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Timing of fungicide application for profitable disease management in oat (*Avena sativa* L.)

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Abstract

The efficacy of tebuconazole fungicide for the control of oat leaf diseases caused by *Pyrenophora avenae* and *Puccinia coronata* was studied during 2003–2005. Two application times and four varieties belonging to three resistance categories were used in the trial series. The aim of the study was to test the effect of fungicide timing and variety resistance on the disease control efficacy and yield increase. The trial series provided diverse results in terms of disease control and economic profitability. There were no single solutions for timing of the fungicide application. Depending on the weather conditions, better efficacy in disease control or higher economic return was achieved from fungicide use at flag leaf stage or at heading stage.

Key words: *Avena sativa*, chemical control, crown rust, oat leaf spot, tebuconazole, application time, yield.

Introduction

Crown rust and leaf spot are major diseases in oat (*Avena sativa* L.). Oat leaf spot, caused by *Pyrenophora avenae* (Ito & Kurib., conidial stage: *Drechslera avenae* syn. *Helminthosporium avenae*) is a seed-borne pathogen, the fungus also survives on host debris but the main source of inoculum is seed infested with the long-lived resting mycelium (Zillinsky, 1983; Clifford, 1995). When infected kernels germinate, the fungus infects the seedling leaves. Produced spores are dispersed to other leaves and they produce new spots. The disease infects oat plants at early stages of development under conducive weather conditions. Disease infestation is favoured by rains and moist, humid periods as spores germinate at temperatures of 10–20ºC and 100% humidity (Motovilin, 2000). Because of the destruction of leaf tissue, photosynthesis is reduced in diseased plants leading to yield decline (Motovilin, Strihekozin, 2000).

Oat crown rust, caused by *Puccinia coronata* f. sp. *avenae* is a long-cycled rust fungus having buckthorn (*Rhamnus* sp.) as alternate host (Nyvall, 1979; Šebesta et al., 1997). Crown rust develops best during mild to warm (20–25ºC) sunny days and mild nights (15–20ºC) with adequate moisture for dew formation (Top crop manager, 2008). In Estonian conditions, the infection usually occurs at heading stage. Weather conditions being favourable for oat growth also favour crown rust, therefore greatest yield losses commonly occur in years when oat yields should be highest. Moderate to severe epidemics can reduce grain yield by 10% to 40% (Top crop manager, 2008).

Both diseases are increasing problem in oat production worldwide, therefore chemical control is widely used to maintain green leaf area and increase kernel yield. A number of fungicides are used to control crown rust and leaf spot, but their use is often limited by economic constraints (Clifford, 1995).

Proper choice of fungicide, its dose and application time are important in achieving the economic efficacy because of low returns caused by low price of oat grain. Efficacy of fungicides is highly dependent on the time of application. Fungicides can have a curative or preventive effect on diseases (Cook et al., 1999). It has been widely recognized (Cook et al., 1999; Dimmock, Gooding, 2002; Jorgensen et al., 2003) that fungicides applied during the period from flag leaf emergence to ear emergence, just after the appearance of first disease symptoms often provide the best prospect for cost-effective control of foliar diseases.

The use of preventive fungicide applications to prolong the duration of green leaf area and to increase the yield has been an increasing trend in farmer's practice over the last decade. The use of fungicides has been effective in disease control but represents an added input cost for producers. At the same time much research has been put into optimization of pesticide use in main cereals. The adjustment of application to complement the general resistance of a variety is important to improve the economics of disease control. Several studies have covered aspects of reduction of environmental concerns and increased economic profitability (Wale, 1994; Hedge, Verrelt, 1999; Mercer, Ruddock, 2003). However, very limited information is available about chemical control of oat leaf diseases and fungicide impact on oat yield and economic profitability.

Oat leaf spot and crown rust differ in their epidemiology – differing in weather conditions favouring the development of epidemics and having different infection times. Therefore these diseases trigger the need of fungicide treatment at different stages of plant development and at different weather conditions.

The aim of the current study was to identify the proper timing of fungicide treatment in control of leaf diseases in oats and to study the effect of variety resistance in control of oat diseases. Other targets were to find the best time for a single fungicide application to control both diseases and to study the effect of fungicide application on yield and economy. We compared two fungicide application times, widely accepted time at flag leaf emergence (BBCH 37) and late application after the heading (BBCH 59). Because of low oat grain price, the avoidance of unnecessary expenses on disease control is of great importance in order to achieve economic profitability.

Materials and methods

Field trials on disease control of oat were arranged in a randomized block design in 20 m² plots with three replicates at Jõgeva Plant Breeding Institute, Estonia during 2003–2005, on *Calcaric cambisol* (*CMc*) soil (K_0, pH_{KCl} 5.8; available P 190, K 180, Ca 1520, Mg 64, Cu 1.3, Mn 41 and B 0.7 mg kg^{-1}). A sowing rate of 500 viable seeds per 1 m² was used in all trials seeded at optimal time in the first week of May. Fertilizer application was 80 N ha^{-1}, 40.5 P_2O_5 ha^{-1} and 40.5 K_2O ha^{-1} using complex fertilizer Kemira Power 18 (18 N, 9 P_2O_5, 9 K_2O) at planting. Additional nitrogen AN 43 80 kg ha^{-1} was applied at shooting stage BBCH 21–23. Previous crop was potato in all years. Four oat varieties with different resistance level were used: 'Jaak', 'Villu' (moderately susceptible to crown rust and oat leaf spot) and 'Hecht', 'Belinda' (susceptible to crown rust, moderately susceptible to oat leaf spot). Varieties 'Jaak' and 'Villu' were in trial in all three years, variety 'Hecht' was used in 2003 and variety 'Belinda' in 2004 and 2005. The varieties were selected based on the data from previous disease scoring trials in the same region (Tamm, 2003). Untreated certified seed was used for all varieties.

Fungicide tebuconazole (250 g a.i. tebuconazole; trade name in Estonia: Folicur EW 250) was used in a single dose of 1.0 l ha^{-1} in an early (BBCH 37–41) or late (BBCH 59–63) application in all trials. Tebuconazole is a broad spectrum fungicide with special strength against several phytopathogenic fungi including *Puccinia* and *Helminthosporium* (Bayer Crop Science). Phenological growth stages were determined according to BBCH-identification keys for cereals (Meier (ed.), 2001). Fungicide applications were started upon the first symptoms of infection and application times are presented in Table 1; all varieties were treated at the same time. The early application (Early T) of tebuconazole was targeted on control of oat leaf spot disease and late application (Late T) was targeted on control of crown rust. First symptoms of oat leaf spot were observed at time Early T in 2003 and 2005, and first symptoms of oat crown rust were observed at Late T in 2003. Fungicides were applied with a bicycle sprayer equipped with 6 Hardy nozzles 4110-12 on a 2.5-m boom using 300 l of water per ha^{-1}.

Disease infection was scored on 30 randomly selected plants in every plot as the percent of leaf area infected. Disease incidence was scored separately for *P. avenae* and *P. coronata* at the time of fungicide applications and 10–15 days after the late treatment at BBCH 71–75. The infection level was expressed as an average of the infection score on second leaves (L-2; the first leaf under the flag leaf). For proper identification of pathogens, leaves with symptoms of *P. avenae* were incubated in a moisture chamber for 6–7 days at 22ºC, and formed spores were examined with the microscope. Crown rust was identified by direct examination of rust pustules by light-microscopy for identification of characteristic spores of *P. coronata*.

Table 1. Dates and growing stages of fungicide applications and disease assessment times in 2003–2005

Year	Fungicide treatment (T)				Disease assessment	
	Early T	BBCH	Late T	BBCH	Third	BBCH
2003	5th July	37–41	15th July	59	26th July	71–73
2004	1st July	41	15th July	63	30th July	75–77
2005	1st July	37–41	15th July	59	1st August	71–73

Trial years differed in weather conditions and their suitability for the development of oat diseases. Year 2003 was characterised by rainy May, moderate temperature in June, warmer and dryer weather in July and very rainy August (Table 2). Such conditions favoured early infection of oat leaf spot and moderate development of oat crown rust. Year 2004 was characterised by droughty May, colder than usual but very rainy June, dry July and rainy August. Especially rainy June favoured infection and development of oat diseases. Year 2005 was dry and hot, it was characterised by lower than average precipitation in June and July and higher than average temperatures in July and August. Weather conditions were suitable for lower level infection of oat leaf spot. Oat crown rust did not develop in droughty conditions.

Table 2. Mean temperature and precipitation for growing seasons 2003–2005 and long term average (1922–2005) at Jõgeva

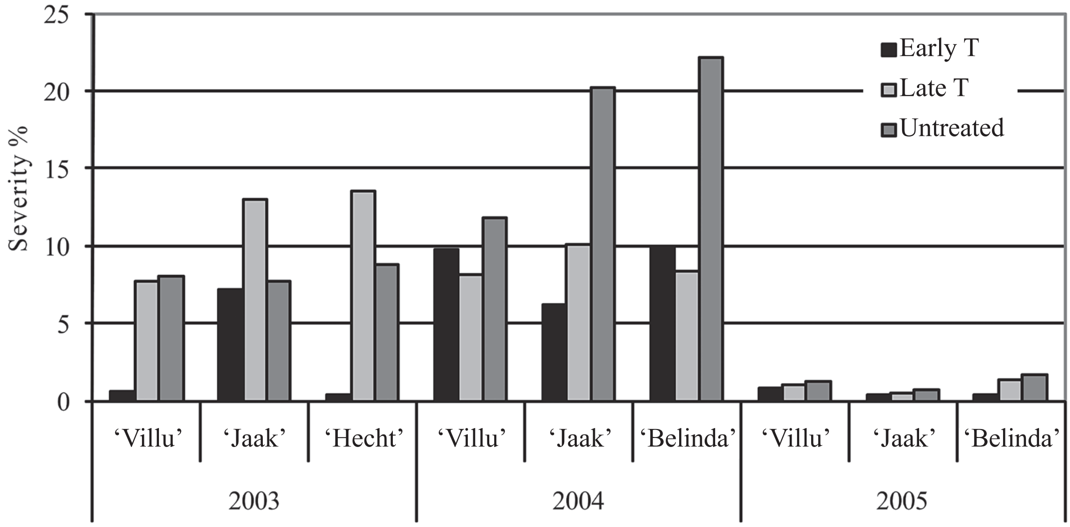
Month	Air temperature ºC			Long term average	Precipitation mm			Long term average
	2003	2004	2005		2003	2004	2005	
May	11.3	10.1	10.5	10.2	101	16	84	50
June	13.0	13.1	14.0	14.4	59	184	50	66
July	19.4	16.2	17.9	16.7	54	68	60	81
August	15.0	16.5	16.0	15.3	187	113	116	87

Development of diseases depends on the presence of indigenous primary inoculum and on existing weather conditions. Oat leaf spot development is favoured by cool and wet weather. The overall sparse oat leaf spot in the present study probably resulted from low inoculum densities and not from weather factors, which were moderately and highly conductive to *P. avenae* in 2003 and 2004, respectively. Germination of urediospores of *P. coronata* needs presence of free water on the leaf surface (Simons, 1985). Oat crown rust is most problematic when the disease develops early and the weather conditions are mild to warm during the day and mild at night with rains or frequent dews. Drier and warmer first half of the vegetation period hindered development of oat crown rust in 2005. As *P. coronata* exists in the form of different races, the appearance of new races affects performance of varieties over time. Trials were harvested with a plot combine harvester "Hege 125" at the full maturity in a single day. The grain yield was adjusted to the 14% moisture content and expressed in kg ha^{-1}. The net yield kg ha^{-1}, harvest yield subtracted amount of grain equal to the cost of fungicide and application, was calculated to analyze the economic benefit of fungicide use. The price of the fungicide Folicur EW 250 (33.55 EUR l^{-1}), cost of fungicide application (7.70 EUR ha^{-1}) and the average purchase price of oat (0.10 EUR kg^{-1}) in Estonia for the period 2003–2005 were used in calculations of yield revenue. All prices were used without VAT.

Statistical analyses were performed with software package *Agrobase* (Agrobase™, 1999) using the factorial analysis of variance. Standard analysis of variance (ANOVA) was performed to determine the main factors and the interactions. Mean separations were made for significant effects with LSD at probability $P \leq 0.05$.

Results and discussion

Oat leaf spot control. Severe infection of *P. avenae* developed in 2003 and 2004 (Fig. 1). All varieties were infected in equal level in 2003 and 2005, disease incidence was significantly lower in variety 'Villu' in 2004 compared to other varieties. Early application of tebuconazole had high biological effect in 2003, significantly reducing infection from 8.0% to 0.6% in variety 'Villu' and from 8.8% to 0.4% in variety 'Hecht' ($R^2 = 0.21$, d.f. = 4, $p = 0.0000$). Late T exhibited very limited effect in variety 'Villu' reducing infection from 8.0% to 7.7%. No effect on disease control compared with untreated was achieved in varieties 'Jaak' (13.0%) and 'Hecht' (13.5%) where infection level exceeded that in the untreated control. Late T exerted no or very limited effect on disease control because infection occurred in early stages of plant development and fungicide was unable to control already established infection. Early T significantly reduced oat leaf spot infection in all varieties at more severe infection in 2004, infection was reduced from 20.2% to 6.2% in variety 'Jaak' and from 22.1% to 10.0% in variety 'Belinda' (R^2 = 0.11, d.f. = 4, p = 0.0709). Under conditions of fast epidemic, Late T resulted in slightly better oat leaf spot control than Early T in 2004. Late T decreased infection from 22.1% to 8.4% in variety 'Belinda' and from 11.8% to 8.1% in variety 'Villu' (R^2 = 0.33, d.f. = 4, p = 0.0000). Significant disease control effect was achieved with Early T in conditions of weak infection pressure in 2005, disease infection was reduced from 1.7% to 0.4% in variety 'Belinda', from 1.2% to 0.8% in variety 'Villu' and from 0.7% to 0.4% in variety 'Jaak' (R^2 = 0.04, d.f. = 4, p = 0.0312). Late T resulted in significant reduction of disease infection only in 'Belinda' this year. In summary of trial years and test varieties, the Late T had lower disease control effect than Early T. Higher disease reduction was achieved in more susceptible varieties 'Hecht' (was grown in 2003) and 'Belinda' (grown in 2004 and 2005). Significantly lower disease control efficacy was observed in variety 'Villu'.

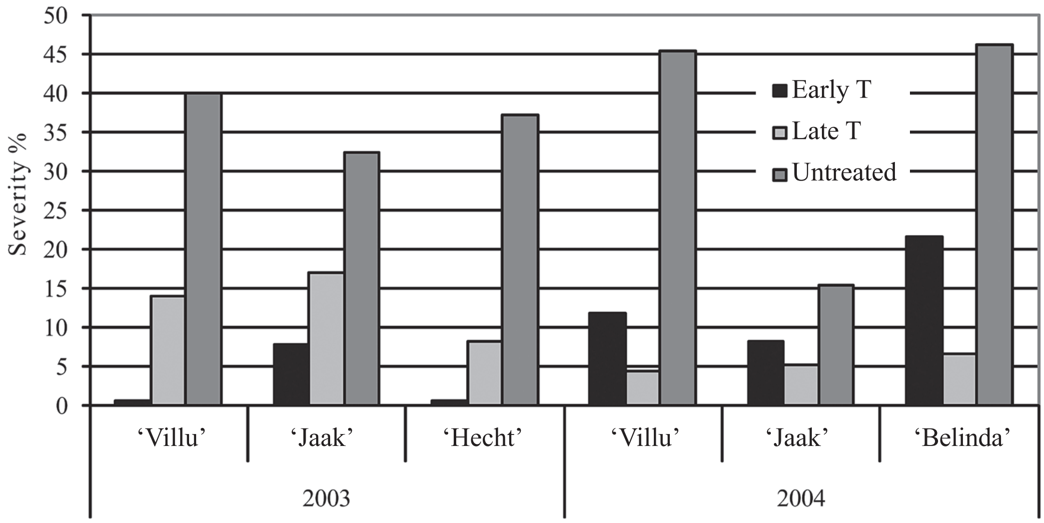


$LSD_{0.05}$ = 0.94 (2003), 1.99 (2004), 0.40 (2005); T – treatment

Figure 1. Oat leaf spot severity caused by *P. avenae* in field trials (2003–2005) assessed at BBCH 71–75

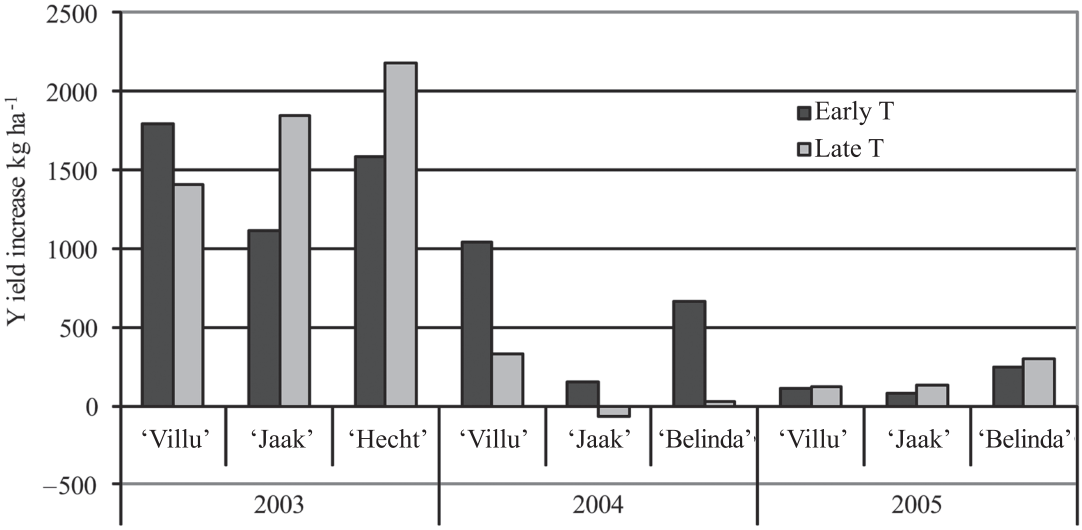
Crown rust control. Oat crown rust caused by *P. coronata* was observed in 2003 and 2004, the disease was absent in 2005. Variety 'Jaak' had lower disease infection than other varieties in both years of crown rust incidence (Fig. 2). All fungicide treatments resulted in significant reduction of oat crown rust infection and there were significant differences between efficacies of different treatment times. Early T was more effective than Late T in 2003 with infection reduction to 7.8% in variety 'Jaak' and to 0.5% in varieties 'Villu' and 'Hecht' (R^2 = 0.55, d.f. = 4, p = 0.0000). Late T was more effective than Early T in 2004, with infection reduction to 5.2% in variety 'Jaak', to 4.2% in variety 'Villu' and to 6.5% in variety 'Belinda' (R^2 = 0.70, d.f. = 4, p = 0.0000). Lowest disease control effect was observed in most resistant variety 'Jaak' for both treatment times and both years.

Grain yield. The yields of untreated plots were 2654 kg ha^{-1} (2003), 5673 kg ha^{-1} (2004), 4633 kg ha^{-1} (2005) in variety 'Jaak', 2557 kg ha^{-1} (2003), 5783 kg ha^{-1} (2004), 4718 kg ha^{-1} (2005) in variety 'Villu', and 2957 kg ha^{-1} (2003) in variety 'Hecht', and 6601 kg ha^{-1} (2004), 5034 kg ha^{-1} (2005) in variety 'Belinda'. Fungicide application provided significant yield increase only in 2003. Highest yield increase from fungicide use in 2003 was obtained from Late T in varieties 'Hecht' (2176 kg ha^{-1}) (R^2 = 0.90, d.f. = 8, p = 0.004) and 'Jaak' (3092 kg ha^{-1}) (R^2 = 0.85, d.f. = 8, p = 0.0136) (Fig. 3). An opposite was observed in variety 'Villu', where higher yield increase was obtained from Early T. The yields were greatly affected by lodging in 2004, especially in variety 'Jaak'. Early T resulted in higher yield increases in 2004 in all varieties. Higher yield increase was observed in varieties 'Villu' and 'Belinda'.



$LSD_{0.05}$ = 2.22 (2003), 2.50 (2004); T – treatment

Figure 2. Oat crown rust severity caused by *P. coronata* in field trials (2003–2004) assessed at BBCH 71–75



$LSD_{0.05}$ = 849 (2003), 756 (2004), 292 (2005); T – treatment

Figure 3. Yield increase in fungicide treated plots in comparison with untreated control (2003–2005)

In conditions of very low disease pressure in 2005 higher yield increases were obtained from Late T. Significant yield increase was obtained only for variety 'Belinda' (296 kg ha^{-1}) (R^2 = 0.88, d.f. = 8, p = 0.0051).

Fungicide impact on net revenue. Fungicide applications resulted in highly significant financial benefit in 2003, when highest benefit (176.25 EUR ha^{-1}) was obtained from Late T in variety 'Hecht'. Lowest benefit (70.75 EUR ha^{-1}) was in Early T in variety 'Jaak' (Table 3). This was the only non-significant difference.

Very diverse financial results were obtained in 2004 when one half of treatments increased the income in the case of the other half of treatments the cost for fungicide application was higher than the price of obtained extra yield. The highest benefit (63.15 EUR ha^{-1}) was obtained from Early T in variety 'Villu', in opposite side was Late T in variety 'Jaak' and 'Belinda', where the cost of fungicide application exceeded the benefit by 37.95 to 47.65 EUR ha^{-1}. None of the differences was significant.

None of the fungicide treatments was profitable in 2005 when cost of fungicide application exceeded the price of extra yield by 11.65 ('Belinda' Late T) to 33.05 ('Jaak' Early T) EUR ha^{-1}. Both applications in variety 'Villu' and Early T in variety 'Jaak' caused significant reduction of yield and income.

Several factors have to be considered in order to achieve the profitability of pesticide treatments. Application of fungicides is particularly critical for small crop where costs of protection must be kept low in order to remain profitable even if it controls the pathogen. Oat is relatively low-input crop and fungicide application is therefore commonly not desirable (Newton et al., 2003). In the current trial series none of the fungicide applications provided yield increase conditions of low disease spread in 2005. Results of some oat experiments have shown that disease control can have economically significant effect on kernel yield (White et al., 2003). The chemical protection against *P. avenae* and *P. coronata* is commonly considered to be economically most reasonable with single fungicide application at growth stages 37–41. In the current trial series, a good disease protection and high profitability with fungicide application at growth stages 37–41 was achieved in variety 'Villu' in 2003. Control measures reducing the amount of initial inoculum will reduce the amount of disease at any particular time (Cook et al., 1999). Seed treatment will reduce the initial inoculum of *Pyrenophora avenae* and the need for foliar fungicide application. This allows postponing the fungicide application or decreasing the amount of fungicide dose. Optimum application timing is at flag leaf emergence, when all leaves are formed. Earlier application could result in insufficient fungicide transport to the forming leaves. Most fungicides provide protection against fungal pathogens for two-three weeks. In practice, fungicide does not cover whole plant area with total efficacy; especially the most sensitive varieties cannot be protected fully under heavy epidemic conditions. Too early preventative fungicide applications can lose the effect for time of late disease establishment. Therefore application of fungicides at heading stage could result in better disease control and better economic profit in conditions of late disease development. In the current trial series, a good disease protection with fungicide application at growth stage 63 was achieved in varieties 'Villu' and 'Belinda' in 2004.

Table 3. Net yield and financial benefit of fungicide treated (T) variants (2003–2005)

Variety	Year	Yield kg ha^{-1}	Net yield kg ha^{-1}		Financial benefit EUR ha^{-1}	
		untreated	Early T	Late T	Early T	Late T
'Villu'	2003	2557	3939.5	3554.5	138.25	99.75
'Jaak'	2003	2654	3361.5	4084.5	70.75	143.3
'Hecht'	2003	2957	4131.5	4720.5	117.45	176.35
'Villu'	2004	5783	6414.5	5705.5	63.15	−7.75
'Jaak'	2004	5673	5415.5	5196.5	−25.75	−47.65
'Belinda'	2004	6601	6853.5	6221.5	25.25	−37.95
'Villu'	2005	4718	4416.5	4423.5	−30.15	−29.45
'Jaak'	2005	4633	4302.5	4350.5	−33.05	−28.25
'Belinda'	2005	5034	4873.5	4917.5	−16.05	−11.65

Notes. Net yield – harvested yield subtracted the amount of grain equal to the price of fungicide and cost of fungicide application (41.25 EUR ha^{-1}). Benefit – net revenue subtracted the cost of yield in untreated control.

Our results indicate that demand for fungicide control is clearly minimal for more resistant genotype (variety 'Jaak'). However, the previous study conducted in Jõgeva PBI has shown that variety 'Jaak' is losing the resistance to *P. coronata* and increased fungicide use could be needed for this variety in the future (Sooväli, Koppel, 2003). The increase of susceptibility of variety 'Jaak' is reflecting a rapid change in frequency of matching pathotypes of *P. coronata*. The same has also been observed between yellow rust and wheat (Hovmoller, 2001).

It is likely that the use of other fungicides can give different results. Full dose of tebuconazole was used in the current trial series. Several investigations have indicated that fungicide doses can be reduced by 50–70% without essential loss in control of diseases (Jorgensen et al., 2003). Providing the same level disease control, the use of reduced fungicide doses will increase the economic profitability.

Conclusions

The results of the current trial series indicated that fungicide use in oat could provide diverse results in terms of disease control and economic profitability.

1. There is no single solution to timing the fungicide application.

2. Weather conditions and variety resistance should be considered when timing fungicide use for achievement of best economic results.

3. Fungicide use is most reasonable in susceptible varieties in weather conditions favourable for disease development.

4. Smaller economic returns are achieved in more resistant varieties. Usually more resistant oat varieties do not need foliar application of fungicides.

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Fungicidų purškimo laiko svarba, siekiant efektyvios sėjamosios avižos (*Avena sativa* L.) ligų kontrolės

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Santrauka

Fungicido tebukonazolo efektyvumas nuo avižų lapų ligų *Pyrenophora avenae* ir *Puccinia coronata* tirtas 2003–2005 m. Bandymų metu tirta du purškimo laikai, naudotos keturios veislės, priskiriamos trims atsparumo kategorijoms. Tyrimų tikslas – nustatyti fungicido purškimo laiko ir veislės atsparumo poveikį ligų kontrolės efektyvumui bei derlingumui. Tyrimų metu gauti skirtingi ligų kontrolės ir ekonominio efektyvumo rezultatai. Nenustatyta esminių skirtumų tarp skirtingų fungicido purškimo laikų. Priklausomai nuo oro sąlygų, geresnis ligų kontrolės ir ekonominis efektyvumas gautas fungicidą purškiant paskutinio lapo arba plaukėjimo tarpsniais.

Reikšminiai žodžiai: *Avena sativa*, cheminė kontrolė, vainikuotosios rūdys, avižų lapų dėmėtligė, tebukonazolas, purškimo laikas, derlius.