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The advantage of Decision Support System for managing spring barley disease in Estonia

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Abstract. A Decision Support System (DSS) I-Taimekaitse focusing on use of timely applied and reduced fungicide rates in control of cereal diseases has been tested in field trials since 2003. We compared the conventional treatment and the DSS-based spray practices in 18 field trials in five agricultural locations over 7-year period. Efficacy of the control of net blotch caused by *Pyrenophora teres* (Drechsler, am *Drechlera teres* Sacc. Shoem), the main fungal disease in spring barley has been tested to determine the economic advantage of DSS use. Compared with the conventional spray practices, the advantage I-Taimekaitse resulted in reduction of application doses by 30 to 60% of the registered rate. According to I-Taimekaitse, the fungicides were applied mainly between heading and flowering growth stages (GS 55–65), whereas traditional routine spraying is commonly made at booting (GS 37–49). The experiment clarifies the cost-benefit of using DSS-based approach in barley disease management with average yield increase above the control in 12.8% and above the conventional treatment in 14.1%. I-Taimekaitse gave competitive disease control and average yield output reduction compared with conventional practice by 9%. In general the Treatment Frequency Index applied in conventional treatment was 0.65 and in DSS 0.41. Although the cost of treatment expense in DSS was 20% less compared with conventional practice, the performance of conventional used spray practices was outstanding in economic return.

Key words: Decision support system, economic return, fungicide, net blotch, spring barley.

INTRODUCTION

Disease control is an especially significant challenge for food security (Brown, 2010). The incidence and severity of plant diseases depend from combination of host plant and pest genotypes, climatic conditions and management practices. Environmentally sound and economically efficient disease control needs considering all these factors. To reduce the use of pesticides it is possible to improve the controls of disease with optimized fungicide application. Decision Support System (DSS) is based on using appropriate doses aimed at minimizing the overall pesticide input (Jørgensen et al., 2008; Shtienberg, 2013). DSS where specific field inspections are omitted and where regional disease data are relied upon may attract more farmers as they save the farmer's time (Jørgensen et al., 2008). For barley, major changes in the crop protection schemes are expected in the Baltic region due to northward spread of new pests and higher disease pressure from native pathogens due to higher precipitation (Olesen et al., 2011). The

DSS can help to inform users of plant disease risk (Gent et al., 2011) and develop a fungicide recommendation on the application time (Newe et al., 2003). The optimal input with fungicides depends on the disease pressure and the climate in the individual season, but the susceptibility of the cultivar in particular plays a major role for the optimal input (Jørgensen et al., 2008).

In Estonia cereals cover nearly 50% of the cultivated area and are the crops that required the largest volume of plant protection products (European Commission, 2007). In 2016, the spring barley growing area in Estonia was 132.6 thousand hectares and the average yield was 3,517 kg ha^{-1} (Statistical Database, 2016). A major foliar disease of spring barley (*Hordeum vulgare*) is net blotch, caused by *Pyrenophora teres* (Drechsler, am *Drechlera teres* Sacc. Shoem) have a significant negative impact on yield and quality (Sooväli & Koppel, 2010). The fungus overwinters in infected barley residue or as seed-borne mycelium. Infection of barley leaves is greatest during humid and cool weather conditions.

Estonian farmers were often use fungicides routinely at high doses. On average they use one spray between stem extension growth stage (GS 35) (Zadoks et al., 1974) and the flag leaf sheath swollen (GS 45) to control foliar diseases on barley (Koppel & Sooväli, 2012). Routine sprays with strobilurins and triazoles are applied to reduce disease pressure uncertainty associated with management of *P. teres* in barley (Heinonen et al., 2013). Strobilurin and Succinate dehydrogenase inhibitors (SDHI)-resistance is confirmed in *P. teres* in Denmark (Jørgensen et al., 2015).

Pest risk models aim at detecting the onset of pest infestations and timing pesticide treatments through economic thresholds integrated in the model algorithms, thereby helping to minimize and optimize pesticide use (Jørgensen et al., 2008; Sønderskov et al., 2014). Models of the Danish Decision Support Systems PC-P Diseases concerning diseases and weeds of cereals were tested and adapted to Estonian conditions. The DSS-based system (I-Taimekaitse at http://itk.etki.ee) focuses on dose-response of fungicide use in Estonia since 2003. Numerous field trials were conducted since this time to support the use of reduced rates. The DSS model of disease control in spring barley has been upgraded in collaboration of Estonian Crop Research Institute and Estonian University of Life Sciences in frames of the project 'Development and implementation of an Internet based decision support system in plant protection' supported by Estonian Ministry of Agriculture. The trials were focused on the testing and adapting the Danish computer-based DSS PC-Plant Protection for disease control under Estonian conditions. The decisions that are supported are recommendations for the timing of the fungicide application to control the disease. All recommendations are based on field and weather data. The decision support predictions include the optimisation of fungicide applications. A DSS pest forecasting model reduces the complexity of integrated pest management (IPM) that may otherwise deter farmers from adopting a full IPM portfolio (Been et al., 2009; Sharma et al., 2011).

The aim of the study was to assess economic return of fungicide use in spring barley. In addition, the DSS-based and conventionally used spray practices for disease control and yield were compared.

MATERIALS AND METHODS

Field trials were conducted during 2003–2009 at five different geographical sites (Saku, Northern Estonia, Jõgeva, Eastern Estonia, Väätsa and Jäneda, Central Estonia, Põlva, Southern Estonia). All trials were laid out in complete randomized block designs with three replicates containing fungicide treatments and untreated control. Treated seeds were sown in 10 m² plots at the rate of 500 germinating seeds per m². All trials were sown at optimal time in the first week of May. Fertilizer rates of 80 kg N ha^{-1} Kemira Power 18 (18 N, 9 P_2O_5, 9 K_2O) were applied at 500 kg ha^{-1}. Additional nitrogen AN43 80 kg ha^{-1} was applied at shooting stage (GS 21–23). *Pyrenophora teres* was allowed to develop naturally in each trial. The conventional treatment, a DSS-based reduced rate treatment and untreated control were compared. Experimental treatments consisted of the fungicides listed in Table 1.

Table 1. Fungicide active ingredients and prices used in field trials 2003–2009

Product and label dose L ha^{-1}	Active ingredient g L^{-1}	Price € L^{-1}
Artea 330 EC 0.4	Propiconazole 250, cyproconazole 80	58
Folicur 250 EW 1.0	Tebuconazole 250	35
Mirage 40 EC 1.0	Prochloraz 400	21
Tilt 250 EC 0.5	Propiconazole 250	43
Tango Super 1.5	Epoxiconazole 84, fenpropimorf 250	21

Fungicides were applied with a bicycle sprayer equipped with 6 Hardy nozzles 4110–12 on a 2.5-m boom using 200 L of water per ha^{-1}. The five varieties Anni, Barke, Baronesse, Inari and Mercada for the experiments were selected to maximize the severity of the *P. teres* for the purpose of the DSS. Untreated certified seed was used for all varieties.

Incidence and severity of net blotch was assessed at growth stages (GS 69–73) on the flag leaf on 3 main tillers at ten randomly selected places per each plot. The percentage of leaf area infected with net blotch was visually estimated. Plots were harvested each year using a plot combine harvester on mid of August and yield was corrected to 14% moisture content and measured in kg ha^{-1}. Treatment Frequency Index (TFI) is calculated by dividing the amount of used fungicide dose by the standard appropriate dose.

Gross margin results were calculated assuming a grain price of 120 € t^{-1} and an application cost of 7.7 € ha^{-1} per treatment. All prices were used without value added tax.

All data were analyzed using the factorial analysis of variance (ANOVA) using statistical software Agrobase (release 20; Winnipeg, Canada). Differences between treatments of disease severity data were analyzed using ANOVA with a factorial analysis. Standard analysis of variance was performed to determine the main factors and interactions. Mean separations were made for significant effects with LSD at probability $p < 0.05$.

RESULTS AND DISCUSSIONS

Timing of foliar fungicide application. Over the period 2003–2009 there were 18 field trials where DSS was compared with the standard conventional fungicide applications. Results revealed that standard routine spraying was used mainly in GS 37–49, whereas in majority of years the DSS-based often suggested application in GS 55–65 and recommended rates varied between 30 and 60% of label dose rate (Table 2). This shows that the DSS recommendation leads to use the fungicide generally later than standard routine. This shows also that farmers accustomed treatment practice was slightly earlier. Under high disease pressure in 2003, 2005 and 2009 early treatment was needed in barley net blotch control according to conventional or DSS.

Table 2. Varieties, fungicide doses and times of application in field trials 2003–2009

Year	Variety	Rate product L ha^{-1}		
		GS 32–35	GS 37–49	GS 55–65
2003	Anni	Artea 0.25	*Tilt 0.17	
	Barke		Artea 0.25	*Tilt 0.15
	Baronesse		Artea 0.25	*Tilt 0.23
2004	Anni		Artea 0.25	*Artea 0.12
	Baronesse		Artea 0.25	*Artea 0.13
	Barke		Artea 0.25	*Artea 0.15
2005	Anni		Tilt 0.25	*Artea 0.15
	Baronesse	Tilt 0.25	*Artea 0.13	
2006	Anni		Tilt 0.5	*Artea 0.15
	Baronesse		Tilt 0.5	*Artea 0.15
2007	Baronesse			Tilt 0.5, *Artea 0.18
	Inari		Tilt 0.5	Artea 0.2
2008	Baronesse			Tilt 0.25, *Tango Super 0.6
	Mercada			Tilt 0.25, *Artea 0.25
	Anni			Tilt 0.25, *Mirage 0.36
2009	Barke		Tilt 0.25	*Folicur 0.47
	Baronesse		Tilt 0.25	*Folicur 0.5
	Anni	Tilt 0.25, *Folicur 0.54		

GS – Growth stage (Zadoks et al., 1974), * – Decision Support System application.

The optimal fungicide input depends on the disease pressure and the climate in the individual season, as well as the susceptibility of the variety plays a major role for the optimal input. Increased incidence of cereal leaf spot diseases over the last 40 decades has been noted in Finland (Jalli et al., 2011). The choice of appropriate fungicide, dose, and spray time is difficult and cause farmers to use higher doses to minimize the risks (Day et al., 2008). The reason why growers use conventional treatment programs is the monitoring and identification of the pests is most difficult. Time management seems to be the main hindrance for integrating the use of monitoring and majority of growers currently use a conventional treatment (Epstein & Bassein, 2003). DSS takes into account field specific conditions, and determines when or if fungicides are needed and resulting spraying come in a later growth stages. Decision support system can help to inform growers of plant disease risk and thus assist in accurately targeting events critical for management (Gent et al., 2011). Our results from experiments using different fungicide timings showed that conventional practice is to apply a high dose of fungicides at flag emergence growth stage.

Effect of treatment program on disease control

The disease pressure varied yearly under the influence of different temperature and precipitation patterns. Diverse climatic conditions during the experiment period (2003, 2008 – exceptionally wet with reduced temperatures and sunlight in the summer; 2004, 2007 – normal, the sum of precipitation was similar as long term average; 2005, 2006, 2009 – drought, the seasons had very warm and dry July) enabled good assessment of treatment regimes in different conditions. This variability increases uncertainty for growers as to best management options. Conventional and DSS foliar application programs provided effective net blotch control. DSS treatment was significantly better than the conventional and untreated (Fig. 1). In 7-year mean the effect of high input treatment was weak compared to the untreated.

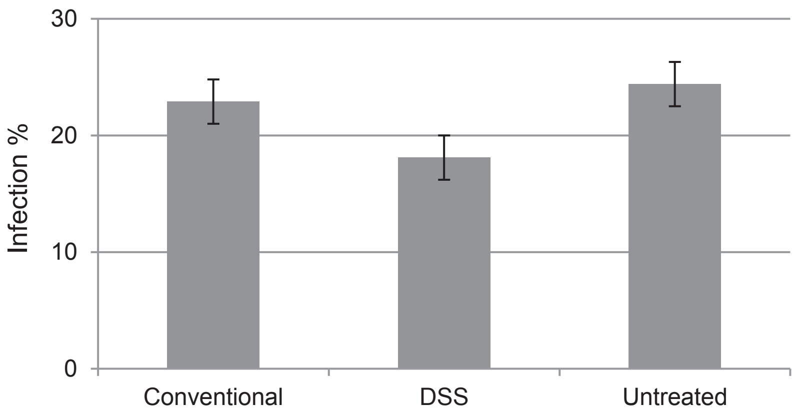

Figure 1. Percentage net blotch symptoms in spring barley leaf in average 2003–2009. $LSD_{0.05}$ = 13.03. DSS – Decision Support System.

Trials confirm control of net blotch is comparable weather conventional or DSS are used to make appropriately timed applications of fungicides. This is indication that the good disease control can be achieved from a relatively low fungicide dose, shown in Table 2. DSS uses weather data to predict infection periods and risk of epidemic progress (Audsley et al., 2005). Advice system DSS gave competitive disease control and reduced fungicide dose in line with or better control effect than the conventional treatments. Replacement of conventional treatment with 'environmentally driven' programs could reduce pesticide use in years with lower disease pressure (Epstein & Bassein, 2003). According to Cooper & Wale (1998) accurate timing of fungicide is crucial in the control of *P. teres* because of a short latent period and the potential for rapid disease development during optimum environmental conditions. The key time period for protection of barley is shortly before and after ear emergence (Young, 2012).

Effect of treatment time on yield

As experiment results differed between the years and there were different responses to fungicides but on average standard fungicide application worked better at GS 37–49 (Fig. 2). In average DSS-based fungicide application in later stage had good effect. The results illustrate that disease control effect for yield with DSS suggestions at earlier growth stages was low because used small doses did not protect the crop sufficiently for potential yield loss. To maximize the yield fungicides have to be applied between stem elongation (GS 32–35) and the heading to flowering (GS 55–65) depending on the susceptibility of the variety and the risk of disease. Furthermore the results verified that DSS-based late treatment gave very good effect with lower doses because DSS system took into account the prevailing weather conditions, the resistant level of the variety and pathogenic situation in the field.

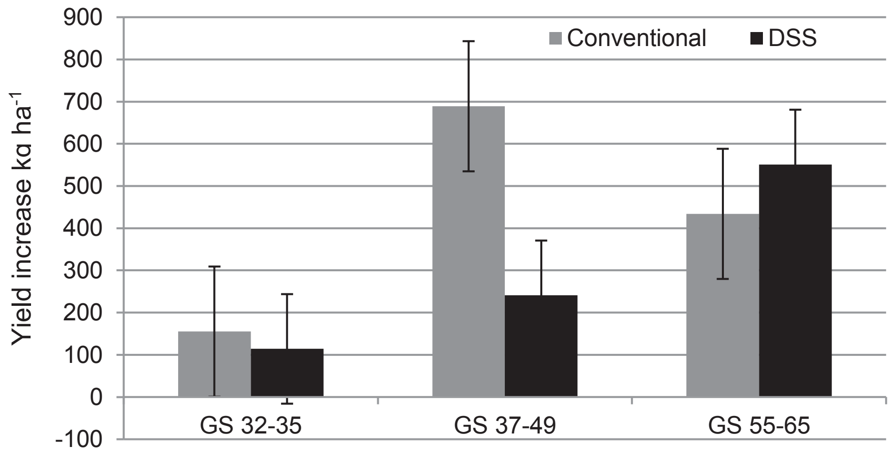

Figure 2. Average yield increase kg ha^{-1} in comparison with untreated crop at different treatment timings in spring barley in 2003–2009. $LSD_{0.05}$ = 572 (conventional), 436 (DSS). DSS – Decision Support System, GS – growth stages.

The results showed a higher yield response to applying a fungicide a conventionally compared to the DSS. As every year is different and there will be different responses to fungicide timings but on average traditional fungicide program seem to be economically justified. Only DSS fungicide program being applied later than conventional practice is likely to deliver bigger yield response in spring barley. Results are in accordance with these obtained by Day et al. (2008) that the optimization and the timing of fungicide treatment in relation to grain formation interacted with effect of disease development required a joined up approach to DSS.

Effect of different factors on disease severity and yield

Results of ANOVA verified that the year and location were major factors to influence the infection severity of net blotch (Table 3). Correlation (R^2 value) between growth region, year and variety contributed to the occurrence of net blotch about 88% (R^2 = 0.8797). The influence of the year correlated highly on the yield formation and had highest impact (R^2 = 0.8090).

Table 3. Sum of Squares of ANOVA of infection of net blotch and yield data

Effect	*d.f.*	Net blotch	*P*	Yield	*P*
Variety (1)	4	10.33	0.1140	6.94	0.0836
Year (2)	6	36.25	0.0000	52.03	0.0000
Location (3)	4	35.99	0.0000	11.45	0.0356
Treatment (4)	2	1.45	0.3019	7.22	0.0345
3 x 4	8	1.89	0.9001	0.76	0.9987
4 x 2	12	1.23	0.9981	1.94	0.9982
1 x 4	6	0.81	0.9590	0.56	0.9953
R^2		0.8797		0.8090	

d.f. – degrees of freedom, *P* – significance level, R^2 – correlation between trial factors.

Fungicide spray practices effects

The field trials clearly demonstrate that DSS recommended fungicide applications later than farmers conventionally used. In average of all trials the Treatment frequency index in common practice was 0.65 and in DSS programs 0.41 (Table 4). The cost of the different treatment expenses varied from 18.1 to 22.1 (€ ha^{-1}) and the reduction of expenses in DSS program was 20% less compared with farmers conventionally practices. Early season fungicide can be cost-effective depending on the variety and inoculum load.

Table 4. Treatment count and economic return on barley in different programs

	Conventional	DSS
Number of trials GS 32–35	3	1
Number of trials GS 37–49	11	1
Number of trials GS 55–65	4	16
Treatment frequency index	0.65	0.41
Treatment expense € ha^{-1}	22.1	18.1

DSS – Decision Support System, GS – Growth stage (Zadoks et al., 1974).

Selecting the appropriate dose is essential to optimize economic returns. Although, results suggest that, when fungicide dose was higher beyond crop needed, the increased dose would increase the economic loss. As defined by Paveley et al. (2001) and Jarroudi et al. (2015) the dose required to optimize positive return will vary substantially between years, sites and varieties. Profit is maximized when the dose of fungicide applied is just the amount that is needed.

Fungicide impacts on monetary terms

Comparing the benefit obtained by conventionally used practice and DSS-based applications, the average net revenue of conventionally used treatment strategy was higher (Table 5). In general, the long period results on yield and value for money show little bit better successful application time and dose were according to conventional practice. Hence the proposed DSS recommended use lower fungicide dose suggested that achieving cost effective means for maintaining sustainable barley production was less profitable. The average conventional treatment return was about 5 € more than the cost of DSS-based fungicide application in barley. Results implied that in average the minimal net revenue did provide no great an economic advantage.

Table 5. Spring barley average yield profit on a monetary basis

Treatment	Net revenue €	Benefit in terms of money € ha^{-1}
DSS	60.90	42.7
Conventional	65.44	43.3

DSS – Decision Support System.

Output from fungicide treatment and profit value

In average higher yield was achieved from convention treatment 4,670 kg ha^{-1} (Table 6). Over the trial period, the highest yield increase above the control due to conventional treatment was 55.1% and due to DSS was 53.6% in variety Baronesse in 2003. The results indicate that the average value of the yield output for Estonia, calculated at a price of 120 € t^{-1} varied between 42.75 (DSS) and 43.29 (conventional) € ha^{-1}. Results indicate that fungicides used in spring barley were more profitable when used as conventional treatments, but the trials data confirm comparable levels of control of net blotch can be achieved when DSS is used in place of conventional fungicide application.

Table 6. The highest output kg ha^{-1} and value € ha^{-1} for treated spring barley calculated by variety

Year	Variety	Yield kg ha^{-1}		Yield % of untreated		Benefit € ha^{-1}	
		Conventional	DSS	Conventional	DSS	Conventional	DSS
2003	Barke	4,507	4,455	1.1	-0.1	-16.62	-18.07
	Baronesse	4,666	4,622	55.1	53.6	176.47	178.55
	Anni	3,570	3,330	30.3	21.5	77.23	56.65
2004	Anni	4,261	4,337	4.1	6.0	-2.22	14.54
	Baronesse	5,630	5,620	30.6	30.4	136.03	141.87
	Barke	6,562	6,167	16.2	9.2	87.19	45.66
2005	Anni	4,633	4,516	2.8	0.2	-3.21	-15.31
	Baronesse	4,084	4,050	6.3	5.4	10.47	9.51
2006	Anni	4,019	4,125	3.9	6.6	-11.08	14.34
	Baronesse	4,578	3,827	19.6	0	60.8	-16.63
2007	Baronesse	4,497	4,656	4.7	8.4	-4.84	28.0
	Inari	4,552	4,483	20.0	18.2	61.88	63.36
2008	Baronesse	5,372	6,266	6.7	24.4	21.75	127.36
	Mercada	6,383	6,287	8.0	6.3	38.07	22.63
	Anni	5,429	5,340	15.5	13.6	68.79	61.41
2009	Barke	3,938	3,808	7.7	4.2	15.51	-8.24
	Baronesse	2,917	2,821	7.8	4.2	6.75	-10.47
	Anni	4,995	5,201	14.2	19.0	56.31	74.28
Average		4,670	4,662	14.1	12.8	43.29	42.75
LSD_{05}		458	491	6.8	6.7	26.33	28.73

DSS – Decision Support System, LSD – lowest significant difference.

The DSS has proved to give good control of pathogen and low product input. The information obtained from current study will use in further development of simplified DSS for the control of barley diseases. Such a system would improve control of net blotch while optimizing fungicide use. We agree with Day et al. (2008) that the decision system should give a ranked list of near optimal spray programs, not just the best and the potential of disease resistance of cultivars should be fully exploited and prophylactic spraying at present is unlikely to be profitable (Mercer & Ruddock, 2003).

CONCLUSIONS

This study confirms the importance of disease levels and fungicide used times and rates. The results allow growers to customize their fungicide treatments to minimise net blotch disease on susceptible varieties for cost-effective disease control.

1.DSS recommended the fungicide use in GS 55–65 that is generally later than conventional treatment in GS 37–49. DSS reduced fungicide application doses by 30 to 60% of the registered rate.

2.DSS-based treatment gave slightly better disease control effect compared with conventional treatment and untreated control.

3.A conventional treatment gave slightly higher yield response compared to the DSS.

4.DSS gave Treatment frequency index 0.41, reduction compared with conventional treatment was 1/3.

5.DSS reduced 20% the cost of treatment expense compared with conventional treatment.

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REFERENCES

Audsley, E., Milne A. & Paveley, N. 2005. A foliar disease model for use in wheat disease management decision support systems. *Ann. Appl. Biol.* **147**(2), 161–172.

Been, T., Berti, A., Evans, N., Guache, D., Gutsche, V., Jensen, J.E., Kapsa, J., Levay, N., Munier-Jolain, N., Nibouche, S., Raynal, M. & Rydahl, P. 2009. *Review of new technologies critical to effective implementation of Decision Support Systems (DSSs) and Farm Management Systems.* Aarhus University, Denmark, 128 pp.

Brown, J.K.M. 2010. Breeding for Resistance as a Component of Integrated Crop Disease Control and Sustainable Food Production. In Dehne, H.W., Deising, H.B., Gisi, U., Kuck, K.H., Russell, P.E. & Lyr, H. (eds): *Modern Fungicides and Antifungal Compounds. VI Proceedings of the 16th International Reinhardsbrunn Symposium.* Friedrichroda, Germany, pp. 27–34.

Cooper, J. & Wale, S.J. 1998. A decision model for timed fungicide application to control *Pyrenophora teres* in winter barley. *International Congress of Plant Pathology 7th meeting, section 2.1.5.* http://www.bspp.org.uk/icpp98/2.1/5.html

Day, W., Audsley, E. & Frost, A.R. 2008. An engineering approach to modelling, decision supportand control for sustainable systems. *Philos Trans R Soc Lond B Biol Sci* **363**(1491), 527–541.

Epstein, L. & Bassein, S. 2003. Patterns of pesticide use in California and the implications for strategies for reduction of pesticides. *Annu Rev Phytopathol* **41**, 351–375.

European Commission. 2007. *The use of plant protection products in the European Union.* Data 1992–2003, 38 pp.

Gent, D.H., De Wolf, E. & Pethybride, S.J. 2011. Perceptions of risk, risk aversion, and barriers to adoption of decision support systems and integrated pest management: an introduction. *Phytopathology* **101**, 640–643.

Heinonen, U., Jalli, M., Junnila, S. & Mäkinen, T. 2013. The management of fungicide resistance in cereals in Finland. In Heinonen, U., Jalli, M., Junnila, S. & Mäkinen, T (eds): *MTT Report 109.* MTT Agrifood Research Finland, Jokioinen, 31 pp.

Jalli, M., Laitinen, P. & Latvala, S. 2011. The emergence of cereal fungal diseases and the incidence of leaf spot diseases in Finland. *Agric. Food Sci*. **20**, 62–73.

Jarroudi, E.L.M., Kouadio, L., Beyer, M., Junk, J., Hoffmann, L., Tychon, B., Maraite, H., Bock, C.H. & Delfosse, P. 2015. Economics of a decision-support system for managing the main fungal diseases of winter wheat in the Grand-Duchy of Luxembourg. *Field Crops Res*. **172**, 32–41.

Jørgensen, L.N., Noe, E., Nielsen, G.C., Jensen, J.E., Ørum, J.E. & Pinnschmidt, H.O. 2008. Problems with disseminating information on disease control in wheat and barley to farmers. *Eur. J. Plant Pathol.* **121**, 303–312.

Jørgensen, L.N., Wieczorek, T.M., Christiansen, H.-B. & Olsen, B.B. 2015. Fungicide resistance- related investigations. In Jørgensen, L.N., Nielsen, B.J., Jensen, P.K., Kudsk, P., Mathiassen, S.K., Hartvig, P. & Kristensen, M. (eds): *Applied Crop Protection 2014.* Aarhus Universitet, Denmark, pp. 83–87.

Koppel, M. & Sooväli, P. 2012. Use of decision support system and field monitoring network in control of cereal diseases with lowered doses of fungicides in Estonia. *Integrated Pest Management (IPM) – National Action Plans in Nordic-Baltic countries. NJF seminar 458.* Tallinn, Estonia, pp. 31.

Mercer, P.C. & Ruddock, A. 2003. Disease management of spring barley with reduced doses of fungicides in Northern Ireland. *Crop Prot*. **22**, 79–85.

Newe, M., Meier, H., Johnen, A. & Volk, T. 2003. proPlant expert.com – an online consultation system on crop protection in cereals, rape, potatoes and sugarbeet. *EPPO Bulletin* **33**(3), 443–449.

Olesen, J.E., Trnka, M., Kersebaum, K.C., Skjelvåg, A.O., Seguin, B., Peltonen-Sainio, P., Rossi, F., Kozyra, J. & Micale, F. 2011. Impacts and adaptation of European crop production systems to climate change. *Eur. J. Agron.* **34**, 96–112.

Paveley, N.D., Sylvester-Bradley, R., Scott, R.K., Craigon, J. & Day, W. 2001. Steps in Predicting the Relationship of Yield in Fungicide Dose. *Phytopathology* **91**, 708–716.

Sharma, A., Bailey, A. & Fraser, I. 2011. Technology adoption and pest control strategies among UK cereal farmers: evidence from parametric and nonparametric count data models. *J. Agric. Econ*. **62**, 73–92.

Shtienberg, D. 2013. Will Decision-Support Systems Be Widely Used for the Management of Plant Diseases? *Annu. Rev. Phytopathol*. **51**, 1–16.

Sønderskov, M., Kudsk, P., Mathiassen, S.K., Bøjer, O.M. & Rydahl, P. 2014. Decision Support System for Optimized Herbicide Dose in Spring Barley. *Weed Tech*. **28**, 19–27.

Sooväli, P. & Koppel, M. 2010. Efficacy of fungicide tebuconazole in barley varieties with different resistance level. *Agric. Food Sci.* **19**(1), 34–42.

Statistical Database 2016. <http://www.stat.ee>

Zadoks, J.C., Chang, T.T. & Konzak, C.F. 1974. A decimal code for the growth stages. *Weed Res.* **14**, 415–21.

Young, C. 2012. Fungicide fine-turning improves spring barley yields. *HGCA-funded LINK project.* <http://www.fwi.co.uk/>