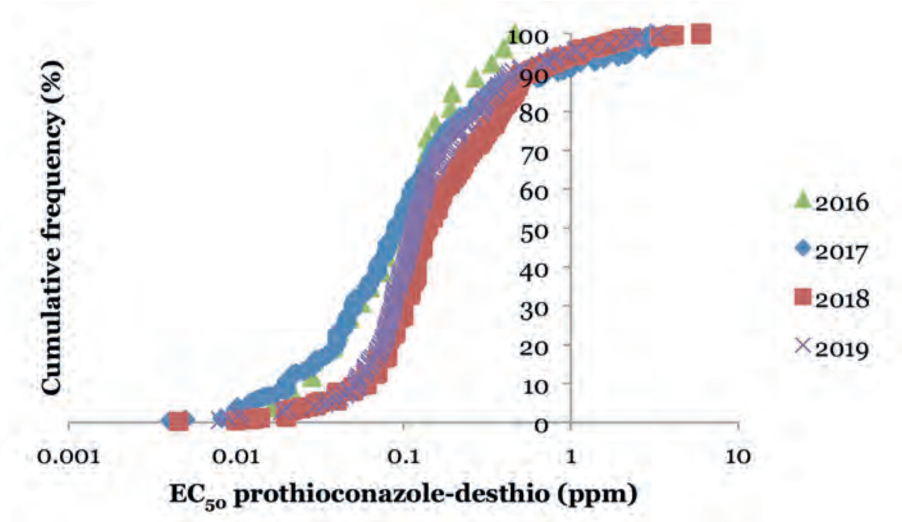


Figure 1. Cumulative frequencies of EC_{50} values of prothioconazole-desthio (ppm) for Danish *Z. tritici* populations 2016-2019. Each point of the curve represents a single *Z. tritici* isolate.

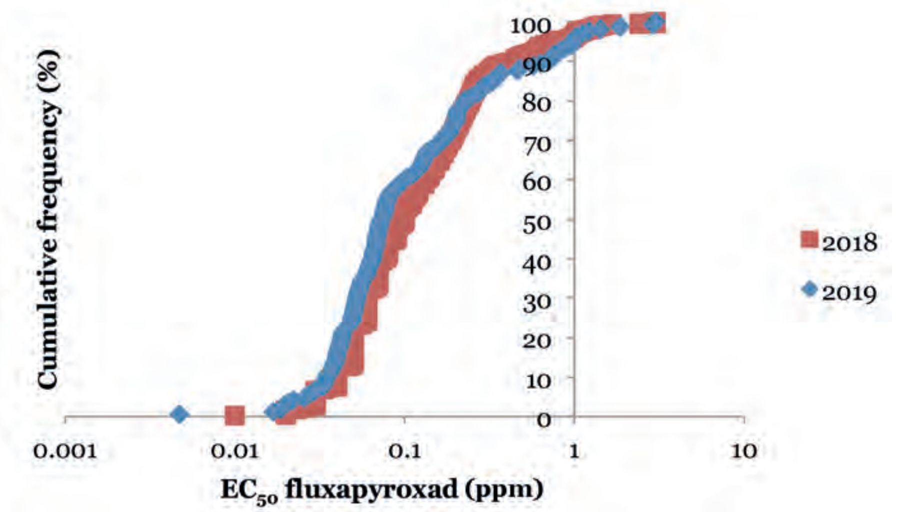


Figure 2. Cumulative frequencies of EC_{50} values of fluxapyroxad (ppm) for *Z. tritici* populations in Denmark in 2018 and 2019.

Table 3. Summary of measured EC_{50} (ppm) values and resistance factors (RF) for epoxiconazole, prothioconazole-desthio and fluxapyroxad assessed for *Z. tritici* in Sweden. The total numbers of isolates tested are shown in brackets.

Year	Epoxiconazole	RF	Prothio-desthio	RF	Fluxapyroxad	RF
2012	0.36 (211)	18	-	-	-	-
2013	0.65 (170)	33	-	-	-	-
2014	0.27 (337)	35*	-	-	-	-
2015	0.33 (227)	12	-	-	-	-
2016	0.52 (212)	24	-	-	-	-
2017	3.17 (163)	170	0.58 (150)	71	-	-
2018	4.53 (127)	181	0.35 (127)	35	0.19 (127)	2
2019	1.15 (25)	58	0.17 (341)	17	0.09 (341)	1
Ref. IPO323	0.02 - 0.03	-	0.01	-	0.10 - 0.20	-

Table 4. Results from individual sites in Sweden with data from sensitivity testing for *Z. tritici* tested for prothioconazole-desthio and fluxapyroxad.

Location			EC_{50}				
			Prothio-desthio	R factor	Fluxa	R factor	Number
19-ZT-SWE-	1	Skövde	0.03	3	0.06	0	20
19-ZT-SWE-	2	Motala	0.06	6	0.19	1	20
19-ZT-SWE-	3	Simrishamn	0.21	21	0.04	0	20
19-ZT-SWE-	4	Smedby, Kalmar	0.04	4	0.03	0	10
19-ZT-SWE-	5	Vickleby, Färjestaden	0.06	6	0.03	0	10
19-ZT-SWE-	6	Albrunna, Degerhamn	0.07	7	0.06	0	8
19-ZT-SWE-	7	Nybble, Örebro	0.06	6	0.08	0	9
19-ZT-SWE-	8	Julita, Äsköping	0.11	11	0.04	0	10
19-ZT-SWE-	9	Skrukeby, Mjölby	0.03	3	0.04	0	10
19-ZT-SWE-	10	St. Åby, Ödeshög	0.59	59	0.09	1	9
19-ZT-SWE-	11	Glyttinge, Linköping	0.11	11	0.12	1	10
19-ZT-SWE-	12	Förråd, Linghem	0.08	8	0.10	1	10
19-ZT-SWE-	13	Skälsund, Norrköping	0.21	21	0.14	1	10
19-ZT-SWE-	14	Ullekalv, Skänninge	0.04	4	0.14	1	10
19-ZT-SWE-	15	Germundsgård, Nossebro	0.06	6	0.17	1	10
19-ZT-SWE-	16	Baggård, Grästorp	0.36	36	0.09	1	8
19-ZT-SWE-	17	Emtunga Gård, Vara	0.32	32	0.10	1	10
19-ZT-SWE-	18	Heljerud, Brålanda	0.60	60	0.13	1	10
19-ZT-SWE-	19	Hedegård, Mellerud	0.49	49	0.12	1	8
19-ZT-SWE-	20	Forsby, Skövde	0.42	42	0.17	1	6
19-ZT-SWE-	21	Lilla Vallskog, Uppsala	0.03	3	0.04	0	10
19-ZT-SWE-	22	Hagby	0.02	2	0.02	0	10
19-ZT-SWE-	23	Sigtuna, Stockholm	0.03	3	0.03	0	10
19-ZT-SWE-	24	Folingbo, Visby	0.03	3	0.05	0	10
19-ZT-SWE-	25	Kattarp, Helsingborg	0.11	11	0.36	2	10
19-ZT-SWE-	26	Vallby, Trelleborg 1	0.60	60	0.16	1	10
19-ZT-SWE-	27	Löderup, Ystad	0.16	16	0.09	1	9
19-ZT-SWE-	28	Hviderup, Eslöv	0.12	12	0.06	0	8
19-ZT-SWE-	29	Smedstrorp, Tomelilla	0.14	14	0.04	0	8
19-ZT-SWE-	30	Bösild, Halmstad	0.07	7	0.06	0	10
19-ZT-SWE-	31	Brunnby, Västerås	0.05	5	0.02	0	9
19-ZT-SWE-	32	Väsby, Tierp	0.03	3	0.03	0	9
19-ZT-SWE-	33	Haga, Enköping	0.27	27	0.02	0	10
Average			0.17	18	0.09	1	341

Results - *Sweden*

As in Denmark, a significant shift in EC_{50} values for epoxiconazole took place in 2017. In 2018, the sensitivity towards this active ingredient continued to decrease (EC_{50} in 2018: 4.53 ppm; 2017: 3.17 ppm; Tables 3-4). In 2019, the resistance level was lower; however, the mean EC_{50} value was still above 1 ppm. EC_{50} values for prothioconazole-desthio were with an average of 0.17 ppm slightly lower in Sweden in 2019 than in previous years (Figure 3; Table 3) and lower than Danish populations in 2019 (0.26 ppm). The results varied among sites (0.03-0.60 ppm). However, in 2019 the EC_{50} were more similar across the country compared to previous years (Table 4). The results for fluxapyroxad were in line with the Danish results (Figure 4) with an average resistance factor of 1.

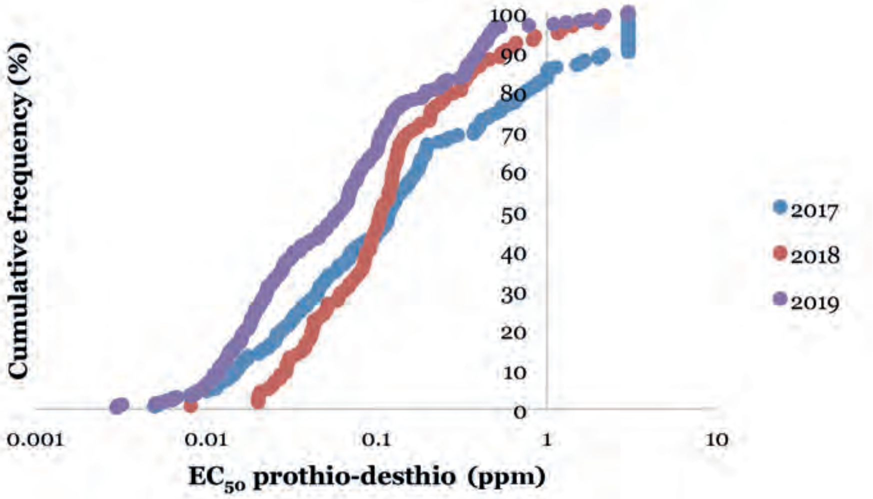


Figure 3. Cumulative frequencies of EC_{50} values of prothioconazole-desthio (ppm) for *Z. tritici* populations in Sweden in 2017-2019.

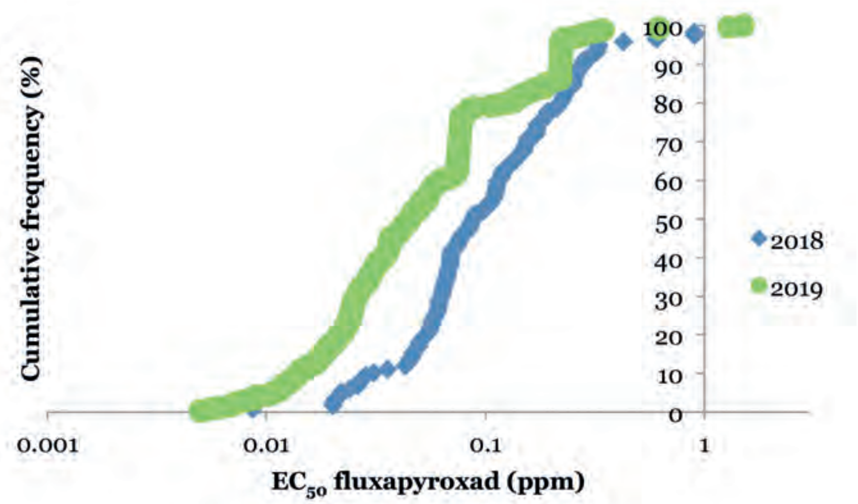


Figure 4. Cumulative frequencies of EC_{50} values of fluxapyroxad (ppm) for *Z. tritici* populations in Sweden in 2018 and 2019.

The sensitivity of difenoconazole and tebuconazole

A subset of 50 *Z. tritici* isolates from Denmark and Sweden was tested for sensitivity to the azoles tebuconazole and difenoconazole. The resistance level for tebuconazole has been at a high level for many years. In 2019, the average EC_{50} value was 6.79 ppm (2018: 6.21 ppm) with single isolates ranging from 0.15 to 30.00 ppm. The average EC_{50} was higher in Denmark (8.20 ppm) than in Sweden (5.91 ppm). The average RF for tebuconazole was > 1000 (reference isolate IPO323: 0.006 ppm). Those values were in line with results from 2018 where the average EC_{50} for *Z. tritici* from Denmark and Sweden was 6.21 ppm with an average RF of > 1000. EC_{50} values for difenoconazole ranged from 0.01 to 0.50 ppm, with an average EC_{50} value of 0.08 ppm and a resistance factor of 10, indicating the presence of a few slightly adapted isolates in the Scandinavian *Z. tritici* population.

***CYP51* mutations in the Danish-Swedish *Z. tritici* populations 2019**

The decline of azole effectivity has been linked to molecular changes in the target gene *CYP51*. In 2019, single isolates from Denmark and Sweden were analysed by Sanger sequencing and qPCR (KASP) for the frequency of the essential *CYP51* mutations in *Z. tritici*: D134G, V136A/C, I381V and S524T (Figure 5). Mutation I381V continued to dominate throughout the region and was present in frequencies of

90-100%. The frequencies for mutations D134G, V136A/C and S524T, all of which have emerged in the past ten years in the Northern European *Z. tritici* population, varied from 6% to 66%. The evolution of *CYP51* mutations in Denmark is illustrated in Figure 5.

Compared to 2018 and in recent years, the frequencies in 2019 remain more and less at the same level. *Z. tritici* populations in the Baltic countries and Finland begin to resemble those in Denmark and Sweden, indicating that the evolution in the *CYP51* gene has reached the north-eastern parts of Europe (data not shown).

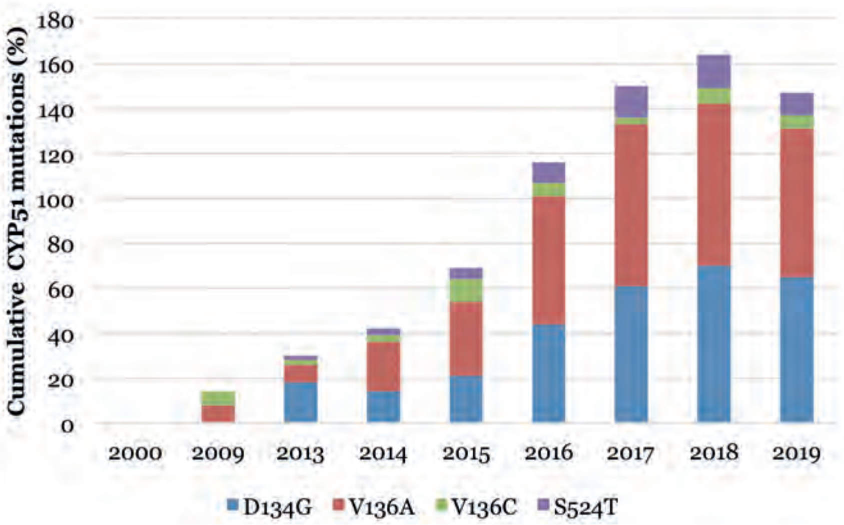


Figure 5. Cumulative frequencies of CYP51 mutations D134G, V136A/C, and S524T for the Danish *Z. tritici* populations 2000-2019.

Sdh mutations conferring resistance to SDHI fungicides

Several point mutations in the *Sdh* subunits have been associated with high EC_{50} values. In 2017 and 2018, the first isolates harbouring the C-T79N mutation were found in Denmark. In Sweden, both in 2017 and 2018, a few isolates were tested positive for the presence of the C-N86S mutation. Again in 2019, single isolates were found with C-T79N in Denmark. It must be stated that *Sdh* mutations exist in the Danish-Swedish *Z. tritici* populations; however, at very low frequencies, and with no field impact yet.

Strobilurin and SDHI resistance in net blotch

In 2019, a total of 19 leaf samples with net blotch (*Pyrenophora teres*) symptoms were collected. The samples were collected by AU Flakkebjerg, SEGES and Jordbruksverket and originated from untreated field trials and farmers' fields. Twelve samples came from Danish fields, seven samples from Swedish fields.

As in previous years, BASF carried out an investigation for point mutation, associated with fungicide resistance. The effect of the F129L mutation on strobilurin field performance is only a partial effect. The data from Denmark show that the level of F129L has remained stable and has not changed. Overall, F129L was found in 83% of all Danish samples. The majority harboured the mutation with < 60%. Furthermore, seven Swedish samples were investigated, three of which were tested negative for F129L, two with < 20% and three with a frequency between 20 and 60% (Table 5).

No *Sdh* mutations were found, with the exception of one locality in Denmark where D-D145G was found.

Table 5. Incidence of the F129L mutation in Danish net blotch samples.

Year	No. of samples	No. without F129L	No. with 1-20%	No. > 20-60%	No. > 60%	No. of samples with F129L %
2008	20	9	5	3	3	55
2009	44	18	7	13	6	59
2010	16	5	3	7	1	69
2011	34	13	4	12	5	62
2012	19	14	1	2	2	24
2013	25	17	2	4	2	32
2014	20	13	2	3	2	35
2015	8	3	0	3	0	38
2016	20	9	3	8	0	55
2017	20	2	4	2	2	80
2019	12	2	3	3	4	83

Genetic analysis of QoI-resistance of *P. tritici-repentis* 2019

Two *P. tritici-repentis* samples from Flakkebjerg were tested for QoI mutations. The cytb G143A mutation was present in both samples with frequencies of approx. 80%.

VI Fungicide strategies against powdery mildew resistance in sugar beet

Thies Marten Heick[1], Anne Lisbet Hansen[2], Annemarie Fejer Justesen[1] & Lise Nistrup Jørgensen[1]

[1] Aarhus University, [2] NBR, Nordic Beet Research

Summary

Two field trials were carried out to test different fungicide control strategies on powdery mildew (*Erysiphe betae*) and to minimise the spread of strobilurin resistance. The treatments included registered products as well as new products including Propulse SE 250 and Revysol. As examples of alternative products, Serenade ASO (Bacillus amyloliquefaciens QST 713) and Kumulus S (sulphur) were also included. All fungicide treatments controlled powdery mildew and rust effectively. Kumulus S reduced powdery mildew significantly and was comparable to the fungicide solutions. Serenade ASO showed only a low effect on powdery mildew. Powdery mildew samples from Denmark and Sweden were tested for strobilurin resistance in 2019. Two samples from Denmark and two samples from Sweden were tested positive for strobilurin resistance in a trial under controlled conditions. All four samples harboured the point mutation G143A, which has been associated with strobilurin resistance. The results from this project show that strobilurin resistance in powdery mildew in sugar beet is a real risk. Furthermore, the results show that powdery mildew can still be effectively controlled and that spray strategies, which may lower the risk of spreading strobilurin resistance are an option.

Field trials

In a collaboration between Aarhus University and NBR, Nordic Beet Research, investigations were initiated to improve the control of powdery mildew in sugar beet. In the project 'Fungicide resistance in powdery mildew in sugar beet (*Erysiphe betae*)' the effect of different control strategies against fungal leaf diseases in sugar beet were tested (Table 1). Two randomised field trials were set up in Guldborg (Lolland) and Flakkebjerg (Zealand). The trials were sown at the beginning of April, and in both trials the cultivar Lombok was used, which is known to be susceptible to powdery mildew and moderately susceptible to rust (*Uromyces betae*). The trials were treated two to three times before disease onset in week 30 (T0), at disease onset in week 31 (T1) and in week 34 (T2). Leaf diseases were scored at 10-day intervals on a scale of 0 to 100 (100 = 100% attacks).

Powdery mildew and rust were the predominant diseases. *Cercospora beticola* and *Ramularia beticola* appeared late and at a low level. Mildew attacks occurred earlier and developed more in Guldborg than in Flakkebjerg, with attacks of 90% and 65% in the untreated check, respectively.

Table 1. Fungicide spray programme tested against fungal leaf diseases in sugar beet.

Trt	T0 (week 30)	T1 (week 31)	T2 (week 34)
1		Untreated	
2		0.5 l/ha Opera	0.5 l /ha Opera
3		0.5 l/ha Revysol + 0.18 l/ha Comet Pro	0.5 l/ha Revysol + 0.18 l/ha Comet Pro
4		0.62 l/ha Comet Pro	0.62 l/ha Comet Pro
5		0.5 l/ha Amistar Gold	0.5 l/ha Amistar Gold
6		0.5 l/ha Propulse SE 250	0.5 l/ha Amistar Gold
7		0.5 l/ha Revysol + 0.18 l/ha Comet Pro	0.25 l/ha Amistar Gold
8		1 l/ha Revysol + 0.375 l/ha Comet Pro	0.5 l/ha Amistar Gold
9	4 l/ha Serenade ASO	4 l/ha Serenade ASO	4 l/ha Serenade ASO
10	4 l/ha Serenade ASO	0.62 l/ha Comet Pro	4 l/ha Serenade ASO
11	5 kg/ha Kumulus S	5 kg/ha Kumulus S	5 kg/ha Kumulus S
12	5 kg/ha Kumulus S	0.62 l/ha Comet Pro	5 kg/ha Kumulus S

Two treatments (trt) at T1 and T2 reduced attacks of mildew significantly compared to the untreated control (Figure 1). No differences were found among spray programmes (trt 2 to 8). Two treatments with 0.5 l/ha Revysol and 0.18 l/ha Comet Pro (trt 3) performed equally well as the standard recommendation of two times 0.5 l/ha Opera. The effect of two applications of 0.5 l/ha Amistar Gold (trt 5) was inferior compared to the other fungicide solutions, particularly for rust control and at later assessment dates. However, there were no statistical differences. The control of spray programmes with different fungicides used at T1 and T2 (trt 6 to 8) was in line with the standard treatment. Those spray programmes can be regarded as an alternative to two times 0.5 l/ha Opera, which also help to reduce the spread of strobilurin resistance in powdery mildew. Three applications of 5 kg/ha sulphur Kumulus S (trt 11) showed a high effect against powdery mildew. The same strategy with 0.62 l/ha Comet Pro at T1 instead of Kumulus S showed a very high control of both moderate and high levels of attack. The application of three times 4 l/ha Serenade ASO (trt 9) had a low effect only at the early assessment dates. The effect of Serenade ASO improved when alternated with 0.62 Comet Pro l/ha at T1 (trt 10). Results, however, varied between the two field trials (Figure 1).

Infection of rust in untreated was moderate to high; between 26% at the site in Guldborg and 63% in Flakkebjerg (Figure 2). In the latter field trial, spray programmes with fungicides started at T1 controlled rust at a high level. The spray programmes that had an application of 0.5 l/ha Amistar Gold at T2 were slightly inferior at later assessments (trt 5-7). However, the effect of treatment 8 with a higher dose of Revysol followed by 0.5 l/ha Amistar Gold was at the same level as the standard recommendation (trt 2). Generally, fungicide treatments had a low effect in the field trial in Guldborg. The treatments with Kumulus S and Serenade ASO were inferior to all fungicide solutions controlling rust (Figure 2).

All spray programmes including fungicides resulted in higher root yield and higher sugar content (data not shown). Also treatments with Kumulus S and treatment 10 (Serenade ASO - Comet Pro - Serenade ASO) increased the root weight and sugar content. No significant differences were seen for yield parameters after a fungicide treatment. Only trt 9 with three applications of Serenade ASO resulted in significantly lower yields.

Attacks of powdery mildew and rust on sugar beet in the field.

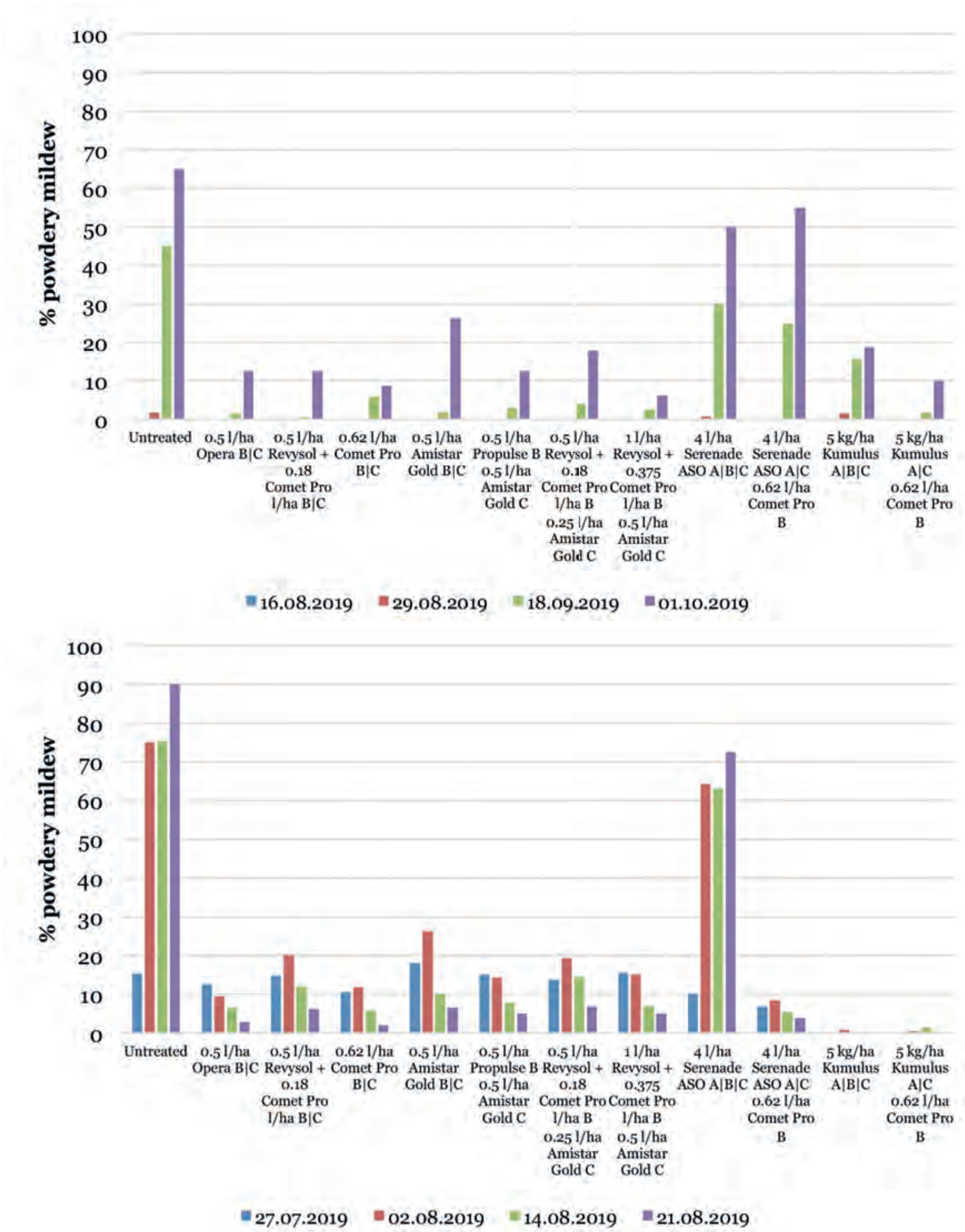
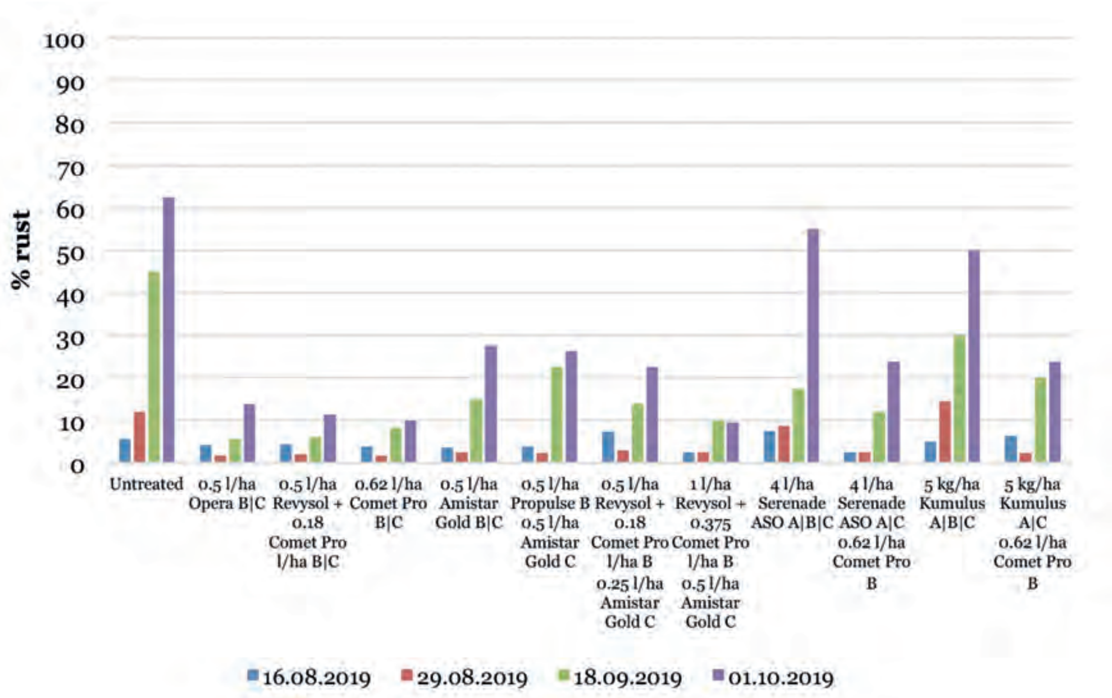


Figure 1. Per cent powdery mildew following different spray programmes assessed at four timings. Flakkebjerg at the top, Guldborg below. A, B and C = spray timings T1, T2 and T3.



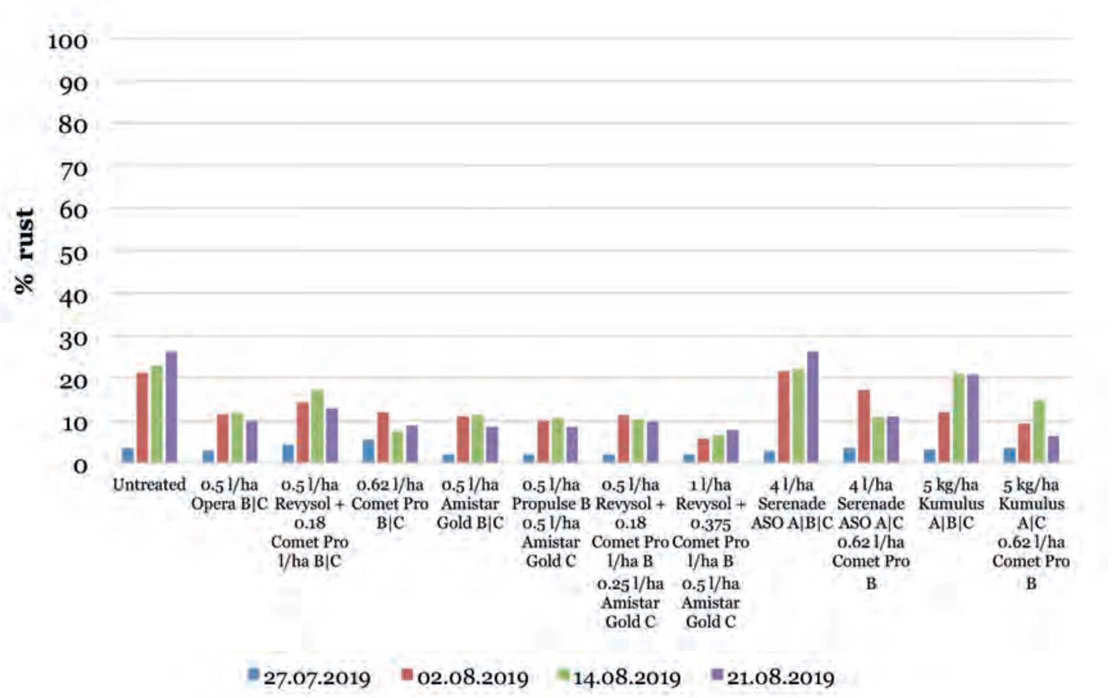


Figure 2. Per cent rust following different spray programmes assessed at four timings. Flakkebjerg at the top, Guldborg below. A, B and C = spray timings T1, T2 and T3.

Resistance monitoring

Powdery mildew was collected in 2019 in Denmark and Sweden and tested for strobilurin resistance. Diseased leaves from ten Danish and four Swedish fields were collected (Table 2). The leaves were used to infect disease-free plants (cv. Lombok) at growth stage 19. Powdery mildew was transferred by rubbing diseased leaves against uninfected leaves. Twelve plants per site were used; three plants were treated with either 0.5 l/ha Comet Pro (pyraclostrobin), 0.5 l/ha Opera (epoxiconazole + pyraclostrobin) or 4 l/ha Serenade ASO (*Bacillus amyloliquefaciens* QST 713).

Table 2. Sites, from where powdery mildew samples were collected.

Danish samples	Swedish samples
1. Rødby, untreated	11. Barsebæk, treated
2. Karleby, untreated	12. Borgeby, untreated
3. Gedser, untreated	13. Lønstorp, untreated
4. Gimlinge, untreated	14. Gasness, untreated
5. Guldborg, treated	
6. Dannemare, untreated	
7. Guldborg, untreated	
8. Gedser, treated	
9. Guldborg, untreated	
10. Karleby, untreated	

Table 3. Powdery mildew attacks 14 days after artificial inoculation. + = starting infection, ++ = moderately infected, +++ = highly infected.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Untreated	+++	+++	++	+++	+++	+++	++	+++	+++	+++	+++	+++	+++	+++
0.5 l/ha Comet Pro	-	+	-	-	-	+	-	+++	-	+++	++	+++	-	+
0.5 l/ha Opera	-	-	-	-	-	-	-	-	-	(+)	-	-	-	-
4 l/ha Serenade	++	+++	++	++	+	+++	++	+	+++	+++	+++	+++	+++	++

Figure 3. Sugar beet plant inoculated with powdery mildew. Untreated (left), treated with 0.5 l/ha Opera (right).

The plants were assessed for powdery mildew one, two and three weeks after inoculation (Table 3). A treatment with 0.5 l/ha Opera controlled all powdery mildew samples (Figure 3); however, powdery mildew developed heavily on four Danish and Swedish samples treated with 0.5 l/ha Comet Pro. Those samples were tested for the presence of *cytb* point mutation G143A, which is associated with powdery mildew strobilurin resistance (Bolton and Neher, 2014). All four samples were tested positive for G143A, indicating that the strobilurin-resistant isolates occur in the Danish and Swedish *Erysiphe betae* population. The presence of resistance has not been seen at field level; however, choosing an alternative fungicide programme in order to minimise the spread of strobilurin resistance should be considered. This is especially the case when powdery mildew is the primary disease.

This project was financed by the Danish Sugar Beet Grower's Association.

References

Bolton, M. D. and O. T. Neher (2014). First Report of Q(O)I-insensitive Powdery Mildew (*Erysiphe polygoni*) on Sugar Beet in the United States. Plant Disease 98: 1004-1004. https://doi.org/10.1094/PDIS-12-13-1217-PDN

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

Isaac Kwesi Abuley & Hans Henning Hansen

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).

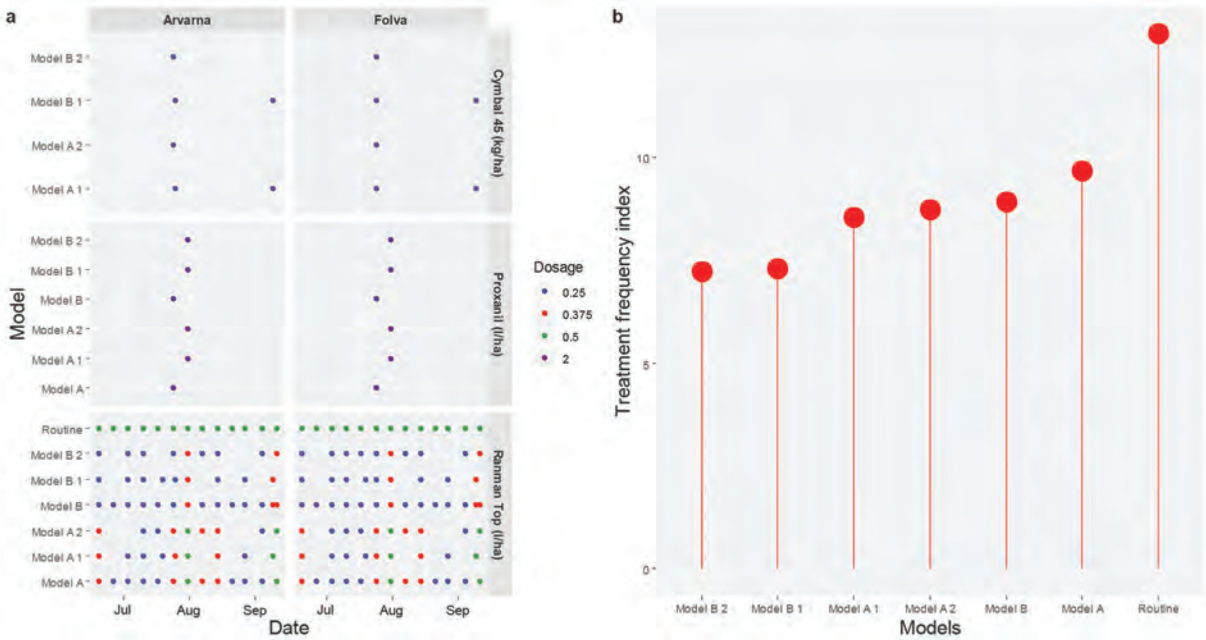


Figure 1. Details of fungicide application according to the models and the routine treatment (a) and the treatment frequency index (b).

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).

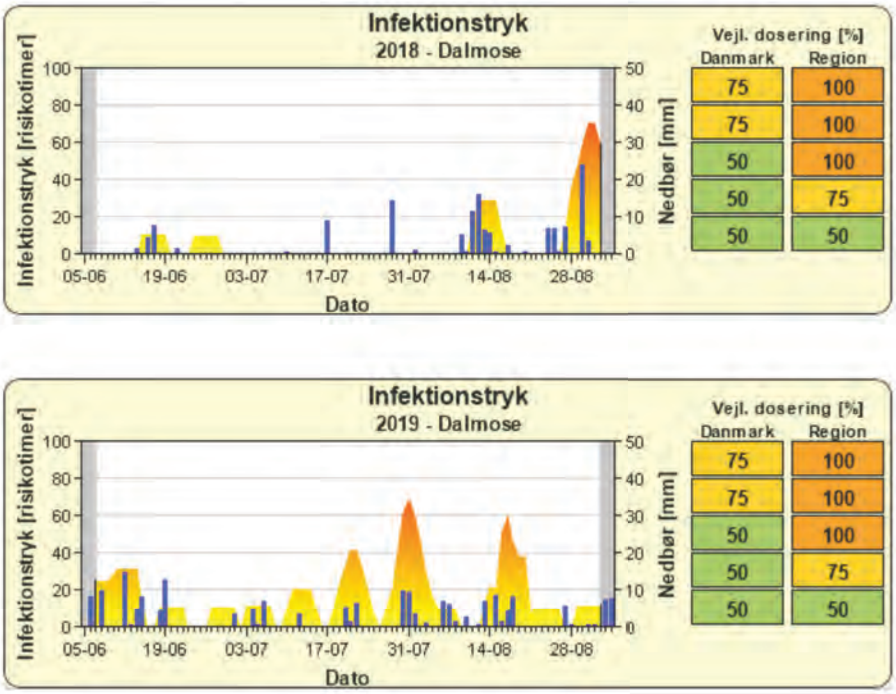


Figure 2. Infection pressure ((“Infektionstryk”) (yellowish coloured area) of late blight in 2018 (upper panel) and 2019 (lower panel) at Dalmose. The blue bars represent the amount of rainfall. The part of the figure with the caption “Vejl. dosering [%]“ shows the recommended dose as a percentage of 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/).

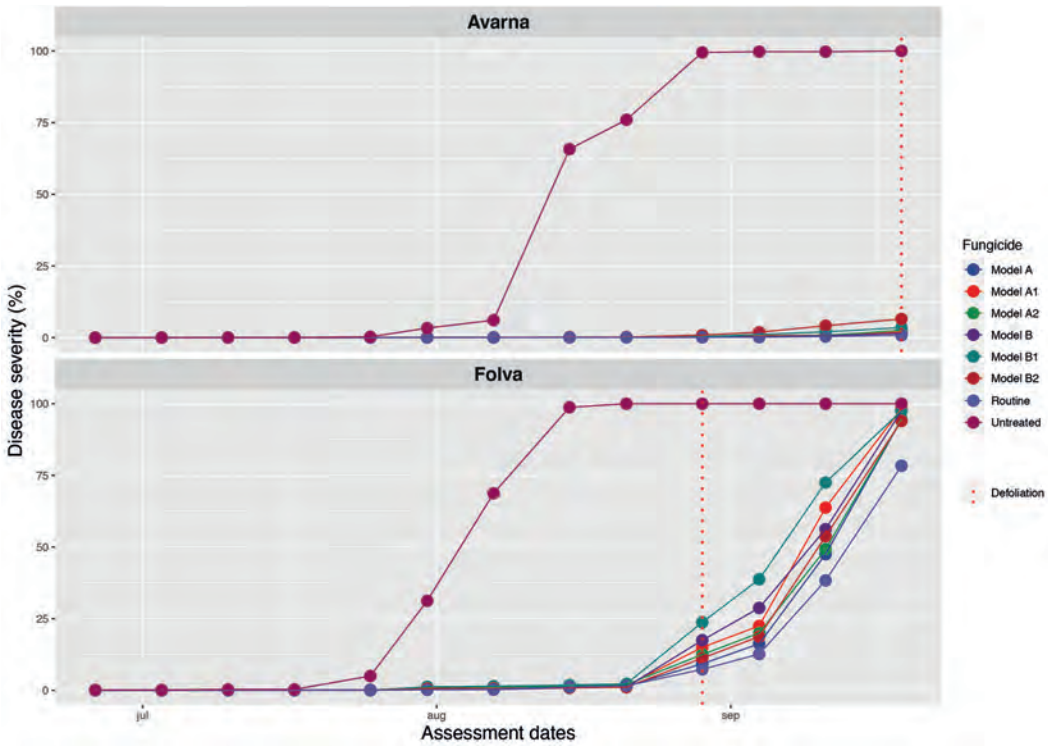


Figure 3. The development of late blight (caused by *Phytophthora infestans*) on Folva and Avarna. The broken red line shows the date defoliation due to senescence began on the cultivars. The disease severity values after this are not included in interpreting the results of the study.

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).

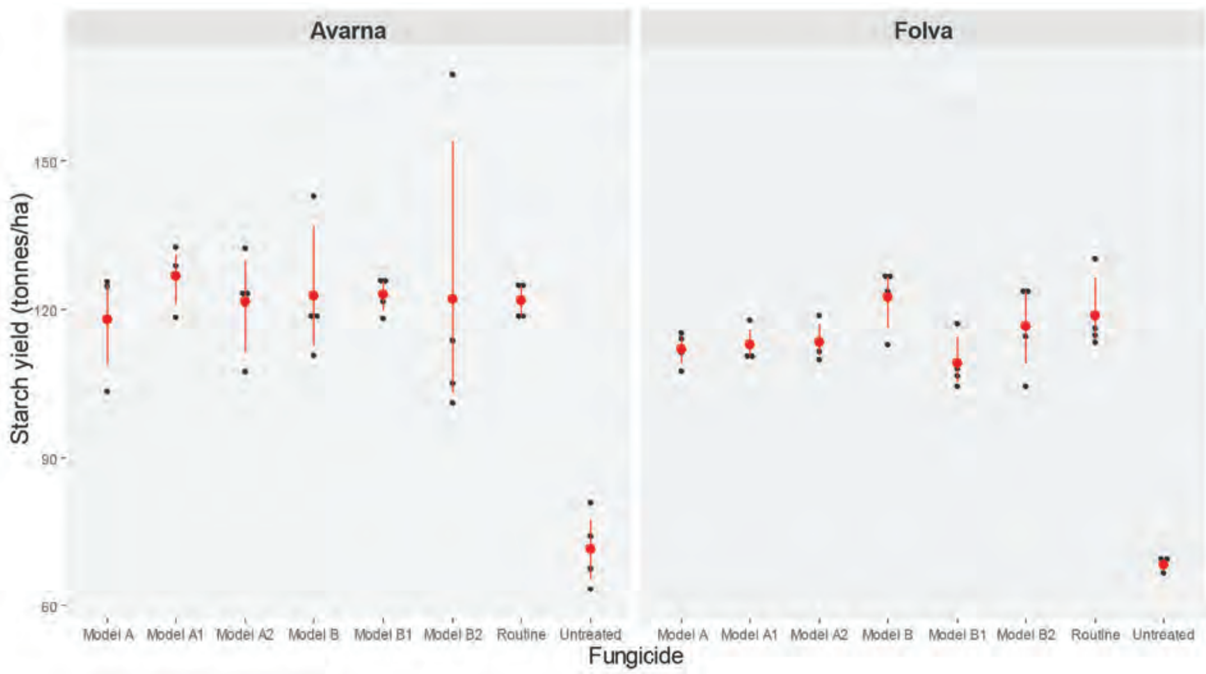


Figure 4. Mean starch yield (red dots) of Folva and Avarna treated according to the models, routine and untreated. The vertical red lines are the 95% bootstrapped confidence intervals and the black dots are the yield values for each replicate per treatment.

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).

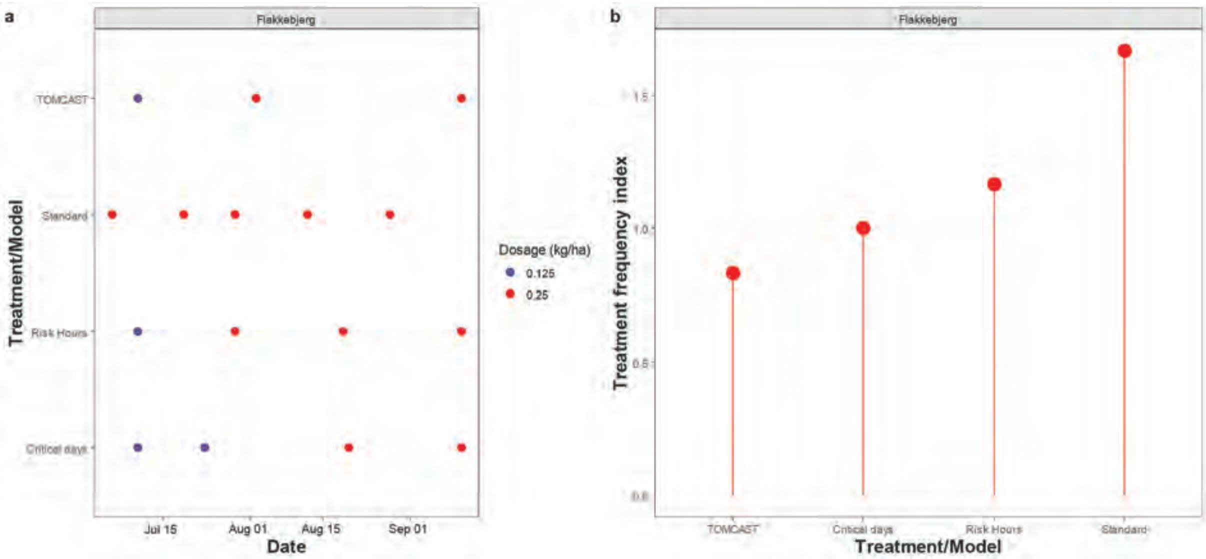


Figure 5. Details of fungicide application according to the models and the standard treatment (a) and the treatment frequency index (b).

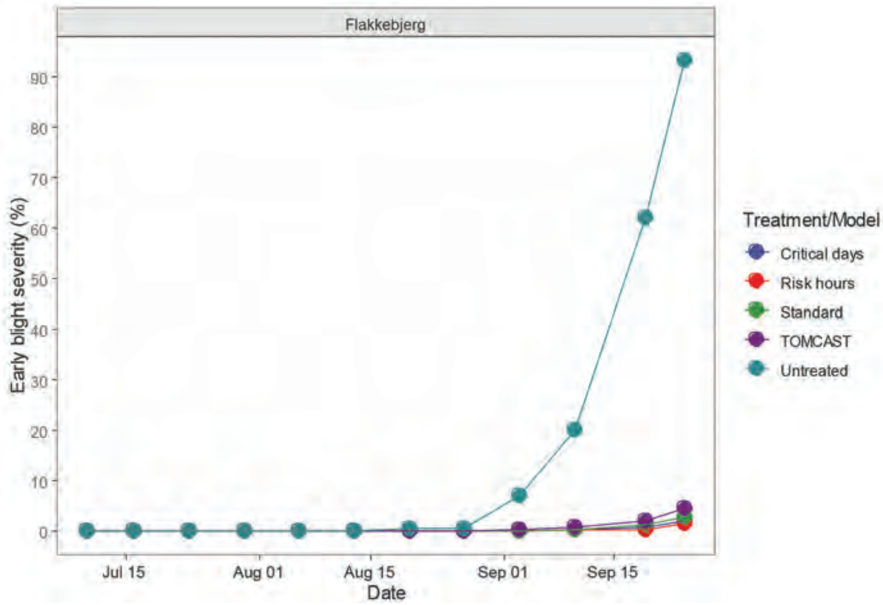


Figure 6. The development of early blight on Avarna treated according to TOMCAST, Risk hours, Critical days, standard application and untreated.

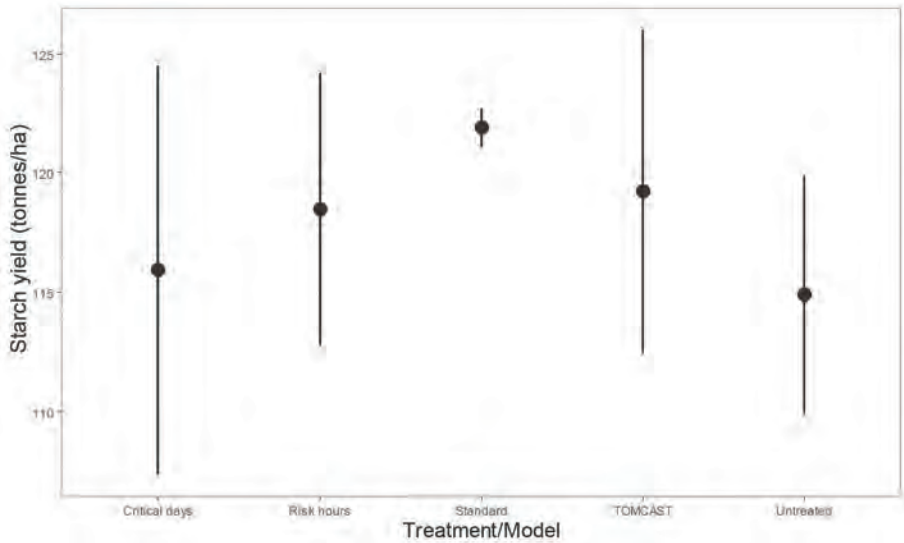


Figure 7. Mean starch yield (dots) of Avarna treated according to TOMCAST, Risk hours, Critical days, standard application and untreated. The vertical lines are the 95% bootstrapped confidence intervals.

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.

References

Abuley, I. K. and B. J. Nielsen (2017). Evaluation of models to control potato early blight (*Alternaria solani*) in Denmark. Crop Protection 102: 118-128. https://doi.org/10.1016/j.cropro.2017.08.012.

Gleason, M. L., A. A. MacNab, R. E. Pitblado, M. D. Ricker, D. A. East and R. X. Latin (1995). Disease-Warning Systems For Processing Tomatoes In Eastern North America - Are We There Yet. Plant Disease 79: 113-121.

Nielsen, B. J. and I. K. Abuley (2018). Control of late blight (*Phytophthora infestans*) and early blight (*Alternaria solani*) in potatoes. In: L. N. Jørgensen, B. J. Nielsen, S. K. Mathiassen, P. K. Jensen, H. S. Kristjansen, T. M. Heick, N. Vagndorf, P. Hartvig and S. Sørensen (eds.). Applied Crop Protection 2017. Aarhus Universitet - DCA - Nationalt Center for Fødevarer og Jordbrug, DCA rapport no. 117, pp. 94-107.

Sands, P. J., C. Hackett and H. A. Nix (1979). A model of the development and bulking of potatoes (*Solanum Tuberosum* L.) I. Derivation from well-managed field crops. Field Crops Research 2: 309-331.

VIII Screening of herbicide efficacy on different *Bromus* species

Solvejg K. Mathiassen

Bromus diandrus is an annual grass weed native to the Mediterranean region but now spread throughout the world. *B. diandrus* is reported as a problematic weed in cereal monocropping and conservation tillage systems (Kleemann and Gill, 2009). In Denmark, it was first reported as a weed in a winter cereal field in Central Jutland in 2018. Few herbicides are effective against *B. diandrus*, and timing is reported to be an important factor for effective control. This paper reports the results of a study on herbicide efficacy against *B. diandrus, B. sterilis* and *B. mollis* to test for any differences in susceptibility of the three weed species.

Materials and methods

Seeds of *Bromus diandrus* were harvested in a winter cereal field in Jutland. Seeds of *B. sterilis* and *B. mollis* were collected from the seed bank at the Department of Agroecology, Aarhus University. The seeds were sown in 1-L pots filled with field soil (sandy loam) for testing the pre-emergence herbicides (Boxer, Stomp CS and Kerb 400 SC) and in pots with a potting mixture (soil, sand and peat) for test of the post-emergence herbicides (Broadway, Atlantis OD, Roundup Bio, Hussar OD, Focus Ultra, Topik EC and Agil 100 EC).

The herbicide treatments are listed in Table 1. Boxer (800 g/L prosulfocarb), Stomp CS (440 g/L pendimethalin) and Kerb 400 SC (400 g/L propyzamide) were applied pre-emergence and at BBCH 10-11. The post-emergence herbicides were applied at BBCH 21-22. Broadway, Atlantis OD and Roundup Bio were also applied at BBCH 30-32 to examine the influence of growth stage on control. Monitor was applied as a single application at BBCH 30-32 and as a split application with the first treatment at BBCH 30-32 and the second treatment at BBCH 32-33. Each herbicide was applied at three doses: ¼ N, ½ N and 1 N.

All spray solutions were prepared in deionised water. Herbicide applications were carried out with a cabinet pot sprayer at a volume rate of 150 L/ha. The plants were harvested 4 weeks after herbicide application and fresh and dry weights were recorded.

Results

Stomp CS applied pre-emergence and at BBCH 10-11 had a low effect on the three *Bromus* species (Table 2). In contrast, pre-emergence application of Boxer produced high effects on *B. mollis*, while significantly lower effects were obtained on *B. diandrus* and *B. sterilis*. The effects on all species declined when application was delayed until BBCH 10-11 (Figure 1, Table 2). The performance of Kerb 400 SC applied pre-emergence was excellent on all three *Bromus* species, but, like Boxer, the effects of Kerb 400 SC declined when applied at BBCH 10-11 (Table 2).

All doses of Broadway, Roundup Bio, Focus Ultra and Agil 100 EC produced high levels of control at BBCH 21-22. No decline in effect was noticed after application of Broadway and Roundup Bio at the later growth stage of plants (BBCH 30-32). Similarly, Atlantis OD showed high levels of control; however, for *B. sterilis* the effect declined at ¼ N (Table 3).

Hussar OD and Topik EC applied at BBCH 21-22 gave insufficient effects on all species. Overall, higher effects were obtained on *B. mollis* and *B. sterilis* compared to *B. diandrus* at all doses. Monitor had a high effect on *B. mollis* and *B. sterilis* when applied as single application at BBCH 30-32 and as a split application with first treatment at BBCH 30-32 and the second treatment 7 days later at BBCH 32-33 (Figure 2). *B. diandrus* was slightly more tolerant with 5-10% and 15-20% lower effects of the split application and single treatment, respectively.

Table 1. Herbicides and application timings included in the pot experiment.

Herbicide	Active ingredient	Active ingredient (g/kg or g/L)	Dose (1 N) g or L/ha	PRE	BBCH 10-11	BBCH 21-22	BBCH 30-32
Boxer	Prosulfocarb	800	4.0	x	x		
Stomp CS	Pendimethalin	455	1.0	x	x		
Kerb 400 SC	Propyzamide	400	1.0	x	x		
Broadway[1]	Pyroxsulam + florasulam + cloquintocet	68.3 + 22.8	220			x	x
Atlantis OD	Mesosulfuron + iodosulfuron + mefenpyr	10 + 2 + 30	0.9			x	x
Roundup Bio	Glyphosate	360	2			x	x
Monitor[2]	Sulfosulfuron	800	12.5				x*
Hussar OD[3]	Iodosulfuron	100	0.1			x	
Focus Ultra[4]	Cycloxydim	100	2.0			x	
Topik EC[3]	Clodinafop	100	0.4			x	
Agil 100 EC	Propaquizafop	100	0.8			x	

In mixture with [1] 0.5 L/ha PG26N, [2] 0.1% Contact, [3] 0.5 L/ha Renol and [4] 0.5 L/ha DASH.
*also applied as a split application at BBCH 30-32 and BBCH 32-33.

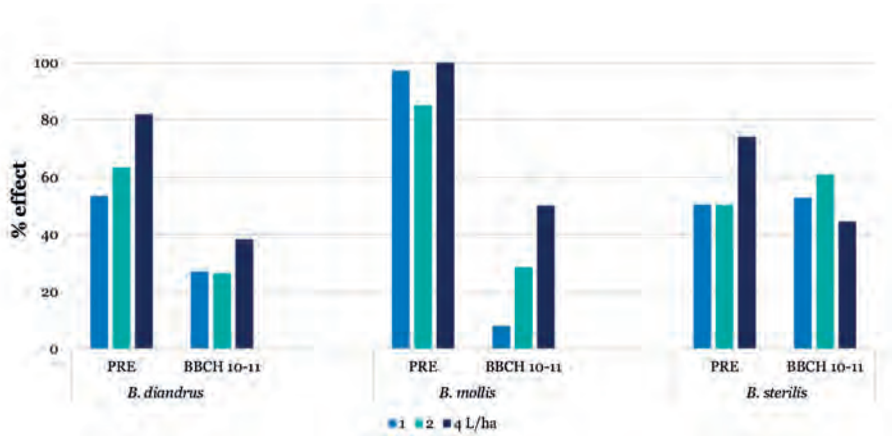


Figure 1. Effect of Boxer on *B. diandrus*, *B. mollis* and *B. sterilis*.

Table 2. Effect (% control) of pre-emergence herbicides on *B. diandrus*, *B. mollis* and *B. sterilis*. Figures in bold are significantly different from other figures at same dose and growth stage.

Herbicide	Doses (g or L/ha)	*B. diandrus*		*B. mollis*		*B. sterilis*	
		PRE	BBCH 10-11	PRE	BBCH 10-11	PRE	BBCH 10-11
Boxer	1.0	53.5	27.0	97.2	8.1	50.6	52.8
	2.0	63.3	26.5	85.0	28.5	50.3	61.0
	4.0	81.9	38.2	100.0	49.5	74.1	44.5
Stomp CS	0.25	10.1	0.0	0.0	0.0	11.7	0.0
	0.5	24.0	0.0	0.0	0.0	0.0	17.3
	1.0	21.0	33.0	12.6	0.0	12.3	0.0
Kerb 400 SC	0.25	100.0	34.4	80.6	0.0	69.0	0.0
	0.5	100.0	6.4	92.6	36.8	100.0	0.0
	1.0	100.0	35.0	100.0	16.1	100.0	17.1

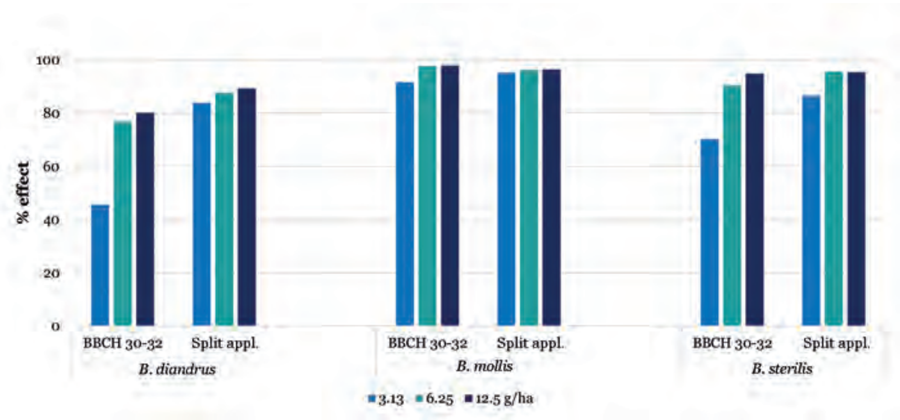


Figure 2. Effect of Monitor on *B. diandrus*, *B. mollis* and *B. sterilis*.

Table 3. Effect (% control) of post-emergence herbicides on *B. diandrus*, *B. mollis* and *B. sterilis*. Figures in bold are significantly different from other figures within same dose and growth stage

Herbicide	Doses (g or L/ha)	*B. diandrus*		*B. mollis*		*B. sterilis*	
		BBCH 21-22	BBCH 30-32	BBCH 21-22	BBCH 30-32	BBCH 21-22	BBCH 30-32
Broadway	55	100.0	95.3	99.5	98.6	98.7	98.6
	110	99.3	96.0	99.6	98.5	99.7	99.1
	220	99.0	95.1	99.7	98.9	99.7	99.2
Atlantis OD	0.23	97.5	86.3	86.1	90.6	46.0	51.8
	0.45	99.1	94.8	99.6	97.8	99.7	97.0
	0.9	99.4	96.0	99.7	98.7	99.6	98.8
Roundup Bio	0.5	99.1	98.3	97.2	99.1	99.8	99.4
	1.0	99.7	98.6	99.8	99.4	99.8	99.5
	2.0	99.6	98.3	99.8	99.3	99.9	99.5
Monitor			45.5		91.5		70.2
			76.7		97.6		90.3
			80.0		97.8		94.7
Hussar OD		23.2		48.0		52.0	
		22.9		51.6		37.0	
		23.2		67.7		41.4	
Focus Ultra		99.5		99.8		99.8	
		99.6		99.8		99.8	
		99.6		99.7		99.8	
Topik EC		9.3		31.9		21.0	
		10.3		42.1		20.0	
		18.7		49.7		22.3	
Agil 100 EC		99.5		99.8		99.8	
		99.5		99.8		99.8	
		99.5		99.7		99.6	

Discussion

Few herbicides are available to control *Bromus* species in winter cereals. Boxer applied pre-emergence can provide some control of *Bromus* species in the autumn but cannot stand alone and will need to be followed by a post-emergence herbicide treatment in the spring. Results with the lowest dose indicated that *B. mollis* was significantly more susceptible to pre-emergence treatment with Boxer than *B. diandrus* and *B. sterilis*.

All post-emergence herbicides authorised for use in winter cereals with activity against *Bromus* ssp. belong to the group of ALS inhibiting herbicides. Broadway seems to be the best choice, providing high levels of control at both growth stages and against all species followed by Atlantis OD, which showed lower effects on *B. sterilis* at ¼ N compared to the other species. (Table 3). Hussar OD was ineffective against all three *Bromus* species. Monitor is no longer registered in the EU. It was included in the test as a reference because it was the recommended herbicide for *Bromus* control in Denmark for many years. Monitor was effective against *B. mollis* and *B. sterilis*, while the effect on *B. diandrus* was significantly lower. Topik EC is the only ACCase inhibitor authorised in winter wheat. The study showed that Topik EC is completely ineffective in controlling *Bromus* ssp.

In oilseed rape Kerb 400 SC controls all *Bromus* species when applied pre-emergence. Post-emergence applications of Focus Ultra and Agil 100 EC also effectively control all *Bromus* species and can be used in several broadleaved crops. Glyphosate was very effective against *Bromus* ssp. and can be used for control pre-drilling and at later growth stages ensuring no fertile seed set. Overall, the screening did not indicate that *B. diandrus* is more tolerant to herbicides than *B. mollis* and *B. sterilis*.

Experiences from the UK and Spain have shown that several cultural measures can be used to reduce *B. diandrus* populations. Ploughing has proved to be effective by reducing the number of panicles/m^2 by up to 80% (Cook and Gosling, 2014). In regard to seed germination *B. diandrus* resembles *B. sterilis* with a short seed dormancy (Del Monte and Dorado, 2011). Therefore, a shallow cultivation soon after harvest will promote germination. Delayed sowing, broadleaved crops in the rotation, spring cropping, cleaning machinery before entering another field and stale seedbeds are other measures that can reduce population density (Cook and Gosling, 2014).

References

Cook S. and P. Gosling (2014). Identification and control of brome grasses. HGCA Information sheet 31.

Garcia A. L., A. Roya-Esnal, J. Torra, C. Cantero-Martinez and J. Recasens (2014). Integrated management of *Bromus diandrus* in dryland cereal fields under no-till. Weed Research 54, 408-417.

Kleemann S. G. L. and G. S. Gill (2009). Population Ecology and Management of Rigid Brome (*Bromus rigidus*) in Australian Cropping Systems. Weed Science 57, 202–207.

Del Monte J. P. and J. Dorado (2011). Effects of light conditions and after-ripening time on seed dormancy loss of *Bromus diandrus* Roth. Weed Research 51, 581-590.

Acknowledgement

The study was funded by 'Erhvervsfinansieret planteavlsforskning'.

B. diandrus in winter wheat (Photo: Michael B. Fleng).

IX Drift from different application techniques in potatoes and the influence of a filter crop in the buffer zone

Peter Kryger Jensen

During field spraying, losses to the surroundings in the form of spray drift inevitably occur. Spray drift is defined as spray liquid transported away from the sprayed area without being deposited. A number of factors influence spray drift of which application technique, meteorological conditions and hedges/buffer zone canopy are considered the most important. The influence of combinations of spray drift reducing techniques was tested in this investigation. During spray drift experiments, the standard prescribes an open area with short cut grass or bare soil in the wind direction from the sprayed area. In this investigation, the spray technical factors were combined with two different situations in the border zone. The border zone consisted of either bare soil or a high filter crop in order to investigate the potential of using a filter crop to reduce spray drift. When buffer zone requirements to pesticides are determined, the standard values used in Denmark and a number of other countries are the so-called Ganzelmeier values, consisting of a large data set of drift values from spraying with standard techniques relevant for the actual crop. These values denote the expected sedimentation spray drift concentration at increasing distance from the sprayed area. Sedimentation spray drift is the fraction of spray drift consisting of the largest and most heavy spray drops depositing at the soil surface close to the sprayed area. Another fraction, the airborne spray drift, consists of the smallest drops with such a low gravity that the drops predominantly follow the wind movements. This fraction is according to international standards measured at different heights on masts placed 5 m from the edge of the sprayed area. Measurement of airborne spray drift is often not included in spray drift experiments as the values are not used for regulatory purposes. Further, the two different drift fractions are believed to be correlated. However, as the use of a high filtering canopy at the edge of the sprayed field could be expected to influence the profile of the spray drift cloud a measurement of the airborne spray drift fraction was included in some combinations in this investigation.

Materials and methods

The investigation was carried out in potatoes, cv. Kuras, cultivated according to normal practice. The crop was established on 16 April with a row distance of 0.75 m and the distance between plants was 0.33 m. The potato crop was fertilised with 147 kg nitrogen per/ha as NPK 14-4-17. Weed control and control of pests and diseases were according to good agricultural practice. A graphical overview of the test area, drift collectors, etc. is shown in Figure 1. The spray drift test was carried out on 21 August at a time when the potato crop was 0.75 m high. The width of the potato area was 24 m and the length 100 m. At the time when the potato crop was established, a filter crop was established at the border of the potatoes and half the length of the potato crop (50 m). Maize (cv. Artikus) was sown on 3 May as a border crop and fertilised with 147 kg/ha nitrogen. The maize filter crop was sown in 4 rows with 0.5 m row distance and 0.05 m plant distance. Following emergence, the plants were thinned to a plant distance of 0.15 m. The maize crop was kept weed-free with herbicides and at the day of the drift test the maize crop had reached a height of 2.0 m. As neighbour to the potato crop at the other half of the length, the soil was kept bare by cultivating the soil in a width of 2 m. At the day of the drift test, the test area next to the maize and the bare soil was short cut cereal stubble. The spray application in the spray drift test was carried out with a lift-mounted Hardi Master Twin equipped with a 15-m-wide boom.

The test was carried out according to the following protocol.

Factor 1. Application technique

1. Reference FF 110-03, 1.2 l/min, 3 bar, 6 km/h 240 l/ha, boom 0.5 m above crop
2. 75% drift reducing technique, ID120-025, 1.15 l/min, 230 l/ha, 6 km/h, boom 0.5 m above crop
3. 90% drift reducing technique, ID120-025, 0.9 l/min, 180 l/ha, 6 km/h, boom 0.5 m above crop
4. Treatment 3 but with Twin air assistance (approx. 20 m/s, 45^0 forward angled)
5. Treatment 3 but with Twin air assistance (approx. 20 m/s, 45^0 forward angled) and boom height reduced to 0.25 m above crop

Factor 2. Border zone (in the wind direction after the last row of potatoes)

1. Bare soil (reference)
2. Maize crop (4 rows at 0.5 m distance and 2.0 m high at the test)

Factor 3. Sedimentation drift: distance from sprayed area (edge of field is 0.25 m from the outermost nozzle)

4 distances: 3 – 5 – 10 and 15 m

Factor 4. Airborne spray drift: measured on masts placed 5 m from the edge of field at the following heights (only factor 1.1 and 1.5)

8 heights: 0.5 – 1.0 – 1.5 – 2.0 – 2.5 – 3.0 – 3.5 and 4.0 m

A schematic overview is shown in Figure 1 and can partly be seen in Photo 1.

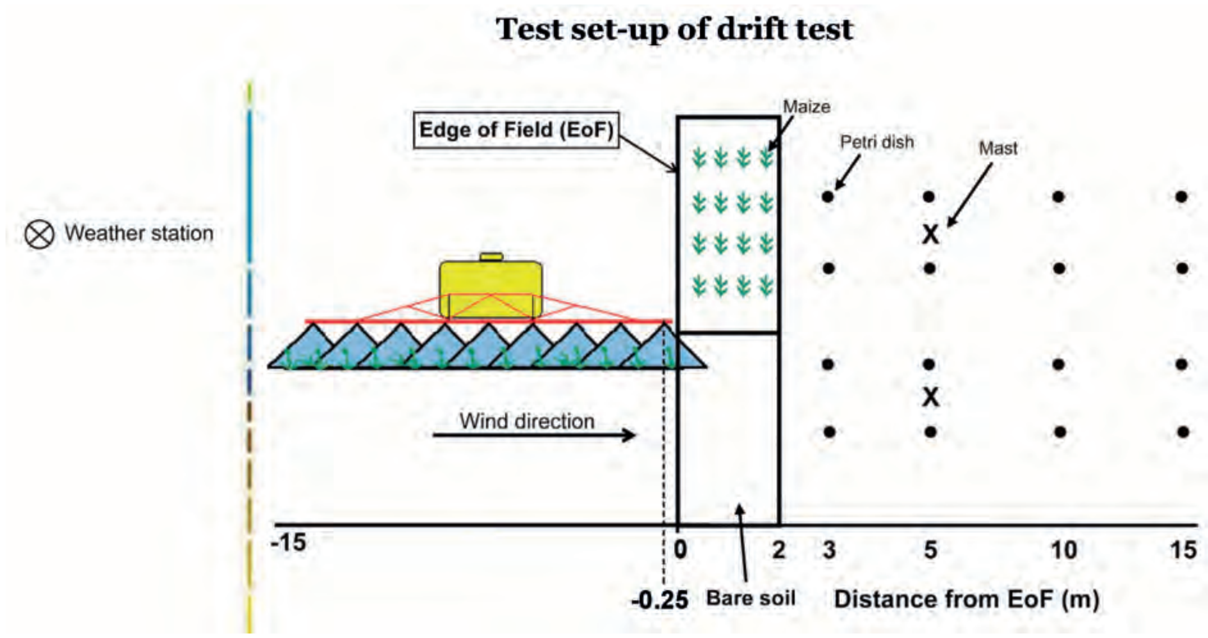


Figure 1. Graphical overview of the test set-up with placement of Petri dishes for sampling of sedimentation drift and masts where airborne spray drift collectors are placed at heights of 0.5–4.0 m.

Sedimentation spray drift was collected on Petri dishes placed just above soil/stubble level. The Petri dishes were placed in 2 rows with a mutual distance of 3 m. Airborne spray drift was collected on a mast placed 5 m from the edge of the field. Airborne spray drift was only measured applying the reference technique (factor 1.1) and technique 5 (factor 1.5). The purpose was to investigate whether the spray drift profile was changed when the spray drift plume passed the filter crop in the border zone. Spray drift collectors on the mast were steel cylinders with a diameter of 2 mm and a length of 50 mm. During the field test, the wind direction should be perpendicular to the sprayed area although a deviation of +/- 30^0 can be accepted. In the test, spray application was carried out at a length of 100 m allowing application to be initiated at least 20 m before the first row of drift collectors and until at least 20 m after the last row of collectors. In combination with the requirement regarding wind direction, this ensures that the drift created during application passes the Petri dishes and the masts with collectors. The sprayed area was in all treatments 15 m wide.

Background contamination was tested placing a Petri dish upwind. During each replicate the wind speed was measured at 2 m height when the sprayer passed the rows of collectors. Temperature and humidity were measured during the entire test.

The spray liquid consisted of tap water and the fluorescent tracer, brillantsulfoflavin. Following each replicate, the Petri dishes and steel cylinders were collected and new ones were mounted. A lid was put on the Petri dishes before collection and the steel cylinders were collected in small 50-ml bottles. All samples were stored cool and dark until analysis.

Photo 1. Application with the reference technique during the test.

Table 1. Wind speed (m/s) measured at 2 m height during each replicate.

Technique	Replicate 1	Replicate 2	Replicate 3	Replicate 4
Reference FF-03	4-5	3-4	3-4	3-5
ID-025 75% red	4	3-4	2-3	2-4
ID-025 90% red	3-5	3-5	2-4	3-5
ID-025 90% red + Twin	3-5	3-5	2-3	3-5
ID-025 90% red + Twin + 0.25 m boom	3-5	3.5	3	2-3

During the test, a stable wind in the interval of 3.5–5.0 m/s was recorded. The temperature varied between 16 and 18^{0}C and the air humidity varied between 55 and 75 RH. The individual measurements of wind speed during each replicate are shown in Table 1.

The tracer in the samples was dissolved with water containing 0.1% non-ionic surfactant and the concentration of tracer was determined. The tracer content was determined using a Perkin Elmer model LS 50B luminescence spectrometer. The Petri dishes (and bottles) were shaken and a sample of 6 μl was used in the fluorescence detector. The sample was excited at a wavelength of 410 nm and after excitation emission was measured at 518 nm. The content of the sample was quantified using a number of standard concentrations ranging from 2 to 192 µg l^{-1}. From the concentration of brillantsulfoflavin in the sample, the total amount of tracer in the sample was calculated. The sedimentation spray drift values at increasing distance from the sprayed area are shown as a percentage of the applied dose. The reference technique FF-03 is an international standard, and the drift reduction obtained using the other techniques is also shown as a percentage of the drift value obtained with the reference technique. The measurement testing milliQwater and non-ionic additive without tracer corresponded to 0.01% of the applied tracer dose. This background value is not withdrawn from the values, but measurements below 0.01% of the applied dose are shown as below detection limit.

Results and discussion

The sedimentation drift values shown as a percentage of the applied dose are shown in Tables 2-3. Table 2 shows the measurements with bare soil as border zone and Table 3 shows the corresponding results with maize as border zone crop. It can be seen from Table 2 that sedimentation spray drift values are reduced significantly when the tested drift reducing techniques are applied. The Lechler ID120-025 nozzle is classified to 75% drift reduction at max 4.0 bar, and it is classified to 90% drift reduction at max 2.5 bar. Using the ID120-025 nozzle at these 2 setttings reduces the spray drift values to low levels. The use of Twin air assistance in combination with the 90% drift reducing nozzle reduces the drift values further. At 3, 5 and 10 m distance air assistance reduces drift values by approximately 75%. The combination of a 90% drift reducing nozzle, Twin air assistance and low boom height reduces the drift values further and values at 10 and 15 m distance are below the detection limit of 0.01% of the applied dose. It is therefore not possible to quantify the influence of reduced boom height.

Table 2. Sedimentation spray drift at increasing distance from the sprayed area. Values are shown as a percentage of the applied dose of tracer. Standard deviation is shown in brackets. Values obtained from application with bare soil (reference) as border zone.

Application technique	Distance from edge of field (m)			
	3	5	10	15
Reference FF 110-03	3.38 (3.09)	1.59 (1.29)	0.45 (0.25)	0.28 (0.16)
75% red, ID120-025	0.25 (0.17)	0.11 (0.06)	0.05 (0.02)	0.03 0.01)
90% red, ID120-025	0.13 (0.08)	0.08 (0.04)	0.06 (0.03)	0.03 (0.01)
90 % red + Twin	0.03 (0.03)	0.02 (0.01)	0.01 ((-)	0.01 (-)
90% red + Twin + 0.25 m boom	0.02 (0.01)	0.01 (-)	bd (-)	bd (-)
bd: below detection limit.				

Table 3. Sedimentation spray drift at increasing distance from the sprayed area. Values are shown as a percentage of the applied dose of tracer. Standard deviation is shown in brackets. Values obtained from application with maize as border zone.

Application technique	Distance from edge of field (m)			
	3	5	10	15
Reference FF 110-03	0.32 (0.20)	0.15 (0.09)	0.14 (0.06)	0.12 (0.06)
75% red, ID120-025	0.03 (0.01)	0.02 (0.01)	0.03 (0.04)	0.02 (0.03)
90% red, ID120-025	0.03 (0.01)	0.02 (0.01)	0.02 (0.01)	0.02 (0.01)
90% red + Twin	0.02 (-)	0.01 (-)	0.01 (-)	bd (-)
90% red + Twin + 0.25 m boom	0.02 (0.01)	0.01 (0.01)	0.01 (0.01)	bd (-)
bd: below detection limit.				

Generally, significantly lower sedimentation spray drift values were found where maize was used as border zone (Table 3) compared to the bare soil reference. However, drift values decreased more slowly with distance where maize was used as border zone compared to the bare soil reference. Hence, the drift reducing effect of maize as border zone decreases at increasing distance when compared to the bare soil reference. With maize in the border zone most of the drift values found, using 90% drift reducing nozzles in combination with Twin air assistance, were close to or below the detection limit, as was the combination including lowered boom height.

Table 4 shows the drift reduction as a percentage when the combinations of drift reducing technique and border zone crop are compared with the FF-03 and bare soil reference situation. In the bare soil situation, combinations of drift reducing nozzle, air assistance and lowered boom height actually reduce sedimentation drift by 99%. Comparing the reference technique with bare soil or maize as border zone shows a 90%-reduction at 3 and 5 m distance where maize was in the border zone (0.32 vs 3.38 at 3 m and 0.15 vs 1.59 at 5 m). However, at increasing distance from the edge of the field, the effect of maize is reduced and the drift reduction with maize constitutes 69% at 10 m and 57% at 15 m. A similar influence of maize in the border zone instead of bare soil can be seen with the ID120-025 nozzle classified to 75 and 90% drift reduction. Drift reduction was 99% at 3 and 5 m distance but decreased to 93% at 15 m. During the test, it was observed that the spray plume was partly lifted above the maize in the border zone. Maize in the border zone thus reduces spray drift significantly; however, the high maize plants in the border zone changed the vertical profile of the spray plume.

Table 4. Spray drift reduction (%) compared to the reference situation (reference FF-03 and bare soil).

Technique	Border zone	Distance from edge of field (m)			
		3	5	10	15
Reference FF 110-03	Bare soil	-	-	-	-
75% red, ID120-025	Bare soil	93	93	89	89
90% red, ID120-025	Bare soil	96	95	87	89
90% red + Twin	Bare soil	99	99	98	96
90% red + Twin + 0.25 m boom	Bare soil	99	99	Nd	Nd
Reference FF 110-03	Maize	91	91	69	57
75% red, ID120-025	Maize	99	99	93	93
90% red, ID120-025	Maize	99	99	96	93
90% red + Twin	Maize	99	99	98	Nd
90% red + Twin + 0.25 m boom	Maize	99	99	98	Nd
Nd: not determined as the absolute value was below the detection limit.					

It was anticipated that a high filtering crop in the border zone might influence the vertical profile of the spray plume, and therefore airborne spray drift measurement was included in two combinations to investigate this. Airborne drift was collected on a mast placed 5 m from the edge of the field, and airborne drift was measured at 0.5 to 4.0 m height using the reference technique and technique 5. However, 15 of the 16 measurements with the strongly drift reducing technique 5 were below the detection limit. The airborne spray profile using the reference FF-03 nozzle is shown in Figure 2.

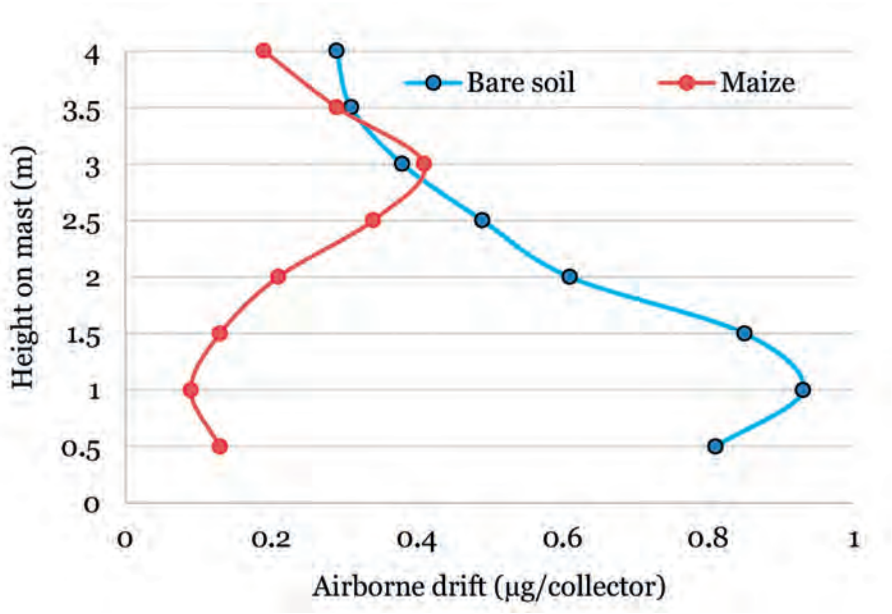


Figure 2. Airborne spray drift measured at 8 heights on a mast placed 5 m from the edge of the field. The application technique used was the reference FF03 nozzle, and the figure shows the different drift profiles obtained with bare soil and with maize in the border zone.

The airborne spray drift values seen with bare soil in the border zone show the typical profile with the highest concentrations near the ground and decreasing values with increasing height. When the maize crop was in the border zone, a significantly different profile was found with the lowest value at 1.0 m height and the highest value at 3.0 m height. However, detectable values were found at 4.0 m height both with bare soil and with maize in the border zone. Generally, the maize crop reduced the airborne spray drift significantly despite the changed profile. In principle, the airborne spray drift in the 2 situations can be quantified integrating the area below the 2 drift profile curves. The different drift profile obtained with maize in the border zone supports the observation that a part of the spray plume was forced over the 2 m high maize crop. At present there are no systematic studies investigating the effect of border structures on spray drift. It is expected that a more efficient drift reduction of the border crop could be obtained if the filter crop was more open. This would allow the spray plume to pass through the crop whereby the wind speed will be decreased, and at the same time parts of the spray plume will be deposited on the filter crop.

Conclusion

The spray drift test shows that it is possible to reduce the spray drift to very low levels by different drift reducing techniques. The combination of nozzles classified to 90% drift reduction in combination with Twin air assistance and reduced boom height reduced the sedimentation spray drift values by 98% or more compared to the reference technique. Use of a high maize crop in the border zone reduced spray drift significantly compared to the reference situation with bare soil. It is assumed that the drift reducing effect of the border zone vegetation could be improved if a more open vegetation was established.

Acknowledgement

The investigation was financed by "Kartoffelafgiftsfonden" as a part of the project: "Mekaniske, termiske og kemiske metoder til nedvisning af kartofler".

X Spray drift from application techniques when desiccating offshoots in strawberry

Peter Kryger Jensen

During field spraying, losses to the surroundings in the form of spray drift inevitably occur. Spray drift is defined as spray liquid transported away from the sprayed area without being deposited. A number of factors influence spray drift of which application technique, meteorological conditions and hedges/ buffer zone canopy are considered the most important. In crops grown at wide row distances and where some of the plant protection applications are carried out as banded applications, there is the possibility to use a shielded application. In this investigation, spray drift from a shielded band application was tested with a broadcast application from a boom sprayer as reference.

Materials and methods

The study was carried out in strawberry grown at a row distance of 0.5 m in a 10-m-wide area. The strawberry crop was established in four beds, each consisting of 4 rows, within the 10-m-wide area. In the spray drift test, a lift-mounted conventional sprayer with a 12-m-wide boom was used as reference. Nozzles were blinded at both ends of the boom to obtain a 10-m-wide application. The shielded band spray equipment used in the test had a working width enabling the equipment to treat four rows at a time, and treatment of the entire area was obtained by driving in each of the four beds. The band sprayer was a modified version of the band spray equipment produced by Garford (https://garford.com/products/band-and-hooded-sprayers/), and the shield on the band sprayer was a Garford shield. A single spray nozzle was mounted in the shield and, in principle, the application occurred in a closed room. It was, however, necessary to leave a short space between the bottom of the shield and the field surface. The drift test was carried out testing the following two application techniques:

Factor 1. Application technique

1. Reference FF 110-03, 1.2 l/min, 3 bar, 6 km/h 240 l/ha, boom height 0.5 m above crop
2. Shielded inter-row application with a TeeJet XR 80-015 per shield. Volume rate 200 l/ha at 4.2 km/h and a nozzle output of 0.5 l/min. The shielded application treated a width of 0.4 m between the rows.

Factor 2. Sedimentation spray drift: distance from edge of the field

4 distances: 3 – 5 – 10 and 15 m

The test was carried out with 4 replicates. The experimental set-up is shown in Figure 1. Sedimentation spray drift was collected on Petri dishes placed just above soil/stubble level. The area in the wind direction from the treated area was short cut barley stubble. The Petri dishes were placed in two rows with a mutual distance of 3 m. Petri dishes were placed 3, 5, 10 and 15 m from the edge of the sprayed area. Background contamination was tested by placing a Petri dish upwind. During the field test, the wind direction should be perpendicular to the sprayed area although a deviation of +/- 30^0 can be accepted. During each replicate, the wind speed was measured at 2 m height when the sprayer passed the rows of collectors. Temperature and humidity were measured during the entire test.

The spray liquid consisted of tap water and the fluorescent tracer brillantsulfoflavin. Following each replicate, the Petri dishes were collected and new ones were mounted. A lid was put on the Petri dishes before collection and the samples were stored cool and dark until analysis.

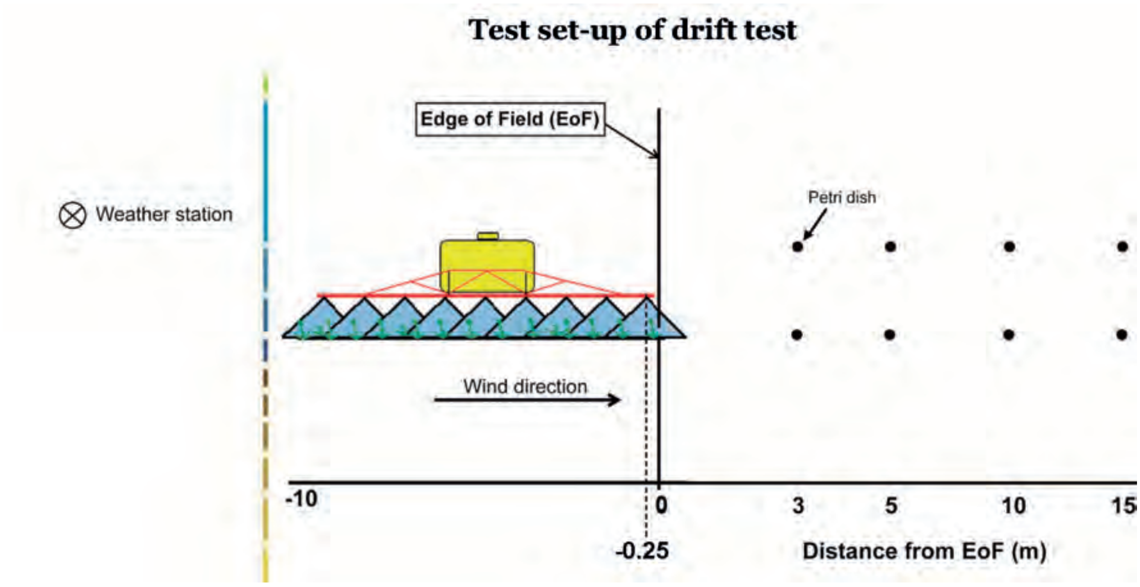


Figure 1. Graphical overview of the test set-up with placement of Petri dishes for sampling of sedimentation drift.

The drift test was carried out on 6 September in the morning on a day when the nearby meteorological station at Flakkebjerg recorded a wind speed varying between 5 and 6 m/s, a temperature in the interval of 12–14^{0}C and a relative humidity of 75%. The individual wind measurements taken during the pass of the spray equipment are shown in Table 1.

Table 1. Wind speed (m/s) measured during application in each replicate. Measurement at 2 m height.

Technique	Repl. 1	Repl. 2	Repl. 3	Repl. 4
Reference FF-03 broadcast appl.	4.0	4.9	4.0	4.2
Shielded band application	3.7	4.2	4.5	5.1

The tracer, brillantsulfoflavin, in the samples was dissolved with water containing 0.1% non-ionic surfactant and the concentration of tracer was determined. The tracer content was determined using a Perkin Elmer model LS 50B luminescence spectrometer. The Petri dishes were shaken and a sample of 6 µl was used in the fluorescence detector. The sample was excited at a wavelength of 410 nm and after excitation emission was measured at 518 nm. The content of the sample was quantified using a number of standard concentrations. From the concentration of brillantsulfoflavin in the sample, the total amount of tracer in the sample was calculated. The sedimentation spray drift values at increasing distance from the sprayed area are shown as a percentage of the applied dose. The reference technique FF-03 is an international standard and the drift reduction obtained using the shielded band application technique is also shown as a percentage of the drift value obtained with the reference technique.

Results and discussion

The drift measured at increasing distance from the edge of the sprayed area is shown in Table 2. The values are shown as a percentage of the applied dose rate.

Table 2. Drift at increasing distance from the sprayed area collected in Petri dishes at soil/stubble level. Values are shown as a percentage of the applied dose rate of tracer. Standard deviation is shown in brackets.

Technique	Distance from edge of field (m)			
	3	5	10	15
Reference FF 110-03, broadcast	0.555 (0.271)	0.492 (0.165)	0.178 (0.109)	0.142 (0.085)
Shielded band application	0.051 (0.016)	0.053 (0.026)	0.018 (0.005)	0.015 (0.005)

The values decrease more slowly with distance from the sprayed area than normally seen but the trend is parallel for the two techniques. This can also be seen in Table 3 where the spray drift reduction obtained using the shielded band sprayer is calculated. The shielded band sprayer reduces the drift values by 89–91% drift at the four distances compared to the reference spraying technique.

Table 3. Drift reduction using shielded band application with FF-03 broadcast as reference (% reduction)

Technique	Distance from edge of the field (m)			
	3	5	10	15
Reference FF 110-03, broadcast	-	-	-	-
Shielded band application	91	89	90	89

The reference technique uses a standard flat fan nozzle size 03. This nozzle is classified close to the border "fine/medium" in the BCPC classification system used to describe the droplet size distribution of hydraulic nozzles. The shielded band spray was equipped with a TeeJet XR 80-015 nozzle, and according to the manufacturer, this nozzle should be classified as "fine" with the pressure used. The obtained drift reduction of approximately 90% compared to the reference should therefore be assigned to the shielding. Use of a classified drift reducing nozzle on the shielded band sprayer will contribute to a further drift reduction when this technology is used. Typically, the effect of combining drift reducing techniques is close to additive.

Acknowledgement
The study was financed by "Danish Horticulture".

XI Spray drift and deposition uniformity with conventional technique and Hardi Twin air assistance at two wind speeds

Peter Kryger Jensen

The prevailing wind conditions influence spray drift during an application. However, the wind conditions also influence the quality of the application in the treated field. Many studies have documented the effect of wind on spray drift and how spray configuration can influence spray drift. The effect of wind on application quality or evenness is less well known. This study investigated the effect of wind on both spray drift and application uniformity in the treated area. The purpose of the study was to measure deposition and deposition uniformity in the target area and sedimenting spray drift from a conventional sprayer and a Hardi Twin sprayer with air assistance at different driving speeds. The aim was to carry out the test at two wind speeds, a normal low wind speed and a wind speed above the one normally recommended for applications with conventional sprayers.

Materials and methods

An LD-025 nozzle at 3 bar (1.0 l/min) was used in all settings to achieve the volume rates and a trailed Hardi Twin sprayer with a 24-m boom width was used with and without air assistance for all settings. Air assistance in settings 2, 4 and 5 was decided by Hardi and varied between the test at low/normal wind speed and the test at high wind speed. Both tests were carried out at Aarhus University Flakkebjerg.

The test at low/normal wind speed was carried out in a short cut stubble field on 27 June 2017 according to the following protocol:

Technique	Speed (km/h)	Volume rate (l/ha)	Air assistance and angling
Conventional	8	150	-
Twin air-assisted	8	150	20 m/s at outlet 43^0-48^0
Conventional	12	100	-
Twin air-assisted	12	100	20 m/s at outlet 43^0-48^0
Twin air-assisted	16	75	20 m/s at outlet 43^0-48^0
Twin air was angled 48^0 when the wind direction was perpendicular to the driving direction and 43^0 when the wind direction changed towards some degrees headwind.			

The test at high wind speed was carried out in a newly emerged/short cut cereal crop on 30 May 2018 with the following configuration:

Technique	Speed (km/h)	Volume rate (l/ha)	Air assistance and angling
Conventional	8	150	-
Twin air-assisted	8	150	57%, 5^0 backwards
Conventional	12	100	-
Twin air-assisted	12	100	57%, 5^0 backwards
Twin air-assisted	16	75	57%, 5^0 backwards

Figure 1 shows a graphical overview of the test area, drift collectors, etc. During the field test, the wind direction should be perpendicular to the sprayed area although a deviation of +/- 30^0 is acceptable. The area sprayed was 24 m wide and 100 m long, leaving a distance of more than 30 m before, respectively after, the rows of drift collectors.

The sprayed area was placed next to a free area (short cut grass or crop with a height of less than 0.15 m) in the wind direction.

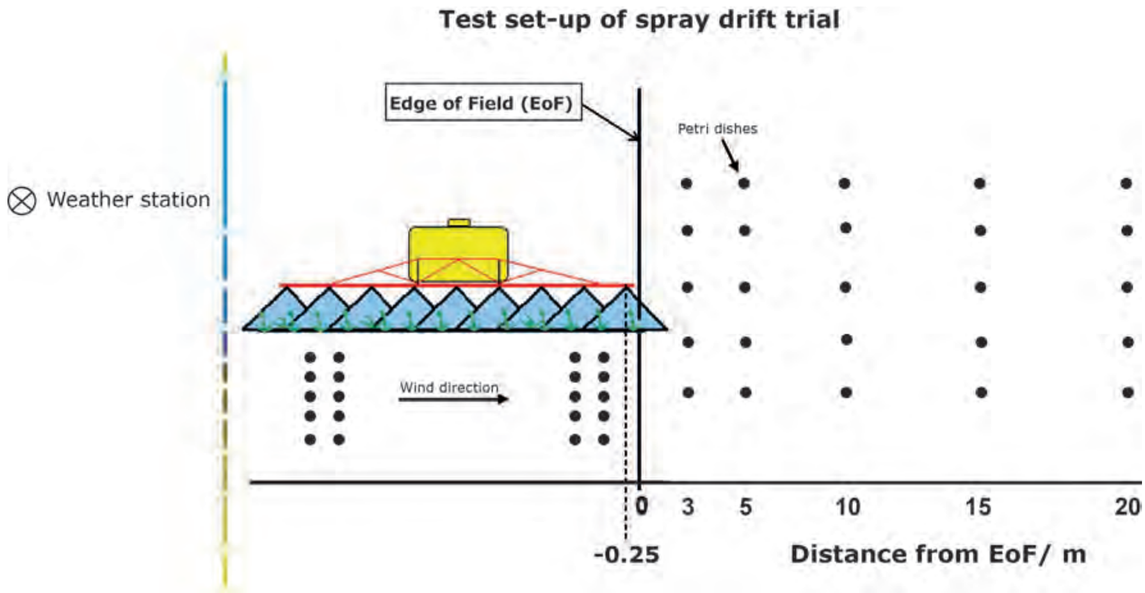


Figure 1. Graphical overview of the test set-up with placement of Petri dishes for sampling of sedimentation drift and deposition below the boom.

The drift collectors were placed at distances of 3, 5, 10, 15 and 20 m from the sprayed track on object carriers at soil level. Zero point was 0.25 m outside the outermost nozzle. Five rows of object carriers were included with a distance of 3 m between the rows. In the sprayed area, five rows of Petri dishes were placed at four distances (1, 3, 21 and 23 m) from the zero point to measure uniformity in the sprayed area. Petri dishes with an area of 149.6 cm^2 were used to collect deposits in the sprayed area and spray drift. The Petri dishes were placed on the object carriers during the spraying to avoid contamination from previous passes. Additionally, one Petri dish was placed upwind during each spraying to check methodology. After one pass of the sprayer, the Petri dishes were collected and stored for analysis. Airborne spray drift was not measured.

The plan included 3 replicates at each spray technique, giving a total of 75 drift values, 60 deposition values and 3 methodology values at each setting. Climatic conditions were measured at an official meteorological station placed at Flakkebjerg. Additionally, wind speed, wind direction, temperature and humidity were measured continuously with mobile equipment during the experiment in the field where the drift test took place. Table 1 shows a summary of these data.

Table 1. Summary of weather conditions during the two tests.

Test conditions	Wind speed (m/s)	Temperature (^{0}C)	Humidity (rh)
Low wind conditions 2017	3.0	14	55
High wind conditions 2018	6.0	25	50

Following the field test, the Petri dishes were stored dark at 5^{0}C until the analysis. The fluorescent tracer brillantsulfoflavin (BSF) was added to the spray liquid corresponding to a dose of 200 g/ha at the low volume rate of 75 l/ha, 267 g/ha at 100 l/ha and 400 g/ha at 150 l/ha. All results are normalised to the same applied dose rate of BSF. The BSF was dissolved in water containing 0.1% non-ionic surfactant and the concentration of tracer was determined. The tracer content was determined using a Perkin Elmer model LS 50B luminescence spectrometer. The Petri dishes were shaken and a sample of 6 µl was used in the fluorescence detector. The sample was excited at a wavelength of 410 nm and after excitation emission was measured at 518 nm. The content of the sample was quantified using a number of standard concentrations. From the concentration of BSF in the sample, the total amount of tracer in the sample was calculated.

The results are presented as a percentage of the applied dose.

Results and discussion

The test at low/normal wind speed was carried out under conditions where the wind speed varied from 2-4 m/s and at a moderate temperature around 15^{0}C. During the test at high wind speed, the wind speed varied in the interval from 4 m/s during the first replicate to 8 m/s during the third replicate and the temperature was around 25^{0}C during the entire test. The relative humidity varied in both tests around 50%.

Deposition in the target area

Figures 2-3 show deposition values in the target area at four positions below the boom. Figure 2 shows the deposition values found at the low/normal wind test. Twin air assistance had a limited influence on deposit values at 8 km/h. However, at 12 km/h air assistance significantly increased deposition compared to conventional application at both 8 and 12 km/h. Application with air assistance at 16 km/h also resulted in higher deposition than conventional spraying but with larger differences between the windward and the leeward side. The most uniform distribution at low/normal wind speed was achieved with Twin at 8 km/h.

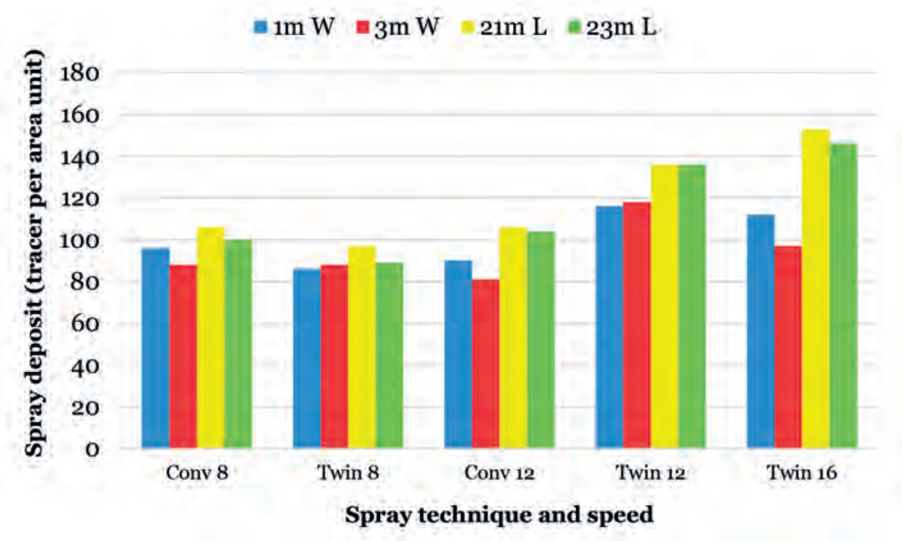


Figure 2. Deposition below the boom at different distances from the end of the boom. The wind direction was perpendicular to the driving direction with Petri dishes placed 1 and 3 m from the end of the boom in the windward side (1 m W and 3 m W) and placed 3 and 1 m from the end of the boom in the leeward side (21 m L and 23 m L). Test at low/normal wind speed June 2017.

Figure 3 shows the corresponding results from the test at high wind speed. There is a larger difference between deposits in the windward and the leeward side, especially with conventional technique at both 8 and 12 km/h. The most uniform application at high wind speed was found using Twin air assistance at 12 km/h closely followed by air assistance at 8 km/h. The values obtained using Twin at 16 km/h was almost the same as in the test with low/normal wind speed.

Droplets are supposed to be transported from the windward side towards the leeward side as seen especially with the two conventional applications. The result is lower deposit values in the windward side and maybe increased values in the leeward side. There is, however, no explanation why the values in the windward side with the Twin at 12 km/h is above 100% of the theoretically applied at all positions. The same sprayer and exactly the same sampling positions under the boom were used during all treatments. The overall conclusion concerning deposition on the target is that Twin applications at 8 and 12 km/h gave a more uniform deposition below the boom than the corresponding conventional applications especially at high wind speeds.

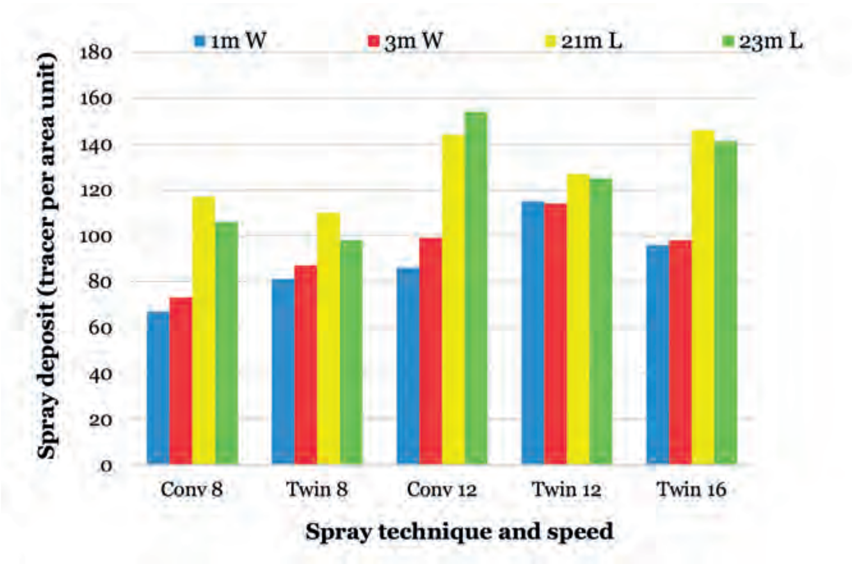


Figure 3. Deposition below the boom at different distances from the end of the boom. The wind direction was perpendicular to the driving direction with Petri dishes placed 1 and 3 m from the end of the boom in the windward side (1 m W and 3 m W) and placed 3 and 1 m from the end of the boom in the leeward side (21 m L and 23 m L). Test at high wind speed May 2018. LSD = 23.5.

Sedimenting spray drift

Figures 4-5 show spray drift values from the two tests. Although the wind speed varied much between the test at low/normal wind speed and the high wind speed test, the absolute spray drift values in the two tests were at the same level. This could be due to the higher temperature in the test at high wind speed and the higher water pressure deficit. In the low/normal wind test (Figure 4), the conventional technique at 8 km/h had the largest drift and the Twin at 8 km/h the lowest values and the three other techniques had intermediate drift values.

In the test at high wind speed (Figure 5) the two conventional applications at 8 and 12 km/h gave the largest spray drift values. Twin at 16 km/h reduced spray drift significantly compared to the two conventional treatments, and the Twin application at 8 km/h had the lowest spray drift values although not significantly different from Twin at 12 km/h. However, drift values for Twin at 8 and 12 km/h were significantly below the Twin values at 16 km/h.

Figure 4. Spray drift at increasing distance from the sprayed area using conventional technique or Twin air assistance at different driving speeds. Drift values are shown as a percentage of the applied dose. Results from test at low/normal wind speed June 2017.

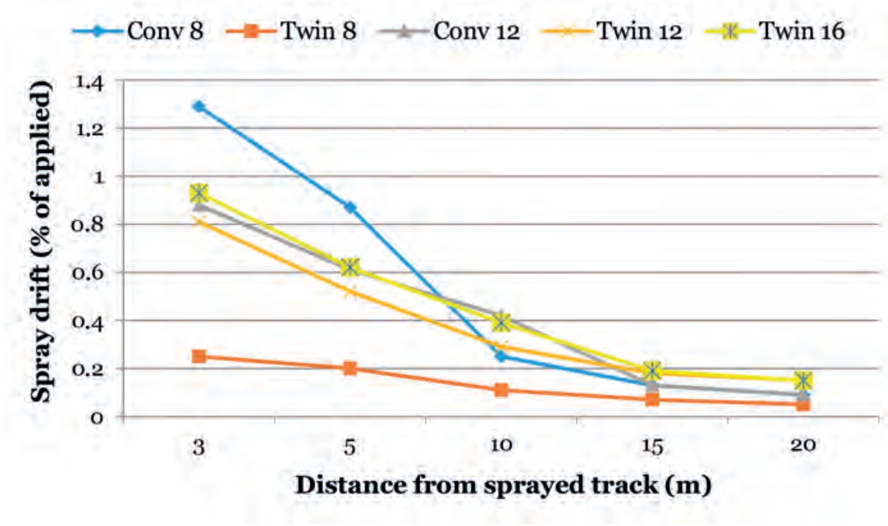
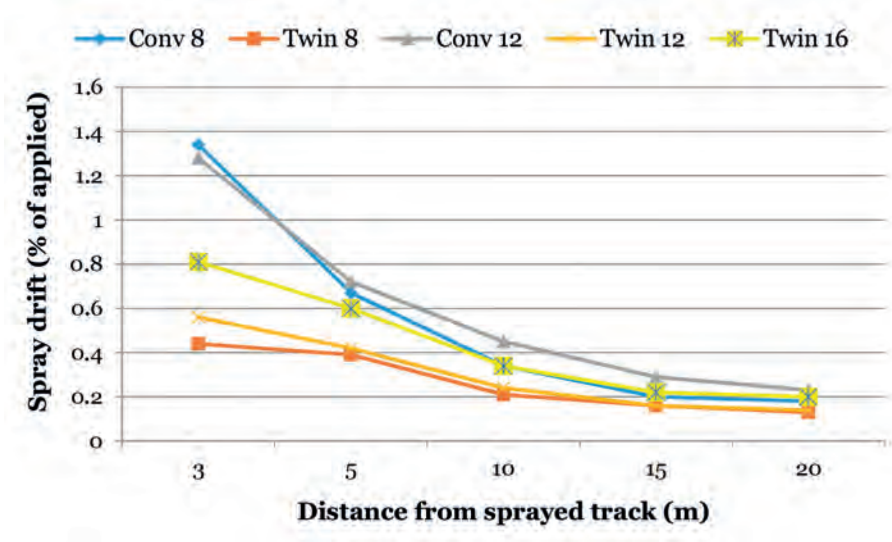


Figure 5. Spray drift at increasing distance from the sprayed area using conventional technique or Twin air assistance at different driving speeds. Drift values are shown as a percentage of the applied dose. Results from test at high wind speed May 2018.



Conclusion

Spray deposition and spray drift from applications at two wind speeds were tested at 8 and 12 km/h with conventional technique and at 8, 12 and 16 km/h with Twin air assistance. A 24-m trailed Hardi Twin sprayer equipped with LD-025 nozzles at 3 bar pressure was used in the test. The atomisation using the LD-025 nozzle at 3 bar is classified as "medium". Measurements of deposits under the boom show that some of the spray was displaced in the crosswind. Deposit values under the boom were generally larger at the leeward side compared to the windward side. The differences were more pronounced in the test at high wind speed where the differences in deposition between the windward side and the leeward side were especially large with the two conventional techniques. The most even distribution below the boom was found with Twin air assistance at 8 and 12 km/h.

The spray drift measurements in the test showed a significantly lower drift from Twin at 8 km/h compared to the other four techniques at both wind speeds. Conventional technique at 8 km/h and 12 km/h gave the highest spray drift. The two Twin applications at 12 and 16 km/h resulted in significantly lower spray drift than the two conventional applications, but higher drift values than Twin at 8 km/h.

Acknowledgement
The study was financed by Hardi International A/S.

XII Results of crop protection trials in minor crops in 2019

Peter Hartvig, Andrius Hansen Kemezys, Louise Hjelmroth, Lis Madsen, Kaspar Ingvordsen, Mie Jensen, Per Elmegaard Andersen & Anja Lunn

In 2019, the minor crops group at AU Flakkebjerg carried out 79 field and greenhouse trials. The group's activities are characterised by covering not only many different crops but also a variety of pests including weeds, diseases and insect pests as well as plant growth regulation. The research activities also involve many different stakeholders and the trials financed by various levy funds, GUDP, agrochemical companies and various private partners. The Swedish minor use project under LRF has also been a major contributor and collaborator in the past few years.

The range of traditional synthetic pesticides has for several years become less and less and this development is very evident in minor crops. Denmark belongs to the EU Northern Zone and the market for pesticides in this zone is small and the agrochemical companies show little interest in minor crops. Therefore, we often experience that if a pesticide does not have an authorisation for a major crop that ensures a certain sale, there is a risk that it will be withdrawn from the market. In other cases, it is often seen that products up for re-registration only apply for the authorisation in the major crop although it previously was used in both major and minor crops.

Because of this, the group's activities have become increasingly characterised by the growing interest in microbial products and other another alternative products – an interest shared by the industry and certain companies. There is also a great interest in products which have an effect on pests but which are not registered as crop protection products. This includes products on the basic substance list but also, for instance, fertilisers, plant elicitors, enhancers or biostimulants. Within weed control there is an awareness that the times when chemistry could handle everything are over and that it is necessary to supplement with other forms of weed control.

However, the testing of chemical solutions is still the major activity in the group, and a summary of the most important activities is presented below.

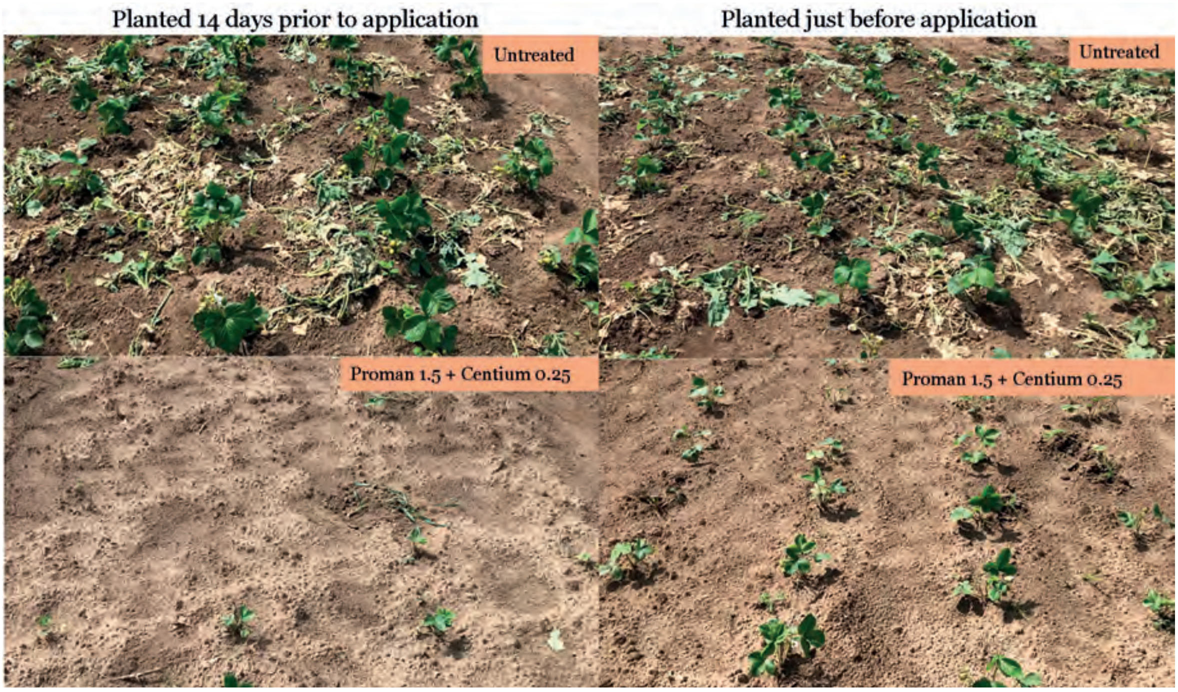
Weed control in vegetables and strawberries

Most of the trials on weed control in vegetables were a continuation of the trials from the previous year with minor changes compared to the previous study plans. The majority of the weed control trials in 2019 were once again carried out as part of the Swedish minor use project under LRF.

Especially the Swedish onion and carrot growers have been severely affected by the limitations in the range of herbicides. The loss of Stomp and Totril has been a theme in the trials for some years. But whereas we in Denmark still have access to Stomp, and Totril has been replaced by Xinca (bromoxynil), the situation in Sweden is different as Stomp and bromoxynil products are banned, and no emergency uses for these products are permitted anymore. Furthermore, the dose rate of Fenix has been significantly reduced to a maximum rate of 0.9 litres per hectare, which is considerably less than the dose rate previously permitted for use in crops like carrot and parsnip. In 2019, the herbicide strategies in onion without Stomp and bromoxynil proved to be quite efficient, although phytotoxic effects on the crops were observed.

The Danish activities on weed control in vegetables and berries have mainly been carried out as part of the GUDP project HORTPROTECT including work with direct sowing and strip tillage in celeriac and strawberries. Another element in the project is testing of 'row-differentiated' weed control, that is to say different weed control within the row (intra-row) and in the space between the rows (inter-row). The testing includes a dual band sprayer allowing intra-row spraying with a selective herbicide and at the same time making a shielded inter-row spraying.

The Swedish strawberry growers are also affected by the very limited availability of strawberry herbicides. Based on earlier experience, a demo trial with two soil-applied herbicides that are authorised in potatoes and oilseed rape – Centium and Proman – was established in order to demonstrate herbicide selectivity in strawberries. The results suggest that the two soil-applied herbicides can be used up to approximately 7 days after transplanting, but if the application is carried out later, there is a risk of severe damage to newly established strawberries.



Photos were taken 13 June (36 days after application) of a strawberry demo trial with soil-applied herbicides. A tank mix of Proman and Centium caused very severe damage to strawberries planted 14 days before application, but the same treatment was safe when applied just after transplanting of frigo strawberries, while they were still relatively dormant. The photos were taken two days after hand-weeding, and weed debris on the soil surface in the untreated plots gives an indication of the weed pressure and it is very clear that a tank mix of Proman and Centium can be considered a very effective weed control when applied just after transplanting. Field trial at Löderup, Sweden 2019.

Weed control in horticultural seed crops

Denmark's status as the world's largest producer and exporter of spinach seeds is the background why the industry is continuously on the lookout for new herbicides or novel ways of controlling weeds. An urgent issue is the ongoing search for a replacement for Asulox, which is a key herbicide in spinach cultivation. The future of phenmedipham – the active ingredient in Betanal – is also uncertain as it is up for renewal of its authorisation, and this has also influenced the herbicide trials in spinach. In 2019, a fairly large matrix trial was carried out in spinach where different herbicide treatments were applied across spinach rows sown at different timings, thus allowing us to evaluate the selectivity of the different herbicide treatments at different growth stages. Apart from spinach, different weed species were sown in rows in for assessment of the efficacy of the treatments. Besides a number of other trials in spinach, weed trials in 2019 were also carried out in pak choi and cress for seed production.

Herbicide screening trials using a 'small plot' sprayer in onions, carrots and strawberries
A specially designed sprayer for 'small plots' allows us to screen a large number of different herbicides in a relatively small area. The area of each plot is usually 1 m^2, and it is a very efficient way of screening herbicides before including them in future large-plot field trials. A few candidate herbicides were identified in the onion and carrot trials that will most likely be tested in the larger scale field trials in the future. The small plot sprayer was also used to mimic an inter-row application in newly established strawberry bed systems with plastic in order to screen a number of known soil-applied herbicides. The need for these trials in strawberries is due to the ban of diquat that has been used for inter-row weed control in strawberry (for more about alternatives to diquat, please see the next paragraph).

Herbicide screening trials using 'small plots' – an efficient way of screening herbicides before including them in traditional large-plot field trials. This photo was taken just before pre-planting application of soil-applied herbicides in strawberries in newly established bed systems with plastic. The idea behind the use of soil-applied herbicides is that it will reduce the need for weed control once the strawberries are planted. Field trial at Osted 2018-2019.

Alternatives to diquat
Diquat is banned in the EU from 4 February 2020 due to concerns related to the exposure of bystanders, residents and birds. Diquat is widely used in minor crops for weed control and as a desiccant before harvest. Diquat is used pre-emergence in a number of seeded vegetables and as a shielded band (inter-row) application in plant nurseries, Christmas trees, pome fruit and berry bushes. Diquat is also widely used as a desiccant in vegetable seed production.

Growers of horticultural seed crops and certain horticultural crops will be greatly affected by the loss of diquat. A few grower organisations have initiated activities both to look for alternatives to diquat and to gather the necessary knowledge and data required for an application for an emergency use of diquat.

The minor crops group participated in a field experiment that provided important data about spray drift when using diquat with boom and shielded sprayers. These data will be used to support applications for an emergency use of diquat where no alternatives are available to diquat.

In 2019 the minor crops group also carried out a few trials with alternatives to diquat in pre-emergence of seeded onions, carrots, parsnips and a seeded nursery crop – oak. A trial with alternatives to diquat as a desiccant in spinach for seeds was also carried out. A few products were identified as having similar properties as diquat, but the alternative products cannot exactly replace diquat. Currently, there are unfortunately no alternative products that can act as quickly and as efficiently as diquat.

Christmas trees – glyphosate free weed control

Denmark is the leading exporter of Christmas trees in Europe. Germany and France are the two largest export markets accounting for more than 50% of the Danish Christmas tree export. Some importers in both countries are requesting 'glyphosate-free' Christmas trees, and as the future of glyphosate in the EU is uncertain, there is also among the growers an increasing interest in Christmas tree production without glyphosate. Currently, glyphosate is a very important herbicide in Christmas tree production and 5 different uses are authorised in Christmas trees including spring and autumn applications (over the trees before and after bud burst, respectively) and as shielded application after bud burst.

The Danish Christmas tree Association's research fund has granted a two-year project to look for alternatives to glyphosate where a number of herbicides used in cereals, maize, potatoes and vegetables were tested in 2019 for efficacy and selectivity to the Christmas trees. The project was initiated in 2018 and a lot of valuable data were collected in 2018-2019. Many of the tested herbicides provided very good weed control. However, most of the products control a far narrower range of weeds than glyphosate, and in some cases it is necessary to use a combination of different products in order to achieve the required level of weed control.

Surprisingly, there were very few occasions in the growing season 2019 when phytotoxic damages were observed on the Christmas trees. After evaluation of the efficacy and selectivity data and the costs of herbicide treatment, new trial plans have been designed for the growing season 2020 where different weed control strategies without the use of glyphosate will be tested.

Control of fungal diseases in vegetables

Apart from the number of trials carried out for agrochemical companies, the trial portfolio of 2019, in line with previous years, included a number of trials conducted for growers' organisations focusing on current challenges and topics. One issue that had been on top of the agenda of both the Danish and Swedish onion growers for some years now is finding alternatives to Acrobat (dimethomorph + mancozeb) for control of downy mildew of onion. The extraordinary warm and dry weather in 2018 created very unfavourable conditions for fungal diseases and in many fungicide trials no or only very minor attacks developed. This includes trials where it was attempted to establish disease through artificial inoculation. Several of these trials were therefore repeated in 2019. This also applied to the trials with the objective of finding alternatives to Acrobat. With some delay, when warm and dry weather in July was replaced by more favourable conditions in August, and after transplanting diseased plants into the trials, a high level of downy mildew developed in the trials. The high disease pressure put the alternatives to a hard test, and only a few strategies came close to matching the Acrobat-based strategies.

Severe attack of downy mildew in onion (*Peronospora destructor*). Field trial at Flakkebjerg 2019.

Control of fungal diseases in spinach for seed production

Fungal diseases can have a great impact on both quality and yield of spinach for seed production. In the growing season 2019, the area of spinach for seed production approached 12,000 hectares and being a high value crop, proper control of fungal diseases can be of major economic importance. Since 2016 work has been going on to develop strategies including other active substances than the few currently authorised fungicides for spinach. Current practice consists of strategies with a relatively high input of pyraclostrobin and boscalid, two fungicides with a high inherent risk of evolution of fungal resistance. The work was carried out in collaboration with Frøafgiftsfonden and started in 2016 with one trial followed up by three trials each year in 2017 and 2018. Due to the warm and dry summer 2018, no data were collected and the trials were repeated in 2019 with the continued focus on finding other effective fungicides with the view to improve resistance management. The main target diseases developed in two of the three trials; however, symptoms were at a very early stage suppressed by wilting prompted by an unknown cause, which challenged the conduction and conclusions of the trials. The results did not provide a clear answer regarding alternative fungicides; however, some new products could be relevant to be studied further.

Plant protection trials in greenhouse cultures

At the request of the Swedish minor use project, the work to find alternatives to Cycocel as a plant growth regulator in greenhouse cultures continued with three trials in 2019. The trials were carried out in *Osteospermum*, white marguerite and zonal pelargonium. Compared to the initial phase of the project with screening of a wide range of products, the plans for 2019 included a few promising candidates selected on the basis of results and experiences from the previous years. The objective of the trials was to optimise efficacy and minimise phytotoxicity. The latter is of significant importance, as ornamentals are subject to restrictions with close to zero tolerance regarding phytotoxicity.

Alternative plant protection products for disease and insect control in pot plants

One of the activities of the GUDP project HORTPROTECT focuses on improving the use of microbial-based plant protection products greenhouse and vegetable production. In 2019, six greenhouse trials covering control of insects and fungal diseases were conducted. The trials on control of insects included green peach aphids in bell pepper, spider mites in pot roses, western flower trips in *Chrysanthemum* and glasshouse whiteflies in common poinsettia. Overall, the results did not clearly identify alternatives to the currently used chemical fungicides. A characteristic of the alternatives is a lower effect and less robustness. Furthermore, the environmental conditions and the method of application have typically more influence on the efficacy compared to synthetic pesticides, as the mode of action for these products is contact related. However, when these parameters are taken into consideration, several of the alternatives are suitable for preventative use and as part of an Integrated Pest Management strategy.

Pepper plants infested by green peach aphids (*Myzus persicae*). Glasshouse trial 2019.

Two other greenhouse trials were set up with a focus on alternative products for control of *Fusarium* in *Cyclamen* and powdery mildew in potted roses. *Fusarium* is a soil-borne disease, which is difficult to control once the plants are infected and it is considered a severe problem in ornamentals. The trial included a range of biofungicides based on different beneficial fungi or bacteria, which are acting by colonising the roots and outcompeting the fungal disease. In these trials, it was not possible to identify effective solutions for the control of *Fusarium*.

The trial on control of powdery mildew in potted roses was a repetition of a trial conducted in 2018. The trial plan was modified based on the 2018 results and updated regarding new relevant products. In contrast to the severe disease pressure seen in 2018, it was not possible achieve a successful infestation of powdery mildew despite several attempts with artificial inoculation. The trial is scheduled to be repeated in 2020.

XIII List of chemicals

Fungicides		
Name	Active ingredients	Gram /L or kg
Adexar Extra	Epoxiconazole + fluxapyroxad	62.5 + 62.5
Aliette	Fosethyl-al	800
Amistar	Azoxystrobin	250
Armure	Difenoconazole + propiconazole	150 + 150
Ascra Xpro	Prothioconazole + bixafen + fluopyram	130 + 65 + 65
Aviator Xpro	Bixafen + prothioconazole	75 + 160
Balaya	Mefentrifluconazole + pyraclostrobin	100 + 100
BAS 751 00 F = Balaya	Mefentrifluconazole + pyraclostrobin	100 + 100
BAS 752 03 F = Revytrex	Mefentrifluconazole + fluxapyroxad	66.7 + 66.7
Bell	Boscalid + epoxiconazole	233 + 67
Bravo 500 SC	Chlorothalonil	500
Bumper 25 EC	Propiconazole	250
Caramba 60	Metconazole	60
Comet granulate	Pyraclostrobin	200
Comet Pro (Comet 200)	Pyraclostrobin	200
Curbatur	Prothioconazole	250
Curzate M68 WG	Mancozeb + cymoxanil	680 + 45.2
Cymbal 45	Cymoxanil	450
Dithane NT	Mancozeb	750
Elatus Era	Azoxystrobin + benzovindiflupyr	30 + 15
Elatus Plus	Benzovindiflupyr	100
Entargo	Boscalid	500
Flexity	Metrafenon	300
Folicur EW 250	Tebuconazole	250
Folpan 500 SC	Folpet	500
GF-3307 = Univoq	Prothioconazole + fenpicoxamid	100 + 50
GF-3308	Fenpicoxamid	50
Imtrex	Fluxapyroxad	62.5
Input EC 460	Prothioconazole + spiroxamine	160 + 300
Juventus 90	Metconazole	90
Kumulus S	Sulphur	800
Librax	Fluxapyroxad + metconazole	62.5 + 45
Luna	Fluopyram	500
MCW 406s	Difenoconazole	250
Narita	Difenoconazole	250
Opera	Pyraclostrobin + epoxiconazole	133 + 50
Opus	Epoxiconazole	125
Opus Max	Epoxiconazole	83
Priaxor	Pyraclostrobin + fluxapyroxad	150 + 75

Fungicides		
Name	Active ingredients	Gram /L or kg
Proline EC 250	Prothioconazole	250
Proline Xpert	Tebuconazole + prothioconazole	80 + 160
Propulse SE 250	Fluopyram + prothioconazole	125 + 125
Prosaro EC 250	Prothioconazole + tebuconazole	125 + 125
Proxanil	Propamocarb + cymoxanil	333.6 + 50
Quilt Xcel	Azoxystrobin + propiconazole	135 + 117
Ranman Top	Cyazofamid	160
Revysol (BAS 750 01F)	Mefentrifluconazole	100
Revytrex	Mefentrifluconazole + fluxapyroxad	66.7 + 66.7
Revycare	Mefentrifluconazole + pyraclostrobin	100 + 100
Revystar XL (BAS 752 00F)	Mefentrifluconazole + fluxapyroxad	100 + 50
Revus	Mandipropamid	250
Revus Top	Mandipropamid + difenoconazole	250 + 250
Rubric	Epoxiconazole	125
Score 250 EC	Difenoconazole	250
Serenade ASO	Bacillus subtilis	1000
Signum WG	Pyraclostrobin + boscalid	67 + 267
Siltra Xpro	Bixafen + prothioconazole	60 + 200
Talius	Proquinazid	200
Tilt 250 EC	Propiconazole	250
Thore	Bixafen	125
Vendetta	Fluazinam + azoxystrobin	375 + 150
Univoq	Prothioconazole + fenpicoxamid	100 + 50
Viverda	Epoxiconazole + pyraclostrobin + boscalid	50 + 60 + 140
Zorvec Enicade	Oxathiapiprolin	100

Herbicides		
Name	Active ingredients	Gram /L or kg
Atlantis OD	Mefenpyr + mesosulfuron + iodosulfuron	30 + 10 + 2
Broadway	Pyroxsulam + florasulam	68.3 + 22.8
Cossack OD	Iodosulfuron + mesosulfuron	7.5 + 7.5
Glyphomax	Glyphosate	360
Glypper	Glyphosate	360
Roundup Flex	Glyphosate	480
Roundup PowerMax	Glyphosate	720

Growth regulators		
Name	Active ingredients	Gram /L or kg
Cerone	Ethephon	480
Medax Top	Mepiquat-chlorid + prohexadion-calcium	300 + 50
Moddus M	Trinexapac-ethyl	250
Stabilan Extra	Chlormequat-chlorid	750
Trimaxx	Trinexapac-ethyl	175

About DCA

DCA - Danish Centre for Food and Agriculture is the entrance to research in food and agriculture at Aarhus University (AU).

The Centre comprises AU departments with food and agricultural science activities. These are primarily Department of Agroecology, Department of Animal Science, Department of Food Science, Centre for Quantitative Genetics and Genomics, and parts of Department of Engineering.

DCA has a Centre Unit, which supports and coordinates DCA activities in relation to research based policy support, industrial and sector collaboration, international collaboration, and communication.

Research results from DCA
Research results are published in international scientific journals, and they are available at the university publication database (pure.au.dk).

DCA reports
DCA also publishes a report series, which primarily communicates policy support tasks from DCA to the Ministry of Food and Environment of Denmark. Further publications include reports that communicates knowledge from research activities. The reports may be downloaded free of charge at the DCA website: dca.au.dk.

Newsletters
A Danish and English DCA newsletter communicate knowledge within agricultural and food research, including research results, advice, education, events and other activities. You can register for the free newsletter at dca.au.dk.

SUMMARY

This publication contains results from crop protection trials, which were carried out at the Department of Agroecology within the area of agricultural crops. Most of the results come from field trials, but results from greenhouse and semi-field trials are included.

The report contains results that throw light upon:

- Effects of new pesticides
- Results of different control strategies, including how to control specific pests, as part of an integrated control strategy involving both cultivars and control thresholds
- Results with pesticide resistance
- Trial results from different cropping systems