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Advances of Fungicide Application for Winter Oilseed Rape

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1. Introduction

The area of oilseed rape has increased dramatically during the last twelve years in Latvia: from 400 ha in 1997 to 93 900 ha in 2009. This is the reason why development of diseases has become one of the most important risk factors for oilseed rape cultivation under intensive management in Latvia.

White stem rot (Sclerotinia stem rot) caused by *Sclerotinia sclerotiorum*, **Phoma stem canker** (blackleg, stem rot, Phoma leaf spot) caused by *Leptosphaeria* spp., and **Alternaria spot** caused by *Alternaria* spp. are the most important diseases of rape all over the world, including the Baltic region and Latvia (Brazauskiene & Petraitiene, 2004; Balodis et al., 2007). **Downy mildew** (caused by *Peronospora parasitica)* has been detected in Poland, Latvia and other regions where rape is cultivated (Sadowski et al., 2002; Bankina et al., 2008). **Powdery mildew** (caused by *Erysiphe cruciferarum)* is a significant disease in the warmer part of Europe (Mert-Türk et al., 2008), but in a temperate climate it is seldom observed, e.g., a high level of the infection was observed in Poland in the years 1998 and 1999 (Sadowski et al., 2002). **Gray mould** (caused by *Botrytis cinerea*) and **wilt** (caused by *Verticillium dahliae)* have been observed very sporadically (Sadowski et al., 2002). **Clubrot** (caused by *Plasmodiophora brassicae*) as an important disease and serious threat to oilseed rape production is recognized in many regions of Poland, especially if rape and other crucifers occupy a large part of the sowing structure (Korbas et al., 2009; Jedrycka et al., 2002). **Snow mould** (caused by *Typhula* spp.), the same as downy mildew, powdery mildew, gray mold, wilt, and clubrot, has been found also in Latvia; however, those diseases are recognized as economically unimportant in this country at present (Bankina et al., 2008).

Sclerotinia stem rot has been reported as one of the most harmful diseases in many countries (United Kingdom, France, Germany, etc.). Different opinions exist regarding economic importance of the disease, as, in some cases, yield losses of up to 50% have been reported (Koch et al., 2007). However, there are data that at least half of fungicide applications have been unnecessary (Young et al., 2007). Analysis of the dataset from official field trials of the German state extension service during 1991–2003 has shown that only 33% of fungicide treatment had been economically effective (Dunker & Tiedemann, 2004).

The development of Sclerotinia stem rot is dependent on meteorological conditions, therefore incidence of the disease differs greatly among the years. The first symptoms of disease are not visible at the time of fungicide application.

Fungicides from different chemical groups are used to control Sclerotinia stem rot: metconazole, tebuconazole, boscalid, and others. Some differences in the efficacy of fungicide application have been observed, but the problem lies not in the choice of a fungicide but in the decision about the necessity of spraying.

Different approaches (including forecast methods and decision-support systems) have been developed to improve efficacy of fungicide treatment and to avoid unnecessary fungicide application. Different risk indicators have been compared to establish the most important and suitable ones for the growers. Part of these systems is based on biological peculiarities of *Sclerotinia sclerotiorum* (germination of apothecia, amount of ascospores in the air, etc.). Agrometeorological computer models have also been developed basing mostly on the weather data and growth stages of rape. The ScleroPro system is easy-to-handle, fully computerized and based on the weather and field-site-specific data; this program has been available for growers and advisors since 2006 (Koch et al., 2007). D. Makowski et al. have analysed systems that are based on determination of rape flowers' infection and on mathematical models. The researchers have found that percentage of infected flowers is more accurate than the calculated algorithm which is based on the development of rape and weather conditions, but the former method is costly and time consuming (Makowski et al., 2005).

The risk-point system developed in Sweden is relatively simple: factors that affect infection by *S. sclerotiorum* are expressed as risk points which, in their turn, for each specific field are summarized and compared to predetermined threshold values. According to this system, the most important factors are pre-crop of rape in a long period, development of rape, level of infection in the previous year, amount of rainfall two weeks before flowering and at the flowering time, weather forecast, and germination of sclerotia (Twengstrom et al., 1998).

Phoma stem canker caused by *Leptosphaeria* spp. (anamorph *Phoma lingam*) is an internationally important disease of oilseed rape causing serious losses of yield in Europe, Australia, and North America (Gugel & Petrie, 1992; West et al., 2001). Basal stem canker and leaf spots are the most important symptoms of the disease; also seed infection and damping of seedlings are observed in some cases. Phoma stem canker is now known to be caused by a complex that comprises at least two species: *Leptosphaeria maculans* (formerly classified as A group of *L. maculans*), and *L. biglobosa* (formerly classified as B group of *L. maculans*). The B group probably includes several subspecies of *L. biglobosa*. *L. maculans* is described as more aggressive and more harmful. While there are differences between A and B group, their life cycle is similar and they coexist on oilseed rape in Europe. Necroses on the upper and lower parts of the stem, slightly different symptoms on leaves, and especially colour and morphology of pure cultures confirm occurrence of *L. maculans* and *L. biglobosa* in Latvia (Balodis et al., 2008).

The source of primary infection is ascospores from the stem debris. Ascospores release through the vegetation season is the reason why effective chemical control is difficult (Gugel & Petrie, 1992). Under conditions of Latvia, ascospores start to differentiate during October, and in late October they are fully differentiated and ripe. Ascospores are found after overwintering and throughout the whole season of rape growing. A similar situation is observed also in other countries. Yield losses are mostly associated with the development of stem canker that restricts uptake of water and nutrients during the seed filling (West et al., 2001). In Australia, root rot has also been detected, but the research results indicate that it causes no additional reduction in the yield (Sprague et al., 2010). In general, the crucial point of possible development of Phoma stem canker epidemic is autumn, when release of ascospores and leaf infection take place.

It has been found that most popular active ingredients against Phoma stem canker are flusilazole, metconazole, prochloraz, and tebuconazole.

Though J. R. Hood et al. have observed poor correlation between severity of Phoma leaf spot and stem basal canker (Hood et al., 2007), there are also results which confirm correlation between early occurrence of leaf spot in autumn and severe basal stem canker (Steed et al., 2007). The efficacy of fungicide sprays depends on the timing of treatment in relation to the plant and disease development. It has been observed that accumulated thermal time determines maturation of ascospores, rate of pathogen growing along leaf petioles and progress of canker in stems, but rainfall mostly influences discharge of ascospores (Evans et al., 2008). The researches suggest that the possible threshold for fungicide application can be 10% incidence of leaf spot in autumn. The most harmful is infection of middle leaves, because senescence of the oldest leaves occurs before the pathogen has reached the stem, whereas the pathogen from younger leaves having reached the upper part of the stem causes less harmful damage (Steed et al., 2007). Most of the authors emphasise the importance of fungicide treatment in autumn, but there are converse data that the greatest additional yield has been obtained by spraying in spring at the beginning of flowering (Karolewski et al., 2009). There are very complicated relationships between the pathogen, the plant development, and the weather conditions which determine development of Phoma stem canker epidemic. Relationships between disease severity and yield losses are unclear, because the data are controversial. In general, fungicide application decreases severity of the disease, but not always increases the yield (Sprague et al., 2010).

There are attempts to develop a forecasting model for improvement of the efficacy of fungicide treatment against Phoma stem canker. The SIPROM-WOSR model has been developed including different factors which describe development of plants, initial source of infection, infection, and yield loss. Different knowledge about the infection process is necessary to implement this model in oilseed rape production (Lô-Pelzer et al., 2010). The Blackleg Sporacle model has been developed to predict onset of seasonal ascospores release: the number of ascospores in the air can be counted by the Burkard spore sampler, or by determining maturation of pseudotechia under a microscope. This model is based on the weather conditions (temperature and rainfall). The results show that the data of ascospores release can be predicted by a weather-based computer model with a set of parameters adapted to different conditions (Salam et al., 2007).

Alternaria leaf and pod spot (blackspot) (caused by *Alternaria* spp.) is one of the most widespread diseases in Poland, Lithuania, and other regions (Sadowski et al., 2002; Brazauskiene&Petraitiene, 2006; Balodis et al., 2008). The disease has been observed on the leaves, stems, and siliques; also seeds can be infected. Development of the disease depends on moisture periods – four hours of continuous wetness are necessary for the development of infection (Hong&Fitt, 1995). Frequent precipitation and high relative air humidity at the time of silique ripening promote development of Alternaria pod spot. Fungicides from different chemical groups are used for the disease control: prochloraz, tebuconazole, and azoxistrobin. Application of fungicides has significantly increased the rape yield in Lithuania (Petraitiene&Brazauskiene, 2007).

The most important diseases of oilseed rape and possibilities of control are widely described in the literature; however, a strong system of disease control has not been developed yet, and the data about necessity of fungicide application are inconsistent. There are very few data about disease control possibilities in the Baltic region, where climatic conditions differ from those in the West Europe: autumns are shorter and winters are longer and cooler, which determines different development of rape and most likely also different development of pathogens.

The aim of our investigations was to clarify peculiarities of the development of winter oilseed rape diseases and to work out recommendations for control of the diseases.

2. Winter oilseed rape production monitoring in farms of central Latvia

2.1 Materials and methods

Monitoring of winter oilseed rape diseases (Alternaria leaf and pod spot, caused by *Alternaria* spp., Phoma leaf spot and stem canker, caused by *Leptosphaeria* spp., and Sclerotinia stem rot, caused by *Sclerotinia sclerotiorum*), described above as important, was carried out during the years 2005–2008 in several randomly chosen farms (9 farms in 2006, and 15 farms in 2007 and 2008) located in central Latvia, which is the region of the greatest sowing area of this crop. Incidence and severity of the diseases were evaluated at different development stages of the crop:

- at 14-19 GS (growth stage according to BBCH scale) – incidence and severity of Alternaria spot and Phoma leaf spot in the autumn of the sowing season; 100 randomly chosen plants per field were evaluated, and severity was expressed in percent of leaf area;
- at 80-85 GS – incidence of Alternaria pod spot; 1000 pods per field were evaluated;
- directly after harvesting – Phoma stem canker and Sclerotinia stem rot were inspected per one meter long row at 10 places in the field. Disease incidence was expressed in percent from totally evaluated plants.

In addition, data on the growing technology (soil tillage method, pre-crops, proportion of area under rape in the total sown area in the farm, fertilization, used cultivar, sowing date and rate, and control of harmful organisms) were collected to explain the obtained data on disease incidence and severity better.

Meteorological conditions during the monitoring years were different. The years 2006 and 2008 were not favourable for *S. sclerotiorum* development; however, in 2007, precipitation two weeks before rape flowering and during flowering stimulated stem rot development. Moisture and temperature conditions in 2007 favoured development also of other above-mentioned diseases.

2.2 Results and discussion

Alternaria spot and Phoma leaf spot were found in the autumn of each sowing year. Incidence of these diseases showed tendency to increase (Alternaria spot – 77% in 2005, 85% in 2006, and 53% in 2007; Phoma leaf spot – 1.1% in 2005, and 19% in 2006 and 2007 on average), but severity remained insignificant (only few percent for both diseases). These data did not give evidence of sharp Phoma stem canker disease spreading during the succeeding year (Balodis et al., 2008). Fungicide (metconazole, 90 g L^{-1}, or tebuconazole, 250 g L^{-1}) application in autumn was based only on the necessity for rape plant growth regulation, and there was no intention of controlling any disease at that time.

The obtained data on Alternaria pod spot incidence fluctuated during the monitoring years (average incidence was 1.8% in 2006, 73% in 2007, and 7.3% in 2008; Table 1), and severity of this disease also remained insignificant. Incidence of Phoma stem canker and Sclerotinia stem rot was registered directly after harvesting. Sclerotinia stem rot initially was assumed as the most harmful rape disease in Latvia, but our observations clearly showed that incidence of the disease fully depends on meteorological conditions, and is low in unfavourable years (2006 and 2008; Table 1). Also incidence of Alternaria pod spot was at least partly connected with meteorological conditions; besides, it should be noted that another reason for its low incidence in 2008 might have been the wide fungicide application in the inspected fields (see below).

Phoma stem canker incidence increased from 42% in 2006 to 83% in 2007, but in the year 2008 it was on average 56% per all inspected fields. Consequently, it can be concluded that Phoma stem canker incidence had decreased compared to the year 2007 (Table 1). For the first time in Latvia's conditions, more attention to this disease was paid during our investigations in 2006. Phoma stem canker caused by *Leptosphaeria* spp. is considered as an important disease of winter oilseed rape in most places where this crop is grown (West et al., 2001; Salam et al., 2003). This conclusion from the literature together with our observations of the disease spread was the reason for our deeper interest in the possible disease control ways.

Field, No	Disease incidence, %								
	Alternaria pod spot			Phoma stem cancer			Sclerotinia stem rot		
	2006	2007	2008	2006	2007	2008	2006	2007	2008
1	×	99.7	5.7	×	91	66	×	68.9	0.0
2	2.0	95.8	5.6	46	79	39	0.0	36.0	6.0
3	1.6	76.1	×	21	96	×	3.0	14.1	×
4	×	82.9	5.3	×	74	43	×	63.1	1.0
5	×	29.1	4.2	×	49	44	×	17.9	0.0
6	2.6	–	4.1	34	96	62	3.0	8.1	2.0
7	1.0	48.1	5.6	47	94	58	3.0	23.7	1.0
8	1.0	38.8	8.2	22	94	52	1.0	28.9	4.0
9	×	92.2	15.2	×	39	56	×	78.2	2.0
10	×	96.0	10.4	×	98	47	×	8.6	1.0
11	4.1	91.4	5.5	25	92	44	3.0	7.5	0.0
12	0.7	67.5	7.0	56	68	65	1.0	36.7	14.2
13	1.6	19.8	6.3	88	86	79	1.0	8.3	0.0
14	×	91.3	11.5	×	89	66	×	25.1	0.0
15	×	92.6	×	×	95	×	×	24.1	×
Ave-rage	**1.8**	**73.0**	**7.3**	**42**	**83**	**56**	**1.9**	**29.9**	**2.4**

Table 2.1. The incidence of Alternaria pod spot, Phoma stem canker, and Sclerotinia stem rot on winter rape in production fields during the disease monitoring years 2006–2008, Latvia

In 2006, farmers did not apply any fungicides against the observed diseases. Whereas during the next two years, fungicides (boscalid, 500g kg^{-1}, or protioconazole, 125 g L^{-1}, + tebuconazole, 125 g L^{-1}, or azoxystrobin, 200 g L^{-1}, + cyproconazole, 80 g L^{-1}) were applied: in seven fields during the season of 2007, and in twelve fields in 2008. The year 2007 was favourable (mild temperatures and very even distribution of precipitation throughout the whole season) for the development of all mentioned diseases, and in subsequent years farmers started to apply fungicides on more occasions, sometimes even without particular need and motivation.

As production of modern oilseed rape started only in 1997 in Latvia, we had very little information about and practically no experience of the disease development cycle in Latvia's conditions as well as of the best ways to control the most widespread diseases. The collected data range was nearly sufficient to clarify some further research directions, and one of them was to develop specific fungicide application schemes against Phoma stem canker, Sclerotinia stem rot, and Alternaria pod spot.

3. Materials and methods

3.1 Trial site, conditions, and crop management

Two-factor (A – cultivar; B – fungicide treatment; see below subsection *Experimental design*) field trials testing several fungicide application schemes (Tables 3.2. and 3.3.) were carried out at the Research and Study Farm (RSF) "Vecauce" (latitude: N 56° 28′; longitude: E 22° 53′) of the Latvia University of Agriculture during 2005–2008.

Winter rape plots were established in the fields with no oilseed rape growing in crop rotation before.

Soil at the trial site was strongly-altered-by-cultivation loam with agro-chemical parameters summarized in Table 3.1.

Parameters	2005/2006	2006/2007	2007/2008
Humus content, g kg^{-1}	19	32	38
pH KCl	7.0	7.2	7.4
P, mg kg^{-1}	147	100	115
K, mg kg^{-1}	122	169	194

Table 3.1. Soil agrochemical parameters on the trial site at RSF "Vecauce" from 2005 to 2008

Winter barley (in 2005) and barley-oat mixture for green forage (in 2006–2007) were used as pre-crops. Traditional soil tillage with mould-board ploughing a month before rape sowing was done in all trial years. Rototilling was used directly before sowing. The crop was fertilized with mineral fertilizers before sowing depending on a year: N at the rate of 12–33 kg ha^{-1}, P – 18–30 kg ha^{-1}, and K – 57–103 kg ha^{-1}. Top-dressing with nitrogen fertilizer was done twice: at the start of vegetation (70 kg ha^{-1} N), and at GS 30–31 (another 70 kg ha^{-1} N). Sowing was done at an optimal time (close to 20 August) for Latvia's conditions. Having obtained more information and experience, the sowing rate was changed during the trial years: 5.0 kg ha^{-1} in 2005, 4.0 kg ha^{-1} in 2006, and 60 germinate able seeds per m^2 for hybrid cultivars and 80 germinate able seeds per m^2 for line cultivars in 2007. Dicotyledonous weeds were controlled using herbicide metazachlor, 333 g L^{-1}, + quinmerac, 83 g L^{-1} (2.5 L ha^{-1}), throughout all trial years; monocotyledons were controlled only in autumn 2005 applying propaquizafop, 100 g L^{-1} (1.0 L ha^{-1}). Insects (mainly *Meligethes aeneus* and *Ceutorhynchus* spp.) were controlled by alpha-cypermethrin, 100 g L^{-1} (0.15 L ha^{-1}), or lambda-cyhalothrin, 50 g L^{-1} (0.15 L ha^{-1}), or thiacloprid, 100 g L^{-1}, + deltamethrin, 10 g L^{-1} (0.75 L ha^{-1}), depending on a year.

The yield was harvested at GS 90-92 (on average from middle of July till early August depending on a year) and was recalculated to 100% of purity and 8% of moisture.

3.2 Meteorological conditions

Meteorological conditions, observed by a local meteorology station at "Vecauce", considerably differed during the research years. In 2005 and 2007, amount of precipitation was enough for successful seed germination. Summer of 2006 was extremely dry and the air temperature was high, which negatively affected seed germination during autumn. An unusually long-lasting autumn and warm winter were observed in the season of 2007/2008. The October of all trial years was characterized by a sufficient number of rainy days with enough precipitation favouring successful oilseed rape disease development. Only in spring-summer of 2007, both the recorded precipitation and temperature were favourable for successful Sclerotinia stem rot development.

3.3 Experimental design

The trials were arranged in randomised blocks in four replications. The plot size was 7–10 m^2. Every year each treatment was compared with untreated check.

With the aim to investigate the action of fungicides as growth regulators in autumn, metconazole, 90 g L^{-1}, and tebuconazole, 250 g L^{-1}, were used during 2005–2007 and 2006–2007 respectively (Table 3.2).

Scheme No	Name	Growth stage according to BBCH scale	
		14–16 GS – autumn	65 GS
1	J_R+J	0.5 L ha^{-1} metconazole, 90 g L^{-1}	0.5 L ha^{-1} metconazole, 90 g L^{-1}
2	F	0.5 L ha^{-1} tebuconazole, 250 g L^{-1}	×

Table 3.2. Application of fungicides as growth regulators in autumn

Scheme No 1 was supplemented with the 2nd treatment against Sclerotinia stem rot (initial idea) during rape flowering (Table 3.2). Decrease in incidence of all three diseases, mentioned in the previous sections, in comparison with untreated check was evaluated. Several cultivars were used in this scheme: 'Excalibur' (F1), 'Falstaff' (line), 'Californium' (line), and 'Elixir' (F1). In the scheme No 2, cultivars 'Aviso' (line) and 'Falstaf' (line) were used in 2006/2007, but 'Elixir' and 'Californium' – in 2007/2008.

With the aim to decrease incidence of diseases Alternaria pod spot, Phoma stem canker, and Sclerotinia stem rot, another eight fungicide application schemes were used (Table 3.3). As our knowledge on the disease causal agents and disease development cycle under Latvia's conditions was incomplete, initially we applied standard schemes. This is the reason why the applied schemes and used cultivars were changed during the trial years.

Schemes No 5, using cultivars 'Aviso' and 'Falstaf' (both are lines), and No 9 (according to Dacom advice), using cultivars 'Californium' (line) and 'Elixir' (F1), in addition to the schemes mentioned in Table 3.2, were applied in 2006/2007. Schemes Nos 3–10 using cultivars 'Californium' (line) and 'Elixir' (F1) were applied in 2007/2008. Schemes Nos 3–7 are standard or routine schemes with preventive fungicide application without deeper idea on the real disease incidence and severity. Oilseed rape growers hope that such application helps protect rape against the main diseases, especially against Sclerotinia stem rot, but schemes No 3, and Nos 6–7 with fungicide application in spring – against Phoma stem canker.

Schemes Nos 8–10 were planned for Sclerotinia stem rot control. The only difference between schemes No 9 (PP) and No 10 (PP_{mod}) was in the applied fungicide dose (Table 3.3); both of them are based on the Dacom (the Netherlands) "*Sclerotinia sclerotiorum* in oilseed rape" control system (commercial program; decision-support system) that provides the grower with advice through a computer program. The user has to input data on field conditions, used cultivar, development of crop (emergence, crop density, crop growth – according to special recording scale), and disease incidence in the closest environment into the program.

Scheme No	Name	Growth stage according to BBCH scale		
		31 – 33 GS	61 GS	65 GS
3	J_p	0.7 L ha^{-1} metconazole, 90 g L^{-1}	×	×
4	C_{61}	×	0.5 kg ha^{-1} boscalid, 500 g kg^{-1}	×
5	C_{65}	×	×	0.5 kg ha^{-1} boscalid, 500 g kg^{-1}
6	J_p+C_{65}	0.7 L ha^{-1} metconazole, 90 g L^{-1}	×	0.5 kg ha^{-1} boscalid, 500 g kg^{-1}
7	J_p+J_{65}	0.7 L ha^{-1} metconazole, 90 g L^{-1}	×	1.0 L ha^{-1} metconazole, 90 g L^{-1}
8	C_{sign}	0.5 kg ha^{-1} boscalid, 500 g kg^{-1}		
9	PP	0.7 L ha^{-1} metconazole, 90 g L^{-1}, – according to Dacom advise		
10	PP_{mod}	1.0 L ha^{-1} metconazole, 90 g L^{-1}, – according to Dacom advise		

Table 3.3. Fungicide application in the succeeding spring and summer

The program is connected with the Dacom automatic meteorological station which provides it with the current weather data and weather prognosis. The system determines whether the present conditions favour an outbreak of disease – commonly referred to as critical periods. When the program has calculated enough risk, advice is given to apply a fungicide, and also the particular fungicide type against Sclerotinia stem rot is recommended.

Scheme No 8, which is a slightly modified system worked out by Swedish researchers (Twengstrom et al., 1998), was included in the trial of 2007/2008. Also this scheme is built on actual observations in the field and on risk calculations, but without a special computer program, which is money consuming. Data on pre-crops in a long period, disease incidence in pre-crop, rape density, amount of precipitation two weeks before rape flowering, weather prognosis, and regional risk (number of apothecia from 100 sclerotia) are evaluated according to the scale in points from 0 (low risk) to 10-15 (high risk – depending on the evaluated parameter). All points are summarized and the result shows necessity to spray:

<40 points – it is not necessary to spray;
40–50 points – decision has to be made on the basis of previous experience;
>50 points – spraying is mandatory.

3.4 Analysis and observations

To evaluate the growth regulation effect of a fungicide, 10-plant (treated according to the Nos 1–2 fungicide application schemes; Table 3.2.) samples were taken randomly from each plot for biometrical analysis at the end of autumn vegetation in the years 2005–2007. Number of leaves per plant, plant, root and shoot weight (g), root length (cm), diameter of root neck (mm), and height of growth-point (mm) were measured in a laboratory.

Disease incidence and severity were evaluated in autumn and in the following summer. Disease incidence was expressed in percent from the evaluated plants. Disease severity was evaluated as damaged leaf area in percent (Alternaria and Phoma leaf spots) or in points (Phoma stem canker) according to Formula (1):

$$R = \frac{\sum a \times b}{N}, \quad (1)$$

where R – disease severity, % or points;
$\sum a \times b$ – sum of multiplication of the infected plants by the respective severity;
N – total number of inspected plants.

Fifty plants per plot were evaluated near the end of the vegetation period (late October) to detect Alternaria spot and Phoma leaf spot incidence and severity.

Ten pods in 10 places per plot at GS 85-89 (BBCH) were evaluated in the summer of 2006 and 2008 to detect incidence of Alternaria pod spot.

In all trial years, fifty randomly selected stems per plot were evaluated directly after harvest to detect incidence of Sclerotinia stem rot and Phoma stem canker.

Phoma stem canker severity (in points 0–4) also was evaluated (according to Formula (1)) after the harvest, but only in August 2008. As more knowledge and experience were obtained in the previous research years, we were able to visually identify both shapes of Phoma stem canker in 2008. A hypothesis was proposed that fungicide application can cause at least decrease in the severity of Phoma stem canker even if the incidence is not decreased. Severity scale: 0 – without any signs of disease; 1 – small lesion was observed; 2 – lesion included ½ of stem; 3 – lesion included 75% of stem; 4 – stem was broken or prematurely ripen (Chigogora & Hall, 1995).

Efficacy of fungicide application was evaluated as biological efficacy which was expressed in percent and was calculated by Formula (2):

$$\left(\frac{D_{check} - D_{treatment}}{D_{check}}\right) \times 100 \quad (2)$$

where D_{check} – severity or incidence of the disease in check plot;
$D_{treatment}$ – severity or incidence in a specific treatment.

The obtained results were statistically processed using analysis of variance.

4. Results and discussion

4.1 Effect of fungicides applied as growth regulators in the autumn of the sowing year

Over-wintering is the key factor for successful winter rape production in the conditions similar to those in Latvia. Wintering of rape depends on the plant development stage in the autumn, which could be affected by the growing manner (including used cultivar, sowing time and rate, and any treatment) and agro-climatic factors. Before the winter period, a rape plant should create a sufficient aboveground and root mass, but, on the other hand, it should not be overgrown. Important characteristics are: root-neck diameter (should reach 8 to 10 mm), height of growth-point above the soil (should be less than 30 mm), and number of leaves (at least 6 to 8 leaves). Researchers from Lithuania, under conditions very similar to those in Latvia, reported that application of a growth regulator increases the number of leaves per plant and the root-neck diameter, and decreases the height of the growth-point of winter rape, thus favouring winter-hardiness of the crop (Gaveliene et al., 2002; Miliuviene et al., 2004). As the sowing time in Latvia's farms differs greatly (from early August, sometimes even late July, to middle of September), plant development regulation might be needed. It is suggested that azole-group fungicides applied in autumn act also as plant growth regulators.

From the results of all our different trials, it is evident that winter rape biometrical parameters were influenced by fungicide application in the autumn period and the used cultivar as well as by the particular growing conditions (see Tables 4.1–4.3). During three trial years, the highest height of untreated rape growth-point was noted in 2005 (on average per four cultivars included in Scheme No 1 (J_R+J) – 35.3 mm). Height of untreated rape growth-point was noted lower with every succeeding trial year, and the lowest it was in 2007 (13.5 mm). In the year 2005, average height (22.5 mm) of the growth-point of plants treated with fungicide was higher than that of untreated plants in 2006 and 2007 (21.1 mm and 13.5 mm respectively). Such substantial decrease in the growth-point can be explained mostly by different meteorological conditions during the different autumns and also by the year-by-year decreasing sowing rate (see subsection 3.1), which could have affected some plant density changes. D. Becka et al. (2004) have reported that more leaves, less height of growth-point, and greater diameter of root-neck is the result of lower crop density, when plants have enough space and no strong intra-specific competition exists. From the three factors (cultivar, fungicide application, and growing conditions) analysed in our investigations, growing conditions of a specific year had the greatest impact on the height of growth-point (percentage of influence η=48%). According to Schemes Nos 1-2, a significant impact ($p<0.05$) of fungicide application in autumn was noted on the height of growth-point in all three trial years (see Table 4.1-4.2). Our experiments also showed a significant impact of the cultivar on the height of growth point. We found that the cultivar with the highest growth-point was hybrid 'Elixir' (see Table 4.1.) – the height of growth-point of this cultivar without fungicide treatment reached 48.1 mm in autumn 2005. Comparing all the used cultivars, we observed that hybrid-type cultivars tended to have a higher height of growth point (see Table 4.1).

Cultivar (Factor A)	Effect of fungicide treatment (Factor B) on plant biometrical parameters							
	Height of growth-point, mm		Root-neck diameter, mm		Number of leaves per plant		Root mass, g	
	C	J_R+J	C	J_R+J	C	J_R+J	C	J_R+J
Excalibur F1	26.0	18.0	8.72	9.06	8	10	6.21	6.68
Californium	17.0	14.7	7.27	7.27	7	8	3.68	4.05
Elixir F1	29.8	19.3	7.85	8.43	8	9	5.09	6.15
Falstaff	20.3	16.3	7.31	7.23	8	9	3.64	3.75
Average	23.3	17.1	7.79	8.00	8	9	4.66	5.16
$LSD_{0.05B}$ or p-value	1.74		$p>0.05$		0.47		0.50	

Table 4.1. The effect of the fungicide metconazole application (Scheme No 1) in autumn on some average 3-year (2005-2007) plant biometrical parameters of winter oilseed rape (C – check without fungicide treatment; J_R+J – fungicide treatment according to Scheme No 1 in autumn)

Application of fungicides as growth regulators in autumn can increase root-neck diameter (Miliuviene et al., 2004), but in our trial, on average per three years, root-neck diameter was not affected significantly ($p>0.05$, see Table 4.1) – there was only a slight tendency for the root-neck diameter to increase; however, this parameter was affected by the used cultivar and the year's conditions. Fungicide application effect on root-neck diameter was substantial in some individual years in respect of the applied fungicide, e.g., in 2007 (see Table 4.3). Similarly to the height of growth-point, also average root-neck diameter was strongly affected (percentage of influence η = 58%) by the conditions of a particular year (average root-neck diameter from Scheme No 1: 9.4 mm in 2005, 8.1 mm in 2006, and 6.2 mm in 2007).

Cultivar	Height of growth point, mm		
	C	J_R+J	F
Aviso	20.45	15.40	14.65
Falstaff	18.33	15.78	13.50
Average	19.39	15.59	14.08
$LSD_{0.05}$	4.09		

Table 4.2. The effect of fungicides metconazole and tebuconazole application on the height of growth-point in autumn 2006 (C – check without fungicide treatment; J_R+J – Scheme No 1 (metconazole); F – Scheme No 2 (tebuconazole))

Also average plant mass was affected strongly by the growing conditions of the trial year (on average per three years from Scheme No 1: 80.5 g in 2005, 32.4 g in 2006, and 25.4 g in 2007; percentage of year's influence – η = 77%). Application of fungicide as a growth regulator can help winter oilseed rape growers to control plant overgrowing. Trial results showed only a tendency ($p>0.05$) for plant mass to decrease after fungicide application. At the same time, a significant impact ($p<0.05$) of fungicide application on the fresh root mass was noted in autumn. A small but significant ($p<0.05$) increase in root mass was observed in all trial years and for all included oilseed rape cultivars (see Tables 4.1 and 4.3). Also a small root length increase was observed as a result of fungicide application. A significant impact ($p<0.05$) of fungicide application, according to Schemes Nos 1–2 in autumn, was noted on the number of leaves per plant in all trial years (Tables 4.1 and 4.3). However, the number of leaves per plant was optimal in respect of fungicide application for good wintering and sufficient branching in the next spring of winter oilseed rape in all trial years.

Cultivar	Effect of fungicide treatment (Factor B) on plant biometrical parameters								
	Root-neck diameter, mm			Number of leaves per plant			Root mass, g		
	C	J_R+J	F	C	J_R+J	F	C	J_R+J	F
Californium	6.54	7.44	7.11	8	10	9	3.04	4.21	3.42
Elixir F1	4.81	4.92	5.51	7	7	8	1.47	1.71	2.01
Average	5.67	6.18	6.31	8	9	8	2.26	2.96	2.72
$LSD_{0.05}$	0.49			0.87			0.39		

Table 4.3. The effect of fungicides metconazole and tebuconazole on some biometrical parameters of winter oilseed rape in autumn 2007 (C – check without fungicide treatment; J_R+J – Scheme No 1 (metconazole); F – Scheme No 2 (tebuconazole))

Our experiments gave us confidence that winter oilseed rape biometrical parameters can be influenced by application of both azole-group fungicides (metconazole and tebuconazole) in autumn. Those results gave motivation for discussion about fungicide application in autumn. In our trials, winter oilseed rape was sown at an optimal sowing time (close to 20 August), which did not contribute to plants' overgrowing very much; fungicide effect might be more marked when rape is sown too early (late July till approximately 10 August). Even from our results we can conclude that fungicide (from azole group) treatment is an effective tool for rape growth regulation in cases when growing conditions and the used cultivar favour rape overgrowing in autumn.

4.2 Disease incidence and fungicide effect on it

Sclerotinia stem rot, Phoma stem canker (also Phoma leaf spot in the sowing autumn), and Alternaria spot (leaf spot in the sowing autumn, and pod spot in the next summer) were noted in all the trial years.

Sclerotinia stem rot was reported as the most important and most harmful rape disease; however, there are data that development of this disease differs depending on site, field, and especially on a year. Different forecast and warning systems related with Sclerotinia stem rot exist. Dacom computer advice (Schemes Nos 9-10) and Swedish risk point system (Scheme No 8) were tested during investigations, and their efficacy was compared with the routine fungicide application at GS 65 (Scheme No 1). During three-year investigations, only one year (2007) was favourable for Sclerotinia stem rot development: incidence of the disease reached 14-15% depending on the cultivar, and efficacy of fungicide treatment was high (57-87%) in this year (Fig. 4.1). The results showed that fungicide application according to Scheme No 1 (such routine scheme is widely used by growers) and Dacom advice (Scheme No 9) was appropriate in the years with high occurrence of the disease.

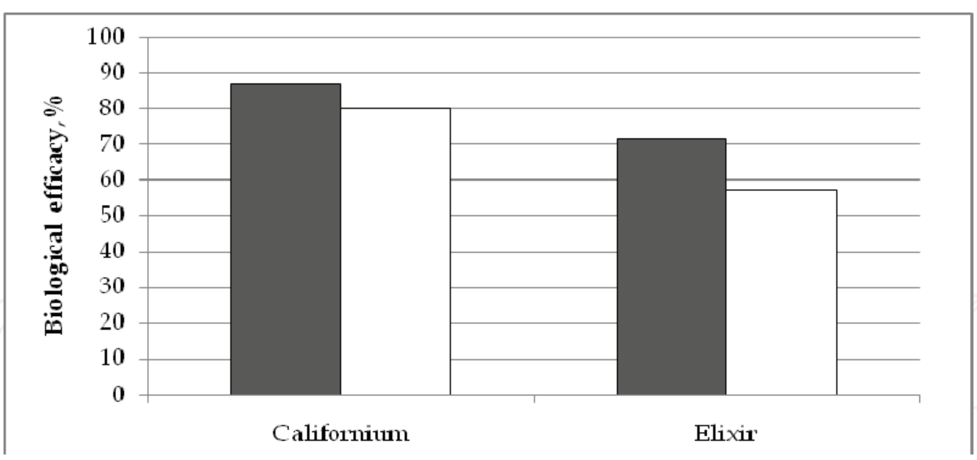

Fig. 4.1. Biological efficacy of fungicide application depending on the treatment scheme (■ – Scheme No 1: 0.5 L ha^{-1} metconazole, 90 g L^{-1},and □ – Scheme No 9: 0.7 L ha^{-1} metconazole, 90 g L^{-1}) and the cultivar, 2007

A similar routine scheme, applying fungicide boskalid, 500 g kg^{-1}, (Scheme No 5 at GS 65) and using cultivars 'Aviso' and 'Falstaf', gave similar results in 2007 (biological efficacy: 100% and 95% respectively). Besides, after treatment with boscalid, 500 g L^{-1}, rape stems visually seemed greener and healthier even during harvesting.

In 2006 and 2008, incidence of the disease did not exceed 3%, and fungicide treatments were not economically beneficial. Due to this, application of fungicides according to routine schemes (No 1 in 2006 and 2008, and Nos 4–7 in 2008) was inefficient. There is large amount of data that routine fungicide application frequently is not reasonable (Dunker & Tiedemann, 2004; Young et al., 2007); results of our investigations confirmed unnecessary treatments also under conditions of Latvia, if meteorological conditions were not favourable for Sclerotinia stem rot development.

Unfortunately, Dacom recommendation also proved to be ineffective in the years 2006 and 2008. The amount of precipitation was insufficient for Sclerotinia stem rot development before and during winter oilseed rape flowering in 2006 and 2008; however, Dacom programme still gave advice to spray (Schemes Nos 9–10). As a result of co-operation with the creators of the programme, it was improved for the next seasons taking into account reference of our data.

Results of Swedish risk point system (Scheme No 8, started in 2008) were disputable: the system did not recommend fungicide application for cultivar 'Californium', but recommended it for cultivar 'Elixir' (having a later time of flowering), which later proved to be unnecessary. Germination of apothecia before and during rape flowering has to be a very important indicator which influences infection of rape with Sclerotinia stem rot. Germination of sclerotia started in 2008, but soil was too dry for the development of apothecia in many places in Latvia. We suggest that this indicator is uppermost if total amount of risk points is 40–50 (threshold value). The obtained results allowed to improve both systems; investigations were continued (in 2008/2009 and 2009/2010) to increase effectiveness of forecasts.

Phoma stem canker, caused by complex of *Leptosphaeria* spp., is a world-wide rape disease, causing serious losses in all regions. Recently, the increasing incidence of stem canker has been observed also in Latvia (Balodis et al., 2008). Incidence of *Phoma* leaf spot of up to 1% was noted in the sowing autumn of 2005, up to 8% – in 2006, and up to 6% – in 2007, but severity of the disease was still very low and mostly did not reach 1%. Leaf spot form is not harmful, and its impact on the yield was not observed. But autumn, as indicated by most of authors, is crucial time for further disease (as stem canker) development, when the pathogen from leaf spots grows and reaches petioles and stems. Fungicide application in autumn is important for Phoma stem canker control. The increasing area under oilseed rape, absence of high-yielding cultivars with high resistance against *Leptosphaeria* spp., and the tendency of growers to shorten crop rotation, leads to increase in the spread and harmfulness of stem canker (West et al., 1999). A similar situation (rapid increase in stem canker incidence during the last years) was observed in Lithuania (Brazauskiene et al., 2007).

In 2006 and 2007, we recorded the total incidence of stem canker (caused by *Leptosphaeria* spp.) directly after the harvest, as in the first years of investigations we were not certain about the presence of both shapes of stem canker in Latvia and we did not know how to diagnose them separately. In our investigations, the incidence of stem canker fluctuated from 48% to 86% in untreated plots. (Table 4.4). The obtained data clearly showed ineffectiveness of fungicide application in 2007, when incidence in treated plots was even higher (on average 89%; Table 4.4).

The only explanation for such high incidence of Phoma stem canker in the treated plots in 2007 was the presence also of Sclerotinia stem rot which was controlled by the fungicide better and the free place on stems was occupied by Phoma stem canker. In untreated plots, high occurrence of Sclerotinia was observed, and Phoma stem canker had less living space. Observations in 2007 also led to the idea that fungicide application schemes which are effective against Sclerotinia stem rot can be ineffective against Phoma stem canker in the years with high incidence of Sclerotinia.

Cultivar	Incidence, %			
	2006		2007	
	Check	J_R+J	Check	J_R+J
Excalibur	64	49	74	91
Californium	48	54	82	86
Elixir	50	35	86	91
Falstaf	74	55	76	88
Average	59	48	80	89

Table 4.4. The incidence of stem canker (caused by *Leptosphaeria* spp.) depending on cultivars and fungicide application: 0.5 L ha^{-1} metconazole, 90 g L^{-1}, at GS 14-16, and 0.5 L ha^{-1} metconazole, 90 g L^{-1}, at GS 65 in 2006 and 2007

Incidence of stem canker differs depending on years, regions, and fields. Virulence of the pathogen is the most important factor which determines the yield losses. Depending on pathogen species (now two distinct species, *L. maculans* and *L. biglobosa*, which have different virulence are determined) yield losses from 1% to 56% have been reported (Gugel&Petrie, 1992). Presence of *L. maculans* and *L. biglobosa* was approved also in Latvia during our investigations (Balodis et al., 2008). Existence of two species and inconsistent data about fungicide efficacy were the reason to evaluate not only incidence, but also severity of stem canker in the trial in 2008 (Fig. 4.2). Basal stem canker (mostly caused by *L. maculans*) was reported as the cause of more harmful damage to a plant if compared with upper stem lesions (mostly caused by *L. biglobosa*).

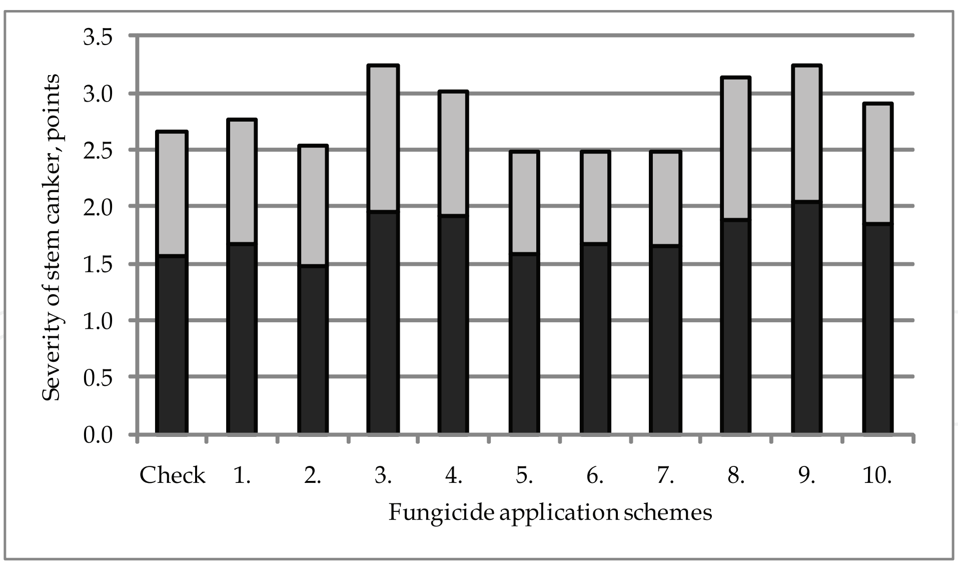

Fig. 4.2. Development of stem canker depending on fungicide application schemes (1 – J_R+J; 2 – F; 3 – J_p; 4 – C_{61}; 5 – C_{65}; 6 – J_p+C_{65}; 7 – Jp+J_{65}; 8 – C_{sign}; 9 – PP; 10 – PP_{mod}; ■ – upper stem canker; ■ – basal canker), cultivar 'Californium', 2008

Severity of stem canker fluctuated within 1.48–2.04 (basal canker) and 0.82–1.28 (upper stem canker) points (max possible is 4 points) for cultivar 'Californium'. Fungicide spraying did not cause a convincing decrease in the disease – only a slight tendency was observed for the

individual treatments (Schemes Nos 2, 6 and 7), where fungicide was applied at least once at GS 14-16 or 31-33, to cause a small reduction in Phoma stem canker severity.
Cultivar 'Elixir' was more susceptible against stem canker in our investigations. Severity of basal stem canker reached 2.56 points (1.9–2.56), on the upper stem part – 0.95–1.67 points. Fungicide application for 'Elixir' was as much ineffective as for cultivar 'Californium'; also the same tendency of some effect of Schemes Nos 2, 6 and 7 was observed.
Infection by ascospores is possible during all autumn period and also during the succeeding spring and summer under conditions of Latvia. Infection of leaves was low in autumn, and it might be possible that infection of stems does not occur in autumn like it is in countries with a milder climate (West et al., 2002). Leaf spot most frequently was observed on the oldest leaves which died during winter, and therefore did not influence development of stem canker. Very contradictory results have been found by other authors, for example, yield losses of 1-56% related to stem canker have been reported (Gugel&Petrie, 1992). There are different recommendations regarding the best time of fungicide application, e.g., J. R. Hood et al. have noted increase in leaf spotting between October and January. They observed that fungicide spray in October is more effective against leaf spots, but spraying in November decreases severity of canker and yield loss (Hood et al., 2007). Under conditions of Latvia, November usually is too late for fungicide application. Average air temperature in November mostly is below 5 °C (5 °C in 2005, 4.3 °C in 2006, and 1.2 °C in 2007). Further investigations which are necessary to find the best fungicide application scheme for decrease of Phoma stem canker have been started in 2009 and are being implemented at present, in 2010.

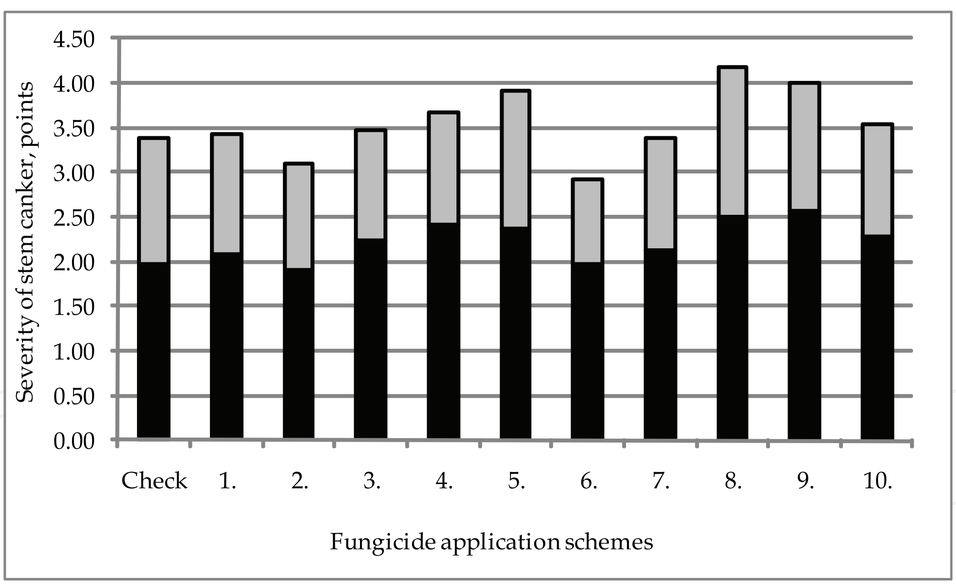

Fig. 4.3. Development of stem canker depending on fungicide application scheme (1 – J_R+J; 2 – F; 3 – J_p; 4 – C_{61}; 5 – C_{65}; 6 – J_p+C_{65}; 7 – Jp+J_{65}; 8 – C_{sign}; 9 – PP; 10 – PP_{mod}; ■ – upper stem canker; ■ – basal canker), cultivar 'Elixir', 2008

Alternaria spot is the most widespread disease in Latvia. The effect of fungicide application according to different schemes was observed during all trial years. Incidence of Alternaria leaf spot in the autumn of the sowing year fluctuated from 43% to 94% (mostly 70-80%) in untreated plots depending on the cultivar and the year (Table 4.5). The severity of Alternaria leaf spot did not exceed 2% in all trial years, which is a typical situation in agro-climatic

conditions of Latvia. O. Treikale (2006) has reported similar results on poor severity of the disease in autumn in Latvia. Fungicide biological efficacy was not stable and fluctuated (0-65%) depending on the year and the cultivar. Similar results were obtained, when metconazole was replaced with tebuconazole (Scheme No 2: F).
Development of Alternaria leaf spot in autumn is dependent on different factors, but mathematically the impact of fungicide application (η%) on disease incidence was 69-74% during our investigations. Findings of Lithuanian researchers have demonstrated a more significant effect of fungicide application on the disease severity than on disease incidence (Petraitiene&Brazauskiene, 2007), but leaf spot severity lower than 2%, as in our trials, could not really influence the development of rape plants in autumn.
Alternaria spot affected also pods. Pod spot is reported as harmful disease in many regions of rape cultivation (Brazauskiene &Petraitiene, 2006). Development of the fungus from *Alternaria* spp. on siliques is equally influenced by the air temperature and moisture in July when winter rape silique ripening period occurs. In our trials, the incidence of pod spot reached only 7% in 2006, and 26% in 2008 when July was dry (17% of the month's long-term average rainfall in 2006, and 76% – in 2008).

Cultivar	Incidence of Alternaria spot on leaves, %					
	2005		2006		2007	
	Check	J_R+J	Check	J_R+J	Check	J_R+J
Excalibur	77	62	81	45	43	44
Californium	86	53	80	43	71	46
Elixir	91	77	79	38	78	42
Falstaf	94	60	83	45	79	28
Average	87	63	80	43	68	40

Table 4.5. The effect of fungicide application (Scheme No 1: 0.5 L ha^{-1} metconazole, 90 g L^{-1}, GS 14-16) on the incidence of Alternaria leaf spot in the sowing autumn depending on the year and the cultivar

Biological efficacy (22-84%) of fungicide application schemes differed depending on the year and the cultivar. Unfortunately, in 2007, which was more favourable for Alternaria pod spot development (136% of the month's long-term average rainfall in July), disease incidence was not evaluated. The obtained results are disputable, and more investigations are necessary to find relationship between development of Alternaria pod spot and its impact on the development of rape. Also influence of the disease on rape yield is still not clear.

4.3 Effect of fungicide application on the yield

Although fungicide application effect on the decrease of three main diseases was contradictory during the trial years, yield increase in plots where fungicides were applied was substantial in 2006 and 2007 (Table 4.6).
More favourable for the development of diseases was the year 2007, and accordingly higher efficacy of fungicide application on yield increase was observed in this year.
Fungicide application according to Scheme No 9 – Dacom advice – provided yield increase in 2007 when Sclerotinia stem rot was widespread (+0.71 t ha^{-1}), but in 2006, the yield in

sprayed plots was of the same level as in untreated check plots. Also other two schemes applied on cultivars 'Aviso' and 'Falstaf' in 2007 gave some average yield increase (No 2: tebuconazole, 250 g L^{-1}, at GS 14-16, gave +0.29 t ha^{-1}; No 5: boscalid, 500 g kg^{-1}, at GS 65, gave +0.63 t ha^{-1}), but the yield was of the same level as in untreated check plots when fungicide tebuconazole, 250 g L^{-1}, (Scheme No 3) at GS 31-33 was applied.

Cultivar	Yield, t ha^{-1}			
	2006		2007	
	Check	J_R+J	Check	J_R+J
Excalibur	6.48	6.80	6.19	6.86
Californium	5.36	5.21	5.17	5.90
Elixir	5.04	6.09	5.40	6.07
Falstaf	5.52	5.92	5.19	5.39
Average	5.60	6.01	5.45	6.07
LSD $_{0.05 \text{ for fungicide treatment}}$	0.31		0.20	

Table 4.6. The effect of fungicide application according to Scheme No 1 (J_R+J) on winter oilseed rape yield in 2006 and 2007

Contradictory results were obtained in the year 2008, when fungicide application by any scheme caused significant ($p<0.05$) yield increase by more than 1.0 t ha^{-1} for cultivar 'Elixir', but the yield of cultivar 'Californium' was of the same level as that of untreated check plot. Also other researchers (West et al., 2001) have reported yield increase depending on cultivars and years. Yield level of any crop is affected by many factors, and disease development and disease control effect are only two of them. But, of course, any rape grower hopes to control disease development by fungicide application and in such a way to increase the yield. A substantial and economical yield increase, if compared with untreated crop, is the main criterion for applying any activity in the field. Our results require continuation of trials in order more reliable data are achieved on fungicide application for the decrease of disease incidence and increase of oilseed rape yield.

5. Acknowledgements

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Plant and plant products are affected by a large number of plant pathogens among which fungal pathogens. These diseases play a major role in the current deficit of food supply worldwide. Various control strategies were developed to reduce the negative effects of diseases on food, fiber, and forest crops products. For the past fifty years fungicides have played a major role in the increased productivity of several crops in most parts of the world. Although fungicide treatments are a key component of disease management, the emergence of resistance, their introduction into the environment and their toxic effect on human, animal, non-target microorganisms and beneficial organisms has become an important factor in limiting the durability of fungicide effectiveness and usefulness. This book contains 25 chapters on various aspects of fungicide science from efficacy to resistance, toxicology and development of new fungicides that provides a comprehensive and authoritative account for the role of fungicides in modern agriculture.

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