ORIGINAL ARTICLE

Cephalosporium stripe disease, crop yield and selected soil properties as influenced by straw management in a micro-plot experiment with winter wheat monoculture

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Abstract

Straw is a valuable by-product of crop production which can be used for various purposes (livestock feed and bedding, bioenergy). However, it should primarily be retained on farmlands to prevent soil organic matter (SOM) losses. Straw retained on the field is usually incorporated into the soil when conventional (with ploughing) and reduced tillage systems are used or left on the soil surface (mulching) when a no-tillage system is practiced. The aim of this study was to determine how different straw management practices (straw removal, straw incorporation and straw mulching) affected the incidence of *Cephalosporium gramineum* on two winter wheat cultivars, the grain yield of these cultivars and selected soil properties based on a long-term micro-plot experiment. Cephalosporium stripe disease was absent or occurred at very low levels (0–2.4%) when straw was removed or incorporated every second year. The disease was most severe, 24–33% tillers infected, in the SM(N) treatment with yearly straw mulching and cv. Bogatka was more tolerant to *C. gramineum* infection than cv. Bamberka. Importantly, yearly straw incorporation into the soil in contrast to straw mulching resulted in low disease levels (5–8% tillers infected) in both cultivars. Only in the case of cv. Bamberka was the grain yield significantly reduced in the SM(N) treatment compared to other treatments. The soil in this experiment contained the lowest level of soil SOM, which amounted to 21.0 g · kg^{-1} soil dry matter (DM), when each year wheat straw was removed (SR). Straw incorporation every second year resulted in 24.2 g of SOM · kg^{-1} soil and the largest amounts of SOM (26.0–26.1 g · kg^{-1} soil) were found with yearly straw incorporation into the soil. Yearly straw mulching was inferior in this respect and the soil in this treatment contained 23.8 g of SOM · kg^{-1} soil DM.

Keywords: *Cephalosporium gramineum*, grain yield, infection level, soil organic matter, straw management, winter wheat

Introduction

Straw, particularly cereal straw, is a valuable by-product of crop production, which can be used for various purposes, e.g., as livestock feed and bedding or for making fuels. However it should primarily be retained on farmlands in order to prevent soil organic matter (SOM) losses and thus to maintain or improve soil fertility and crop productivity (Hazarika *et al*. 2009; Lemke *et al*. 2010; Kuś 2015). Straw and other crop residues retained on the field are usually incorporated into the soil plough layer or sub-surface layer when conventional (with ploughing) and reduced tillage systems are used or left on the soil surface (mulching) when a no-tillage system is practiced. The primary goal of reduced and no-tillage systems is to diminish soil erosion and nutrients run-off, and to reduce fuel/labor costs of crop production (Blecharczyk *et al*. 2007; Hazarika *et al*. 2009; Laird and Chang 2013; Smagacz 2018). Published results on the effects of these systems on soil properties, plant establishment, weed infestation and fungal pathogens are inconsistent (Lemke *et al*. 2010; Seehusen *et al.* 2017; Smagacz 2018). For example, with respect to plant diseases in Poland Horoszkiewicz-Janka *et al*. (2012) grew winter wheat under conventional (with ploughing) and reduced tillage (without ploughing) systems and found no significant differences in plant infection by fungal leaf and root pathogens. On the other hand Małecka *et al.* (2014) reported higher infestation of this crop by stem base and root infecting fungi under reduced and direct drilling systems than under conventional tillage, but the opposite was true in the case of fungal leaf and ear diseases. In contrast to the above-mentioned fungal diseases of cereals no such information is available in Poland about the influence of the tillage system or straw management on Cephalosporium stripe disease.

Cephalosporium stripe is a vascular disease of cereals caused by the soil-borne fungal pathogen *C. gramineum* Nisikado and Ikata (syn. *Hymenula cerealis* Ellis & Everh.), which has been found in many regions of the world where frosty winters occur. Cephalosporium stripe is widespread in the Pacific Northwest of the USA, where the disease can be quite severe and cause serious grain losses, particularly in winter wheat grown in short rotations or in monocultures with reduced tillage (Douhan and Murray 2001; Quincke *et al.* 2014). Based on field experiments with two soils in Oregon artificially inoculated with *C. gramineum* Quincke *et al*. (2012) reported grain yield losses ranging from negligible to about 41% in the case of winter wheat genotypes with low and high susceptibility to the pathogen, respectively. In Poland this pathogen was first detected on field grown triticale in the north-eastern part of the country (Martyniuk 1993). Subsequent filed experiments, also with artificially inoculated soil, showed grain yield losses as high as about 60% in the case of the most susceptible cultivar Kobra (Martyniuk and Stachyra 1997). The fungus survives in soil as a saprophyte on previously infected host residues, on which it forms sporodochia with numerous, unicellular conidia during wet and cool seasons of the year. *Cephalosporium gramineum* can actively colonize and infect root tissues of winter cereals, however the main source of infection are conidia entering the plant vascular system through wounds in roots created by freeze injury and frost heaving of soil during the autumn-winter period (Douhan and Murray 2001; Quincke *et al*. 2014). For these reasons spring-sown cereals are not infected, although these crops are susceptible to *C. gramineum*. After entry into the plant, the pathogen colonizes and blocks water conducting vessels (xylem) of the vascular system, which results in yellow striping on leaves (Fig. 1), stunted tillers and often premature blighting of ears (Martyniuk 1993; Quincke *et al*. 2014).

Although variation in the degree of resistance among cultivars has been demonstrated, genotypes with complete resistance to *C. gramineum* have not been found in commercial winter wheat cultivars (Martyniuk *et al*. 1995; Martyniuk and Stachyra 1997; Quincke *et al*. 2011; 2012). Currently available fungicides are also ineffective in controlling *C. gramineum* infections, therefore the incidence of this pathogen can be controlled only by agrotechnical measures, e.g., crop rotation or straw management (Martyniuk 1993; Quincke *et al*. 2014).

The objective of this study was to determine how different straw management practices (straw removal, straw incorporation and straw mulching) affected the incidence of *C. gramineum*, crop yields and selected soil properties in a long-term winter wheat monoculture. The advantage of this experiment was that it was conducted without artificial soil inoculation with the pathogen, in contrast to the majority of studies reported earlier. Furthermore, the effect of different straw managements on soil quality (SOM – soil organic matter, pH) was also included in this study.

Materials and Methods

This study was based on a long-term micro-plot experiment located on an experimental field in Puławy (GPS coordinates: 51.415218, 21.960489), Lublin voivodship, Poland. Lysimeter-like micro-plots (1.5 m^2) with concrete walls were filled to the depth of 1.0 m with an alluvial soil (clayey silt containing 18% sand, 71% silt and 11% clay). At the onset of the experiment the soil contained 21.4 g · kg^{-1} soil DM (dry matter) of SOM and had a pH of 6.5. This experiment was initiated in 1998 and consisted of the following treatments with three replications in complete randomization: SR – straw removed, S2(N) – straw incorporated into the soil every second year with additional N fertilization for straw decomposition, S3 – straw incorporated each year without additional N, S3(N) – straw incorporated each year with additional N, and SM(N) – each year straw retained on the soil surface (mulching) with additional N. After harvest, straw was collected from plots of particular treatments, cut into 1–2 cm fragments and then evenly distributed on the soil surface in the same plots. In the treatments with straw incorporation, it was mixed with soil by digging to the depth of 20–25 cm. Before digging 25 g · m^{-2} of Polifoska fertilizer (4% N, 12% P_2O_5, 32% K_2O, 2% MgO, 9% SO_3) was added to each plot. In the treatments: S2(N), S3(N) and SM(N) 3 g · m^{-2} of ammonium nitrate (34% N) was applied to facilitate straw decomposition and to reduce soil N immobilization during this process. Stubble digging was also applied in the SR treatment but no soil disturbance was performed in the SM(N) treatment (mulching). Before sowing, each plot was divided into two halves (0.75 m^2 each) on which two winter wheat cultivars (*Triticum aestivum* L.) were seeded. Here, we report results obtained in the years 2015, 2016 and 2017 when cultivars Bamberka and Bogatka were grown each year. During the first 10 days of October both wheat cultivars were sown at the rate of 350 seeds · m^{-2}. Before sowing, seeds were treated with commercial seed dressing Maxim 025 FS at the rate recommended by the producer. In each growing season nitrogen fertilizer in the form of ammonium nitrate (34% N) was applied at the dose of 16 g N · m^{-2}, which was split as follows: 7.2 g in the spring at the beginning of plant vegetation (BBCH 22–23), 5.6 g at stem elongation (BBCH 33–34) and 3.2 g at early heading (BBCH 51–53). Plots were hand-weeded and plants were protected against fungal leaf diseases according to the current recommendations of Institute of Plant Protection (IOR – PIB). At full ripeness plants were hand-harvested to measure grain yields and selected yield components and these results were calculated per an area of m^2.

Each growing season at the beginning of June the incidence of Cephalosporium stripe disease was assessed by counting wheat tillers with yellow striping on their leaves (Fig. 1). The disease incidence was expressed as the number of diseased tillers per m^2 plot area and percentages of infected tillers in relation to the total number of tillers per m^2 were also calculated.

In 2016 after harvesting of the crop, the soil was sampled to determine the content of SOM and soil pH. Soil samples (five per plot) were taken between stubble rows from the plough layer (0–25 cm) using a soil corer (30 mm internal diameter). Field moist soil samples were passed through a sieve with 2 mm openings, air dried and stored at room temperature. Determinations of: C org. (PN-ISO 14235 – Soil Quality – Determination of organic carbon by sulfochromic oxidation) and soil pH [potentiometerically in 1 : 2.5 suspension of soil in 1 M KCl (ISO 10390 – Soil Quality – Determination of pH)] were performed in the certified chemical laboratory of the Institute of Soil Science and Plant Cultivation in Puławy, Poland. The content of SOM was calculated as follows: C org. × 1.724 (Ostrowska *et al.* 1991).

Fig. 1. Stripes caused by *Cephalosporium gramineum* on winter wheat leaves

The data were subjected to two-way analysis of variance (ANOVA) using the FR-ANALWAR software based on Microsoft Excel, with significance of differences assessed by Tukey test at $p \leq 0.05$.

Results and Discussion

Different straw management practices applied and analyzed in this experiment found significant differences of winter wheat infestation by *C. gramineum*. Wheat tillers infected by *C. gramineum* were counted in 2016 and 2017 and the results presented in Table 1 indicate

Table 1. Number of tillers with Cephalosporium stripe symptoms (m^{-2}) in two winter wheat cultivars as influenced by straw management (Means for 2016–2017). Values in brackets indicate the percentage of diseased tillers in relation to the total number of tillers

Cultivar	Straw management					Mean
	SR	S2(N)	S3	S3(N)	SM	
Bamberka	2.0 (0.4%)	11.6 (2.4%)	37.6 (8.1%)	26.0 (5.4%)	159.0 (33.2%)	46.6 (9.8%)
Bogatka	0	11.6 (2.4%)	30.3 (7.1%)	29.6 (6.3%)	121.0 (24.3%)	38.5 (8.0%)
Mean	1.0 (0.2%)	11.6 (2.4%)	34.0 (7.6%)	27.8 (5.8%)	140.0 (28.7%)	42.6 (8.9%)

SR – straw removed; S2(N) – straw incorporated every second year + N; S3 – straw incorporated each year without N; S3(N) – straw incorporated each year + N; SM(N) – each year straw retained on the soil surface (mulching) + N; LSD (number of tillers) $p \leq 0.05$ for cultivar – 5.0; straw treatment – 11.8; interaction – 11.3

that when straw was removed (SR) from the plots Cephalosporium stripe disease was absent (cv. Bogatka) or occurred at a very low level (0.4% tillers infected in cv. Bamberka). *Cephalosporium gramineum* infection was also low, with about 2.4% of wheat tillers infected, when straw was incorporated into the soil every second year [S2(N) treatment] and the cultivars did not differ in this respect. Percentages (5–8%) of *C. gramineum* infected tillers for both cultivars in S3 and S3(N) treatments were in general significantly higher than those in SR and S2(N) treatments. The disease was most severe, 24–33% tillers infected, in the SM(N) treatment with yearly straw mulching (Table 1). These results are consistent with those obtained in the USA, where this cereal disease has been broadly studied, as in this country winter wheat is commonly grown in monocultures with no-ploughing (conservation) soil tillage systems which are conducive to Cephalosporium stripe (Douhan and Murray 2001; Quincke *et al.* 2014). Extensive studies performed in the USA have shown that a no-till system and straw mulching increase Cephalosporium stripe intensity in winter wheat at least for two reasons. Firstly, sporulation of *C. gramineum* on straw left on the soil surface is much more intensive than on straw which is incorporated into the soil, where competition with other soil microorganisms is high. Secondly, the pH of the soil surface layer in conservation tillage systems is usually more acidic, [as we also found (Fig. 3)], and under these conditions conidia production and plant infection by the pathogen are higher than in tillage systems with ploughing (Murray and Walter 1991; Quincke *et al.* 2014). Straw management practices are also important in the case of other fungal diseases of cereals. For example, in Norway Hofgaard *et al.* (2016) reported that straw residues combined with reduced soil tillage promoted inoculum survival and the incidence of *Fusarium* spp. on cereals.

In Poland the effect of straw management on the occurrence of Cephalosporium stripe disease in cereals has not yet been studied. The results of our experiment clearly indicate that this disease can be a serious problem in winter wheat production also in our country, particularly when this crop is grown in short rotations or in monoculture with straw retention on the soil surface (no-tillage system). On the other hand, our findings also indicate that even in winter wheat monocultures plant infestation by this pathogen can be negligible when straw of the crop is incorporated into the soil plough layer and that N fertilizer applied to facilitate straw decomposition had no significant effect on the disease (Table 1). Due to the limited number of lysimeter-like plots available in our experiment additional N fertilization was applied only in the treatment with yearly straw incorporation and also because this system is most commonly used by farmers in Poland (Smagacz 2018). Earlier it has been shown that

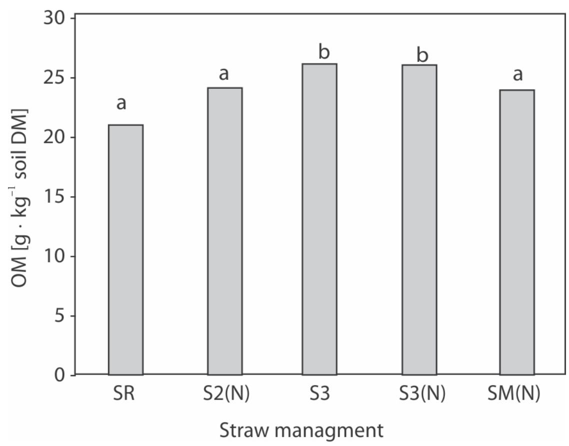

Fig. 2. Organic matter (OM) content in soil under winter wheat as influenced by straw management. SR – straw removed; S2(N) – straw incorporated every second year + N; S3 – straw incorporated each year without N; S3(N) – straw incorporated each year + N; SM(N) – each year straw retained on the soil surface (mulching) + N. Values with the same letter do not differ significantly ($p \geq 0.05$)

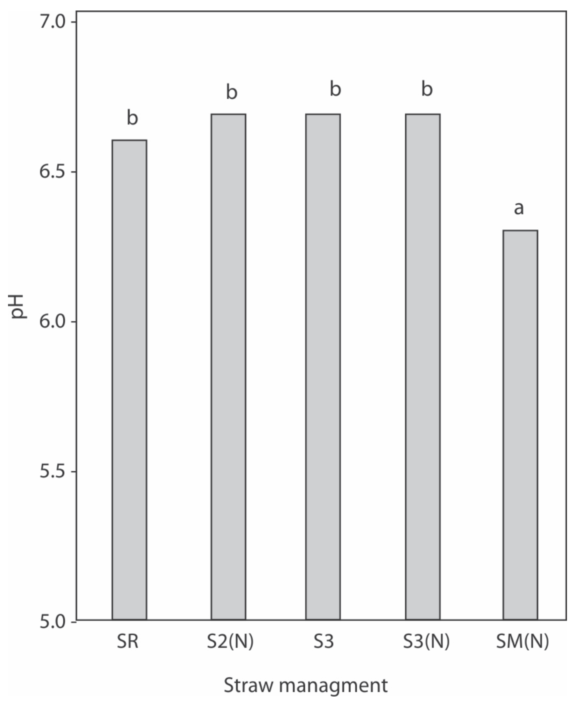

Fig. 3. Soil pH (KCl) under winter wheat as influenced by straw management. SR – straw removed; S2(N) – straw incorporated every second year + N; S3 – straw incorporated each year without N; S3(N) – straw incorporated each year + N; SM(N) – each year straw retained on the soil surface (mulching) + N. Values with the same letter do not differ significantly ($p \geq 0.05$)

sufficient N availability in soil can stimulate straw degradation and thus decrease the survival of some fungal plant pathogens (Garrett 1972; Quincke *et al.* 2014). Future studies should elucidate if such an interaction is also true for *C. gramineum*. This would be of particular importance for growing winter wheat in short rotations or as a monocrop in conservation soil tillage systems. Moreover, preliminary experiments by Pietr (2016) showed that lime applied to winter wheat residues before incorporation into the soil increased straw decomposition and humus formation. Since liming increases soil pH which restricts sporulation of *C. gramineum* on crop residues (Murray and Walter 1991), it can be the subject of future experiments to determine if this treatment would reduce Cephalosporium stripe incidence when straw is left on the soil surface.

In our study only two winter wheat cultivars were compared and the obtained results show that the cultivar Bogatka with higher yielding potential was less susceptible to *C. gramineum* infection than cv. Bamberka (Tables 1 and 2). The more severely infected cv. Bamberka gave significantly lower grain yields in the SM(N) treatment than in the other treatments, while the yields of cv. Bogatka did not differ significantly in all the treatments (Table 2). In the present experiment, which was conducted on a heavy, clayey soil, we observed only an insignificant occurrence of wheat stem base and roots infecting fungi, e.g., *Gaeumannomyces graminis*. Therefore, we attribute the grain yield reduction in the case of cv. Bamberka mainly to *C. gramineum* infection. Also, in the previous experiment with yearly straw incorporation Smagacz (2010) reported only a slight infestation of winter wheat by stem base infecting fungi, which had no significant effect on grain yields.

Cephalosporium stripe disease had no significant effect on the number of ear tillers · m^2 (Table 3), but it caused the deterioration of grain quality as expressed by the weight of seed hectolitre in the SM(N) treatment, particularly in the case of the severely infected cv. Bamberka (Table 4). These preliminary results indicate that broader studies on the susceptibility of winter wheat cultivars to *C. gramineum* are needed and justified (Quincke *et al*. 2011). Growing of less susceptible cultivars would be an important measure to reduce *C. gramineum* incidence and yield losses of winter cereals grown in plough-less tillage systems, which are being increasingly used all over the world (Hofgaard *et al*. 2016; Pecio and Jarosz 2016; Smagacz 2018).

Table 2. Grain yield [g · m^{-2}] of two winter wheat cultivars as influenced by straw management (means for 2015–2017)

Cultivar	Straw management					Mean
	SR	S2(N)	S3	S3(N)	SM(N)	
Bamberka	651	677	669	701	568	653
Bogatka	663	719	733	668	690	695
Mean	657	698	701	684	629	674

SR – straw removed; S2(N) – straw incorporated every second year + N; S3 – straw incorporated each year without N; S3(N) – straw incorporated each year + N; SM(N) – each year straw retained on the soil surface (mulching) + N; LSD $p \leq 0.05$ for cultivar – 24.2; straw treatment – 55.1; interaction – 77.9

Table 3. Number of ear tillers [m^{-2}] in two winter wheat cultivars as influenced by straw management (means for 2015–2017)

Cultivar	Straw management					Mean
	SR	S2(N)	S3	S3(N)	SM	
Bamberka	454	482	473	485	489	477
Bogatka	430	462	464	429	478	453
Mean	442	472	468	457	483	465

SR – straw removed; S2(N) – straw incorporated every second year + N; S3 – straw incorporated each year without N; S3(N) – straw incorporated each year + N; SM(N) – each year straw retained on the soil surface (mulching) + N; LSD $p \leq 0.05$ for cultivar – 21.7; straw treatment – ns; interaction – ns

Table 4. Hectolitre grain weight [kg · hl^{-1}] of two winter wheat cultivars as influenced by straw management (means for 2015–2017)

Cultivar	Straw management					Mean
	SR	S2(N)	S3	S3(N)	SM(N)	
Bamberka	77.0	76.3	76.0	75.2	72.5	75.4
Bogatka	77.5	77.2	77.0	76.7	75.4	76.8
Mean	77.3	76.8	76.5	76.0	73.9	76.1

SR – straw removed; S2(N) – straw incorporated every second year + N; S3 – straw incorporated each year without N; S3(N) – straw incorporated each year + N; SM(N) – each year straw retained on the soil surface (mulching) + N; LSD $p \leq 0.05$ for cultivar – 1.1; straw treatment – 2.4; interaction – 2.5

Different straw management practices applied in the experiment also resulted in a significant differentiation of the studied soil properties (Fig. 2 and 3). The soil under 18 years of continuous winter wheat cultivation contained the lowest level of SOM, (21.0 g · kg^{-1} soil DM), when each year wheat straw was removed from the plots (SR treatment) and this content was lower than that in the soil at the beginning of the experiment (21.4 g SOM · kg^{-1} soil DM). Straw incorporation or mulching resulted in a substantial increase of SOM in the soil and the largest amounts of SOM (26.0–26.1 g · kg^{-1}) were found in the S3 and S3(N) treatments with yearly straw incorporation into the soil. In the SM(N) treatment with yearly straw mulching and in the S2(N) treatment with straw removal every second year the soil also accumulated higher amounts of organic matter than the soil of the SR treatment. However these increases were much smaller than those in the S3 and S3(N) treatments (Fig. 2). In the case of the SM(N) treatment the soil pH significantly decreased in comparison to the other treatments (Fig. 3). This was apparently the effect of long-term surface application of mineral N fertilizers, which in the absence of soil mixing and liming resulted in a slight soil acidification. A similar effect was also observed in previous experiments (Blecharczyk *et al.* 2007; Pecio and Jarosz 2016). With respect to SOM our findings are consistent with results of earlier studies, showing that the SOM content increases after regular application of straw, either by incorporating it into the soil or retention on the soil surface. This beneficial effect is very important for maintaining or improving soil quality (Hazarika *et al.* 2009; Lemke *et al.* 2010; Smagacz 2010; Laird and Chang 2013).

Conclusions

The objective of this study was to determine the effects of different straw management practices (straw removal, straw incorporation and straw mulching) on the occurrence of *C. gramineum*, crop yields and selected soil properties in a long-term micro-plot experiment with winter wheat monoculture. Cephalosporium stripe disease was absent or occurred at very low levels (0–2.4%) when straw was removed or incorporated every second year. The disease was most severe, 24–33% tillers infected, in the SM(N) treatment with yearly straw mulching and cv. Bogatka was less infected by *C. gramineum* than cv. Bamberka. The most important outcome of this study was, that in contrast to straw mulching, yearly straw incorporation into the soil resulted in low winter wheat infestation by the pathogen (5–8% tillers infected), and that also in this treatment the largest amounts of SOM (26.0–26.1 g · kg^{-1}) accumulated in the soil. Future studies should elucidate if N or lime application to straw left on the soil surface (mulching) would reduce the survival and sporulation of *C. gramineum* on plant residues and thus decrease winter wheat infestation by the pathogen.

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