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Importance of Agronomic Practice on the Control of Wheat Leaf Diseases

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Received: 25 February 2018; Accepted: 6 April 2018; Published: 8 April 2018

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Abstract: Soil tillage and crop rotation are considered important tools in wheat leaf disease control; however, the results of investigations are inconsistent. The aim of the present study was to determine the effect of the soil tillage system and cropping sequence on the development of winter wheat leaf diseases in 2012–2017. The disease development was assessed in a two-factor experiment: (a) soil tillage system; and (b) crop rotation. Foliar fungicides were used uniformly in all variants. The results showed that tan spot (caused by *Pyrenophora tritici-repentis*) dominated in 2012, 2013, and 2016, but the level of Septoria tritici blotch (*Zymoseptoria tritici*) was essentially lower and exceeded the severity of tan spot only in 2015. The agronomic practice used significantly influenced only the development of tan spot. Reduced soil tillage and continuous wheat sowing substantially increased tan spot severity, especially when both practices were used simultaneously. Short crop rotation (only wheat and oilseed rape) provided sufficient control of tan spot in ploughed fields, whereas in non-ploughed fields, the level of this disease did not decrease. The results could be explained by differences in the pathogens' life cycle: *P. tritici-repentis* ascospores in wheat debris is the main source of infection; in contrast, *Z. tritici* spreads by conidia from living plants.

Keywords: reduced soil tillage; crop sequence; *Pyrenophora tritici-repentis*; *Zymoseptoria tritici*

1. Introduction

Winter wheat is one of the most profitable crops in Latvia—it covers almost 25% of the country's arable land. As a consequence, wheat is grown in continuous wheat sowings or short rotations where only wheat and oilseed rape are included. Farmers are searching for more beneficial cropping systems, a result of which is that different types of conservation tillage have become increasingly popular. Conservation tillage systems are recognized as sustainable agricultural production systems that improve soil fertility and allow for saving resources [1]. On the other hand, reduced soil tillage may increase the level of diseases, especially in combination with poor crop rotation. Many investigations have been carried out regarding the advantages and disadvantages of these systems, but the results are still inconsistent or contradictory.

Wheat leaf diseases are widespread globally and are an important risk factor that decreases the yield of wheat. Septoria tritici blotch, caused by *Zymoseptoria tritici*, is considered the most prevalent and devastating wheat disease in many countries [2], whereas tan spot, caused by *Pyrenophora tritici-repentis*, has been found to be the most widespread pathogen in Western Canada [3]. Both diseases are also the most frequent and harmful wheat diseases in the Baltic region, including Latvia [4,5].

Studies of the impact of agronomic factors on the development of wheat leaf diseases have revealed high variations in the effect of crop rotation and soil tillage. Several investigations have proven the importance of crop rotation as an important tool for wheat disease control and as a possibility for decreasing fungicide pressure. Wheat leaf diseases are considered the most important factor in decreasing the yields in wheat-after-wheat fields in Uruguay [6]. Andert et al. (2016), concluded that less fungicides were necessary if crop sequences were used and a high risk of wheat diseases was observed if the pre-crops and pre-pre-crops were cereals and maize [7]. However, Fernandez and colleagues found that the level of wheat leaf spot was similar in different cropping systems, including peas or other non-cereals [8]. The impact of crop rotation depends on the dominant pathogens; however, the results obtained in different countries and under diverse conditions differed. Outbreaks of tan spot have been related to poor crop rotation [2,9], whereas Gilbert and Woods (2001) did not find any effect of crop rotation on the occurrence of *P. tritici-repentis* [10]. The development of Septoria tritici blotch in connection with crop rotation is still unclear. Crop rotation has decreased the level of this disease in Saskatchewan, although not in all years and not for all cultivars [11].

The impact of soil tillage systems is even more unclear. It has been reported that non-inverse tillage increased the level of tan spot [9]. However, other authors do not support these findings. Moldboard ploughing did not reduce the level of wheat leaf diseases in Poland [12], and Krupinsky et al. (2007) concluded that other factors mitigated the negative impact of reduced soil tillage, for example, in years with unsuitable meteorological conditions for leaf spot development, reduced tillage did not increase the level of tan spot [13].

The aim of the present study was to determine the effect of soil tillage systems and cropping sequence on the development of winter wheat leaf diseases.

2. Methods and Materials

This study is a continuation of previous investigations in a large multifaceted field experiment established at the study and research farm "Peterlauki" of the Latvia University of Life Sciences and Technologies (56° 30.658° N, 23° 41.580° E) in the autumn of 2008 [14,15]. Different aspects (soil chemical and physical properties, peculiarities of plant growth and development, changes in weed spectrum, etc.) were investigated [16,17], and the evaluation of wheat diseases was only one part of extensive long-term trials. The present research demonstrated the development of leaf diseases depending on the agronomic practices used.

The development of winter wheat leaf diseases was assessed in a two-factor experiment: (a) soil tillage system (A1—traditional soil tillage with ploughing at the depth of 22–24 cm (TT); A2—reduced soil tillage with disc harrowing up to the depth of 10 cm (RT)); and (b) crop rotation (B1—continuous wheat (W-W); B2—oilseed rape and wheat (W-OR); B3—crop rotation where barley and faba beans were included (CS)). Trials were arranged using a split-plot design in two replications (area of each plot 0.25 ha), and four sub-replications were established within each plot. In this study, data obtained in 2012–2017 were analyzed except for the year 2014, when plots were resown with spring wheat because of the extremely bad overwintering of winter wheat. The cultivar "Zentos" was used every year. This cultivar is characterized by good productivity, winterhardiness and disease resistance.

The severity of diseases was assessed weekly: for three upper leaves—until growth stages (GS) 32–69—and for two upper leaves—until GS 75. Growth stages were noted according to the "Biologische Bundesanstalt, Bundessortenamt und Chemische Industrie" (BBCH) scale. The total disease impact during the vegetation period was estimated by calculating the area under the disease progress stairs (AUDPS) [18].

By using three-way ANOVA, the effect of year and both factors—soil tillage system (A) and crop rotation (B)—on the total impact of the diseases during the vegetation period (AUDPS) was determined. To test the main effects, the following statements were defined: the main effect of years compared the levels of years (2012–2017, except 2014) after averaging the levels of soil tillage system and crop rotation; the main effect of soil tillage system compared the level of soil tillage system (TT vs.

RT) after averaging the level of crop rotation and years; the main effect of crop rotation compared the level of crop rotation (W-W, W-OR, CS) after averaging the level of soil tillage system and years; the soil tillage system by crop rotation interaction examined the interaction of the soil tillage system (TT vs. RT) and crop rotation (W-W, W-OR, CS) after averaging the years. The post hoc multiple comparison least significant difference (LSD) test was used to determine which groups were significantly different.

All agronomic measures were applied uniformly according to the requirements of agronomic practices under the conditions of intensive wheat production. The foliar fungicides epoxiconazole (62.5 g L^{-1}) and fluxapyroxad (62.5 g L^{-1}), dose 2 L ha^{-1}, were sprayed across all wheat plots at the heading stage every year except 2013. That year, two treatments were necessary: the first treatment was epoxiconazole and fluxapyroxad during stem elongation in the amounts described before, and the second treatment was epoxiconazole (84.0 g L^{-1}) and fenpropimorph (250 g L^{-1}) at a dose of 1.2 L ha^{-1}, during heading.

The meteorological conditions differed in the years of investigation (Table 1). To describe the conditions of disease development, the hydrothermal coefficient (HTC)—the ratio between the sum of temperatures and the total precipitation amount during vegetation when the temperature was above 10 °C—was used [19].

Table 1. Meteorological situation during the period of investigation.

Year	Growth Stages	Number of Rainy Days	Amount of Precipitation, mm	Average Temperature, °C	Hydrothermal Coefficient
2012	32–55	8	44	12.4	1.1
	55–75	23	247	17.1	2.9
	32–75	31	291	15.5	2.3
2013	32–55	9	61	12.6	2.1
	55–75	10	85	15.9	1.1
	32–75	19	146	14.9	1.3
2015	32–55	26	34	14.6	0.6
	55–75	29	89	13.8	1.1
	32–75	55	123	14.1	0.9
2016	32–55	6	27	13.4	0.6
	55–75	24	115	17.6	1.3
	32–75	30	142	15.9	1.1
2017	32–55	12	34	12.4	0.8
	55–75	24	106	16.3	1.3
	32–75	36	140	14.6	1.1

3. Results

Tan spot, Septoria tritici blotch, and mildew were observed throughout the whole investigation period, but other leaf diseases were not detected. Meteorological conditions as well as other conditions including the efficacy of fungicide treatment, influenced the level of these diseases significantly ($p < 0.001$) (Figure 1). Tan spot dominated in 2012, 2013, and 2016, but the level of Septoria tritici blotch was essentially lower and exceeded the severity of tan spot only in 2015. Mildew was observed every year; however, the disease severity never reached 2% during the evaluation. Therefore, the value of the AUDPS for mildew was too small to evaluate the influence of these factors.

The soil tillage method influenced the development of wheat leaf diseases, but this impact was ambiguous (Figure 2). The level of tan spot essentially ($p = 0.01$) decreased in ploughed plots, and the value of AUDPS (average data) was almost 50% higher in fields with shallow tillage when compared to conventionally ploughed plots. In contrast, the level of Septoria tritici blotch was statistically significantly ($p = 0.001$) higher in plots where the soil was ploughed; however, this difference was only 23%.

Importantly, the scheme of the crop sequence only influenced ($p < 0.001$) the development of tan spot (Figure 3), but this factor had no impact on the level of other diseases. The lowest level of tan spot was observed if crop sequence was used. A slightly higher severity was determined if wheat was rotated with oilseed rape; however, this difference was not statistically significant. Continuous wheat sowings increased the severity of tan spot essentially, which was three times higher than in fields where wheat was grown in rotation with other crops—faba beans, oilseed rape, and barley.

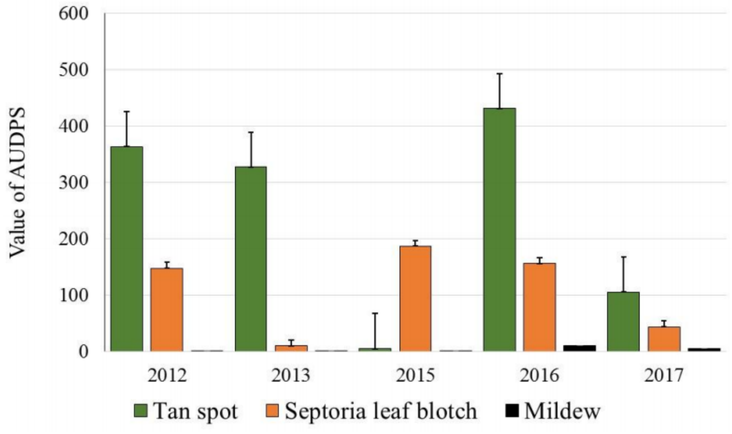

Figure 1. Development of winter wheat leaf diseases depending on year (average data).

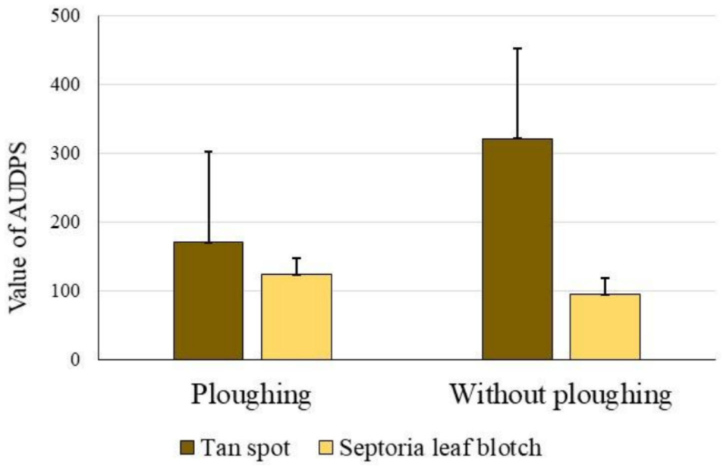

Figure 2. Development of tan spot and Septoria tritici blotch depending on soil tillage.

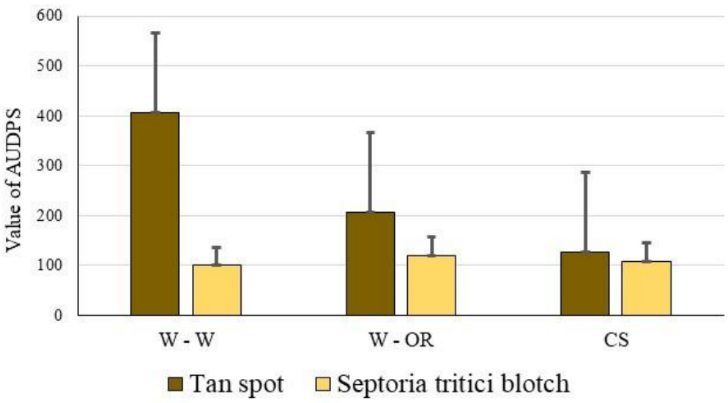

Figure 3. Development of tan spot and Septoria trit*ici* blotch depending on crop sequence scheme: W-W—continuous wheat; W-OR—short rotation of only wheat and oilseed rape; CS—crop sequence.

The development of tan spot was influenced by both the soil tillage method and crop sequence; furthermore, the interaction between these factors was important (Figure 4). In general, the level of disease was higher in plots without ploughing (except fields with crop sequence). Ploughing mitigated the effect of wheat as a pre-crop or a pre-pre-crop, and short crop rotation decreased the disease level. In ploughed fields, short crop rotation (only wheat and oilseed rape) also provided sufficient control of tan spot, and, in contrast, the level of diseases significantly varied among all schemes of crop rotation if the fields were not ploughed. In contrast to any other variant, the combination of continuous wheat sowings and reduced soil tillage increased the severity of tan spot twice.

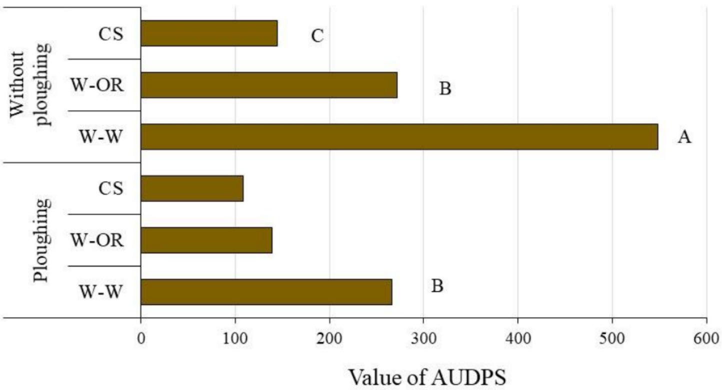

Figure 4. Development of tan spot depending on crop sequence and soil tillage method. Different letters among trials' means indicate significant differences according to a post hoc multiple comparison LSD test.

4. Discussion

The total impact of wheat leaf diseases during the whole vegetation period is often characterized by the area under the disease progress curve (AUDPC); however, in this study, we used AUDPS based on the investigations of Simko and Piepho [18]. They proposed the use of AUDPS as this approach, according to their observations, might be more precise in cases where disease progression was frequently observed and started at the time of the appearance of first symptoms, and continued until the disease reached the plateau phase (in our case, from the start of stem elongation until milk ripening).

These investigations were a continuation of our previous studies. During the first few years of the trials, the authors observed the influence of the pre-crop on tan spot development, especially under reduced soil tillage [14,15]. Three to nine years after the establishment of the trials, the crop sequence schemes were completely realized and repeated, and the possible effects of each particular soil treatment had also accumulated. Based on these multi-year results, a better overall evaluation of each agronomic practice is possible. It is important to emphasize that our study was a large field investigation where the size of one plot was approximately 0.25 ha, which allowed us to refer the results to real wheat production conditions. The importance of large field trials has also been underlined by Lensen et al. (2013), who concluded that farmers accepted research results from small-plot studies poorly [20].

Tan spot (caused by *Pyrenophora tritici-repentis*) and Septoria tritici blotch (caused by *Zymoseptoria tritici*) were the dominating diseases in our study, but the level of mildew (*Blumeria graminis*) was low throughout the whole observation period. Similarly, in a study in France, Septoria tritici blotch was observed every year and with large variations in severity, while mildew was only noted in some years and with low severity [21]. The same situation was also registered in our earlier investigations, which may be explained by choices of cultivar—'Zentos' demonstrated resistance to mildew.

All three investigated factors and their interactions significantly affected the level of wheat leaf diseases; however, the influence of each particular factor should also be evaluated.

Disease development was influenced by the meteorological conditions of that year, and other factors such as the application of fungicides also had an impact on disease severity. One treatment of fungicides during heading was used every year, but the efficacy differed slightly. The spring of 2013 was wet and cool, and HTC exceeded the indicators of other years approximately twice (Table 1). These conditions promoted the distribution of Septoria tritici blotch, therefore two treatments were carried out. This result supports the findings of Fernandez et al. (2016) in Canada, who highlighted high correlations between disease severity and the amount of precipitation [8].

In our study, the severity of tan spot was higher than that of Septoria tritici blotch, the only exception being in 2015, when Septoria tritici blotch exceeded the level of tan spot. That year, the vegetation period was dry, and the HTC was less than 1.0; however, 26 rainy days (precipitation >1 mm) were recorded during stem elongation until heading, which could have promoted infection with *Z. tritici* in accordance with other studies [9,21].

Several investigations have proven the importance of soil tillage as a possible tool to decrease the disease level. In our studies, the level of tan spot was, on average, significantly higher in fields without ploughing, but the severity of Septoria tritici blotch was higher in ploughed plots. Similar results have been obtained by research in the United States, where Septoria tritici blotch dominated under conventional tillage but tan spot dominated under conservation tillage [10]. Additionally, investigations in Germany did not demonstrate an influence of soil tillage where the same levels of fungicides were used independently of the soil tillage method [22]. It is possible that these results were determined by the relationships between pathogens. Fernandez et al. (2016) found a negative correlation between the presence of *Z. tritici* and the presence of *P. tritici-repentis* [3].

There have been many investigations that prove the efficacy of crop rotation in decreasing the level of wheat leaf diseases. Cropping sequence significantly influenced the severity of wheat leaf diseases in Western Canada [3]. Similar conclusions have been drawn in Poland, where wheat as a pre-crop increased the level of Septoria leaf blotch [23]. In our investigations, tan spot severity depended on crop sequence—the level of disease was essentially higher in continuous wheat sowings. On average, short crop rotations (only wheat and oilseed rape) also slightly decreased the level of disease; however, this difference was not statistically significant. Our research suggests that the diverse effects of agronomic practices in relation to various diseases could be explained by differences in the pathogens' life cycle under Latvian conditions. The main source of *P. tritici-repentis* infection is wheat debris where ascospores develop, but *Z. tritici* mostly survives in living plants such as pycnidia, therefore the existence of plant debris is less important [5].

It is considered that ploughing decreases the level of diseases, but crop sequence can reduce the disease level even without ploughing [7]. Average data from the five-year investigations clearly showed that the level of tan spot was directly dependent on soil tillage and crop sequence. Reduced soil tillage increased the severity of tan spot, i.e., the disease level under continuous wheat sowings in ploughed fields was the same as in fields with reduced tillage and short crop rotation. This could be explained by the poor degradation of wheat debris if wheat was grown in rotation only with oilseed rape and the soil was not turned over. In this case, only a crop rotation with a three-year break in continuous wheat growing showed an essential decrease in tan spot severity. Short rotations provided sufficient control of tan spot if ploughing was used. Unfortunately, we do not have a sufficient amount of data to evaluate the impact of agronomic practices on the spread and development of other wheat leaf diseases.

Long-term investigations are required to completely understand the influence of agronomic practices on the development of wheat leaf diseases as the disease severity depends on very different factors and the impact of agronomic practices could be mitigated by meteorological conditions and relationships between pathogens as well as between other microorganisms.

5. Conclusions

Tan spot and Septoria tritici blotch were the most important wheat diseases in Latvia, but the severity of both diseases varied significantly among the years. Continuous wheat sowings significantly increased the severity of tan spot, especially in combination with reduced soil tillage; whereas short rotations (oilseed rape and wheat) provided a sufficient decrease in tan spot severity only if the fields had been ploughed. In contrast, the development of Septoria tritici blotch mainly depends on meteorological conditions, and agronomic practice is less important.

Acknowledgments: The research was supported by the state research program "Agricultural Resources for Sustainable Production of Qualitative and Healthy Foods in Latvia", project No. 1 "SOIL", and by a grant from the Ministry of Agriculture "Influence of minimal soil tillage on its fertility maintenance, development and distribution of pests as well as crops' yield and quality in resowings".

Author Contributions: Biruta Bankina: research idea, writing the manuscript; Gunita Bimšteine: summarisation and analysis of data; Irina Arhipova: statistical processing of data; Jānis Kaņeps: conduction of trials; Terēze Stanka: conduction of trials.

Conflicts of Interest: The authors declare no conflict of interest.

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